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Sokasi Commodity Production: The Utilization of Bamboo Stem Fiber Composite to Create Balinese Local Products

Nyoman Arya Wigraha[1]*, Djoko Kustono[2], Tuwoso[3], Dwi Agus Sudjimat[4]

[1,2,3,4] Ganesha University of Education, Singaraja, Indonesia, [234]State University of Malang, Indonesia

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ABSTRAK

Tujuan dari penelitian ini adalah untuk mengetahui kombinasi optimal campuran yang mengandung serat bambu dan resin poliester, dengan penambahan sabut kelapa sebagai bahan penguat. Tujuan utama penelitian ini adalah untuk menguji uji tarik guna menentukan faktor kekuatan yang paling sesuai. Selain itu, penelitian ini bertujuan untuk mengevaluasi bagaimana perubahan parameter tertentu mempengaruhi karakteristik tarik material komposit. Parameter yang diamati antara lain proporsi matriks terhadap volume sabut kelapa, persentase konsentrasi alkali, dan panjang sabut kelapa. Tahap fabrikasi komposit melibatkan penggunaan metode hand lay-up dan Metode Taguchi. Alasan pemilihan desain eksperimen ortogonal L4(23) adalah karena terdapat tiga parameter proses, dan setiap parameter memiliki dua level. Persidangan diduplikasi sebanyak lima kali. Faktor penting yang diteliti meliputi rasio matriks dan volume sabut kelapa, konsentrasi alkali, dan panjang sabut kelapa. Berdasarkan hasil yang diperoleh dari penelitian ini, telah dibuktikan bahwa kombinasi yang paling efektif untuk mencapai kekuatan tarik tertinggi adalah matriks yang menyumbang 60% komposisi, sabut kelapa menempati 20% volume, dan konsentrasi alkali 5. %, dan helai sabut kelapa berukuran panjang 30 mm. Hasil uji kuat tarik komposisi khusus ini adalah 54,34 MPa. Selain itu, panjang sabut kelapa merupakan faktor paling signifikan dalam meningkatkan kekuatan tarik, dengan kontribusi sebesar 42,560%.

ABSTRACT

This research aims to determine the optimal combination of a mixture containing bamboo fibre and polyester resin, with the addition of coconut fibre as a reinforcing material. The main objective of this research is to test tensile tests to determine the most suitable strength factor. In addition, this research aims to evaluate how changes in specific parameters affect the tensile characteristics of composite materials. The parameters observed include the proportion of the matrix to the volume of coconut fibre, the percentage of alkali concentration, and the length of the coconut fibre. The composite fabrication stage involves using the hand lay-up and Taguchi methods. The reason for choosing the L4(23) orthogonal experimental design is that there are three process parameters, each with two levels. The trial was duplicated five times. Important factors studied include the ratio of matrix and volume of coconut fibre, alkali concentration, and length of coconut fibre. Based on the results obtained from this research, it has been proven that the most effective combination to achieve the highest tensile strength is a matrix that accounts for 60% of the composition, coconut fibre occupies 20% of the volume, and an alkali concentration of 5.%, and coconut fibre strands measuring 30 mm long. The tensile strength test result of this particular composition was 54.34 MPa. Apart from that, the length of coconut fibre is the most significant factor in increasing tensile strength, with a contribution of 42.560%.

1. INTRODUCTION

Bamboo fiber, along with other natural fiber composites, presents several benefits such as the ability to be renewed and recycled (Girijappa et al., 2019; Jawaid et al., 2022; Zhao et al., 2022), decomposition in the natural surroundings (Radzi et al., 2022; Siakeng et al., 2019). In addition, natural fibers are more cost-effective than synthetic fibers and have excellent mechanical properties (Mohammed et al., 2023; Suriani et al., 2021). Nevertheless, bamboo fiber does possess inherent drawbacks, such as a significant sugar content ranging from 42.4% to 53.6%, a substantial lignin content ranging from 19.8% to 26.6%, and a moisture content between 15% and 20%. As a result, bamboo fiber easily gets tangled and has a tendency to soak up moisture (high hygroscopicity). Bamboo plants are classified under the order Graminales, the family Gramineae, and the subfamily Bambusoideae (Chalopin et al., 2021; Soreng et al., 2022; Zhou et al., 2017). Asia is the main geographical region where these plants are predominantly distributed, although they can also be found in tropical regions throughout Africa and the Americas. The growth pattern of bamboo plants usually takes the form of a cluster, growing to heights between 0.3 m and 30 m, with stem diameters ranging from 0.25 cm to 25 cm, and stem walls that can be as thick as 25

*Corresponding author.
E-mail addresses: arya.wigraha@undiksha.ac.id (Nyoman Arya Wigraha)

mm (Canavan et al., 2016; Hamid et al., 2023; Jihad et al., 2021). Although these plants live for a longer period, they typically die without producing any flowers. Bamboo exhibits a remarkable tensile strength of approximately 200.5 N/mm^2 and an impact strength of about 63.4 Joule/m^2 (Napitupulu et al., 2022; Yuwanda, 2017). It has a density of 0.8 grams per cubic centimeter and shows a creep strength that can reach 230.9 Newton per square meter (Chaowana et al., 2021; Fei et al., 2016; Shao & Wang, 2018). If bamboo fibers are mixed with resin and a matrix, they can produce a different composite that is suitable for various uses, like car bumpers. Previous study carried out by Arma consisted of experiments using polyester resins combined with different amounts of bamboo fibers, namely 30%, 35%, and 40% (Arma, 2011). The study's findings showed that the tensile strength improved with an increase in bamboo fiber content (Al Huseiny & Nursani, 2020; Nuklirullah et al., 2022; Refiadi et al., 2018).

The specimens with the highest tensile strength values, 46.3 MPa, were those with a 40 percent volume fraction, and the specimens with the lowest tensile strength values, 19.68 MPa, were those with a 30 percent volume fraction. In the past few years, there has been a shift in global attention towards bamboo materials, mainly due to the crisis faced by tropical forests, which were previously a major source of wood. Bamboo is acknowledged as an environmentally-friendly material (Borowski et al., 2022; Huang et al., 2023; Xu et al., 2022), capturing the heightened interest of developed countries for the purpose of construction. The idea of eco-friendly design has spurred research into bamboo composites, waste wood utilization, and bamboo componentry. Bamboo composites can be used as building materials, decorative accents, interior accessories, and space-filling elements (Komarudin et al., 2021; Silva et al., 2020; van Dam et al., 2018).

Bali is famous for its export of diverse handicrafts such as woven items, bamboo, rattan, woodwork, and other artworks (Isnaini, 2019; Putra et al., 2023). The year 2022 witnessed a significant influence of Balinese handicraft exports, specifically in categories like wicker crafts ($3.1 million), bamboo crafts ($2.6 million), furniture ($21.4 million), along with other categories (Marsudiarso & Susanto, 2022; Pakpahan & Yoshanty, 2022). This resulted in a combined export value of $116.6 million. Bali's craft exporters are expecting support or aid from the government, specifically for Micro, Small, and Medium Enterprises (MSMEs), in light of the uncertain global situation in 2023. The support we are looking for involves helping people to attend local and global exhibitions, which would in turn help to grow the market for handicrafts made in Bali. Bamboo composite materials show potential not only for building exhibition booths but also for being used as valuable crafting materials for interior accessories, contributing to the craftsmen's income and benefiting the region due to the high value of wood and bamboo handicrafts (Mutia et al., 2016; Refiadi et al., 2018). This is in accordance with the top 13 export products, and the data highlights the practicality of such initiatives.

2. METHOD

The research undertaken is of an experimental nature. The study includes a range of independent variables consisting of: 1) The volume proportion of coconut fiber to resin. 2) Alkali level. 3) Coconut fiber size. Tensile testing has been selected as the dependent variable for this research. Tensile testing is a method used to assess the properties and condition of a material. In this test, the load is applied gradually, causing the material to experience an increase in length that aligns with the force being applied. The values that remain unchanged throughout this study are as listed: 1) 1. Bamboo vol. (20%), 2) Length of time for immersing in alkali solution (2 hours), 3) The ratio of resin to catalyst is 100 parts of resin to 1 part of catalyst, 4) Length of bamboo fibers is 60 millimeters, 5) Direction of fiber alignment (parallel). Before starting the process of creating composite specimens using the hand lay-up method, various preparatory steps are required in order to conduct this study.

3. RESULT AND DISCUSSION

Result

Comparing the Matrix and Fiber Volume Ratios. Calculations are crucial in determining the matrix and fiber volume ratios during the fabrication of tensile test samples. The relevant information needed to calculate the tensile test specimen includes the mold's volume, which measures 9.78 cm3. After obtaining this data, weight calculations are carried out for both the fiber and the matrix, according to the guidelines provided in Table 1. Test Specimen Weight. The measurement of the test specimens' weight was determined by using digital scales. Table 2 displays the masses of the specimens obtained as a result. Result of Tensile Testing. The results of the tests to measure the stretching capability were obtained by conducting experiments using a machine specifically designed for these tests at the Material Laboratory of

Bangka Belitung State Polman. These experiments were carried out according to the regulations outlined in the ASTM D-638 standard. The results of the tensile test have been organized in Table 3.

Table 1. Volume Ratios

Experimental Specimen	Volume ratio of matrix and fiber	Alkali level	Coconut fiber weight *(g)*	Bamboo fiber weight *(g)*	Resin weight *(g)*
1	70 : 30	2 %	1.10 *gr*	1.38 *gr*	9.14 *gr*
2	70 : 30	5 %	1.10 *gr*	1.38 *gr*	9.14 *gr*
3	60 : 40	2 %	2.20 *gr*	1.38 *gr*	7.83 *gr*
4	60 : 40	5 %	2.20 *gr*	1.38 *gr*	7.83 *gr*

Table 2. Specimen Masses

Ratio of matrix volume and coconut fiber volume (%)	Alkali (%)	Tensile Strength (Mpa) Replication					Average (Mpa)
		1	2	3	4	5	
70:30:00	2%	13.8	12.65	13.66	13.33	14.15	13.51
70:30:00	5%	13.05	14.05	13.37	13.76	12.83	13.41
60:40:00	2%	14.68	15.89	14.53	14.43	15.05	14.91
60:40:00	5%	15.82	15.25	15.09	16.21	15.87	15.64

Table 3. Tensile Test Data

Ratio of matrix volume and coconut fiber volume (%)	Alkali (%)	Coconut Fiber (mm)	Tensile Strength (Mpa) Replication					Average (Mpa)
			1	2	3	4	5	
70:10:00	2%	30	52.5	54.3	48	55.9	54.3	53
70:10:00	5%	60	39.8	40.1	46.3	48.3	45.5	44
60:20:00	2%	60	38.4	32.1	37.9	40.2	36.9	37.1
60:20:00	5%	30	51.1	55.3	55.6	57.6	52.1	54.34

From the information provided in Table 3, it is evident that there is a relationship between the length of coconut fiber and the resulting tensile strength. Moreover, the data mentioned earlier suggests that a coconut fiber length of 30 mm produces the highest level of tensile strength. The matrix containing 60% fiber volume, 20% concentration of alkali, and coconut fiber of 30 mm length shows the highest average strength, measuring at 54.34 MPa on average. After finishing the four-step process mentioned earlier, the results of the experimental calculations regarding the behavior of the material in a tensile test are provided in Table 4.

Table 4. Results of Experimental Calculations on Tensile Test Response

Experiment	Factor			Replication					Amount	Mean
	A	B	C	1	2	3	4	5		
1	1	1	1	52.5	54.3	48.0	55.9	54.3	265	53.00
2	1	2	2	39.8	40.1	46.3	48.3	45.5	220	44.00
3	2	1	2	38.4	32.1	37.9	40.2	36.9	185.5	37.10
4	2	2	1	51.1	55.3	55.6	57.6	52.1	271.7	54.34
						Average			47.11	

Based on the data provided in Table 4, it can be deduced that the most favorable outcome for the tensile examination of composite fibers is attained by conducting the fourth combination experiment, resulting in a measurement of 54.34 MPa. Therefore, it can be inferred that the experimental results indicate a composite fiber tensile strength value that is within the 60:20 range of the matrix volume ratio and coconut fiber volume. In addition, a evaluation is performed to identify how factor levels affect the average value of the composite fiber tensile test, taking into account factors A, B, and C. Moreover, a study is conducted to determine how different levels of factors affect the mean value of the composite fiber tensile test. The important factors include the proportion of matrix volume to coconut fiber volume, the concentration of alkali, and the length of coconut fibers. Examples and outcomes depicting the calculation of the average tensile test value for each factor are presented below. Determination of Variable Combination for Response. Determining the optimal combination of response variables heavily relies on accurately calculating the averages of the variables utilized. Table 5 outlines the computation and display of the combined average for the three variables.

Table 5. Average Scores of Each Factor in the Tensile Test

Symbol Variable	Process Variables	Level 1	Level 2
A	Ratio of matrix volume and coconut fiber volume (%)	48.5	45.72
B	Alkali level (%)	45.05	49.17
C	Coconut Fiber *(mm)*	53.67	40.55
Total average score of tensile test		**47.11**	

The normality test performed on the tensile test response data showed a p-value of 0.150, indicating that it is higher than the specified significance level of 0.05. Therefore, no evidence was found to reject the null hypothesis (H0), suggesting that the data adheres to a normal distribution. The image below, labeled Figure 1, displays the results of the average data testing software, including the findings of the average similarity test. This observation can be made from the image.

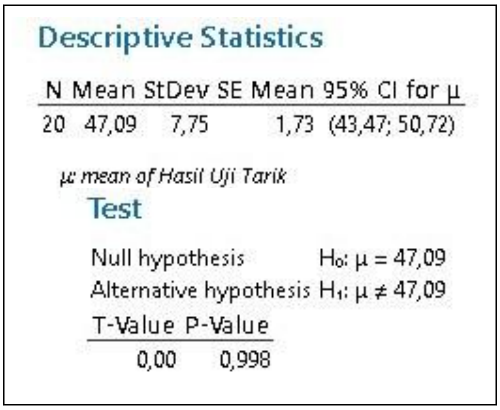

Figure 1. Average Similarity

The p-value calculated for the mean similarity test of the experimental response results is 0.998, which is greater than 0.05. Therefore, the null hypothesis (Ho) remains unchanged and is not refuted. This indicates that the average values obtained from the statistics are consistent with the level of significance, suggesting that the test conducted is appropriate.

Discussion

Ratio of Matrix Volume and Coconut Fiber Volume in Relation to Response. The increase in the volume fraction of coconut fibers is clearly linked to the enhancement of the composite's tensile strength. The average tensile strength of the 70% : 10% volume fraction in the Response Table for Means is recorded as 53.00 MPa, while the 60% : 20% volume fraction shows an average tensile strength value of 54.32 MPa, the highest in both cases. The volume fraction of 70% : 10% undergoes a decrease in its tensile strength when compared to the volume fraction of 60% : 20%, which has the highest average tensile strength of 54.32 MPa. The average tensile strengths of the two volume fractions show no substantial differences, as the influence of the volume fraction on the composite's tensile strength is limited. Effect of Alkali Percentage on Response. The fiber surface shows noticeable changes when exposed to NaOH solutions with concentrations of 2% and 5%. Specifically, the composites achieved their highest tensile strength values when treated with a 5% NaOH concentration (Napitupulu et al., 2022). The connection between the fiber and resin in composites containing 2% of alkali-treated fibers is not completely formed as a result of a wax-like layer present on the surface of the fiber. As a result, when subject to tensile testing, the main reason for the decrease in tensile strength is primarily due to the breaking of the connection between the fiber and matrix caused by shear stress on the surface of the fiber, often called "fiber pull-out." Despite the tissue/filler and fiber's capability to withstand greater loads and strains with reduced tensile strength, the weakening of the bond between the fiber and filler results in a decline in the composite's tensile strength. Coconut Fiber Length in Relation to Response. Composites that have a fiber length of 30 mm demonstrate higher tensile strength in comparison to those with a fiber length of 60 mm. The difference in outcomes is due to the successful and consistent spread that can be achieved using the

30 mm fiber length throughout the process of manufacturing composite materials. The equal distribution of the reinforcement elements, specifically bamboo fiber and coconut fiber, contributes to a strong bond with the matrix component, polyester resin. As a result, the direct enhancement of the composite's tensile strength occurs when it is reinforced with bamboo and coconut fibers. The highest level of strength is attained when the composite fiber length reaches 30 mm because the 60 mm composite absorbs more water. Increased water absorption results in higher levels of tensile stress, thereby allowing for improved distribution of loads. As a consequence, this leads to a greater frequency of bonding events between the matrix and the fiber. As a result, the tensile strength of the composite is greatly increased.

After examining the aforementioned research, it can be concluded that the composite material consisting of bamboo fiber with coconut fiber filler exhibited positive outcomes during the tensile test. The tensile test parameters obtained from histograms clearly show the outcomes, specifically the ratio of matrix volume and the volume of coconut fibers, indicating that there is a proportion of 60% matrix volume to 20% coconut fibers. Moreover, the inclusion of the histogram showing a 5% alkali concentration and the histogram indicating coconut fiber length of 30 mm both play a significant role in attaining a composite material composition that possesses the highest possible tensile strength. It is worth mentioning the remarkable correlation observed between the results of the histogram and the findings obtained directly through the researchers' investigation. Consistently, the maximum tensile strength is achieved when the volume ratio between the matrix and coconut fiber is 60%:20%, with a 5% alkali percentage, and using coconut fiber of 30 mm in length. The histogram results demonstrate this pattern by showing a normal curve shape, where most of the bars are located below the curve.

Therefore, the best combination of variables consists of a volume fraction of 60%:20%, a histogram showing an alkali percentage of 5%, and a histogram displaying coconut fiber length set at 30 mm. Figure 2 presents the highest average tensile strength value of 54.34, which is achieved by considering the combined influence of these variables on the composition of the composite material. The implications of this research are very important in the context of developing coconut fiber composite materials. These findings provide a solid foundation for manufacturers to optimize their manufacturing processes, taking into account variables such as matrix and fiber volume fractions, alkaline treatment, and fiber length. Thus, manufacturers can produce coconut fiber composites with consistently better tensile performance. This research spurs the development of environmentally friendly high-performance materials, as it optimizes the use of renewable natural resources and reduces dependence on non-recycled raw materials. These implications are not only relevant in the materials industry, but also have a positive impact on environmental sustainability. The results of this study have direct implications in industrial applications, such as construction, automotive, and manufacturing, where improved coconut fiber composites can be used to improve product durability and performance. The findings also provide a solid foundation for continued research in the field of natural fiber composites, opening the door to research on the influence of other process variables and the development of more sophisticated production techniques. By paying attention to these implications, industry stakeholders and researchers can take appropriate steps to put these research findings into practice and develop more sustainable and high-performance products.

4. CONCLUSION

Several significant conclusions can be made by analyzing the data from the tensile test conducted on bamboo fiber composites containing coconut fiber filler. To start with, the tensile strength of the composite is greatly affected by the ratio of matrix to fiber volume. The most favorable outcome was observed when the matrix constituted 60% of the volume and the fiber accounted for 20%, resulting in an average tensile strength of 54.34 MPa. In addition, the level of alkali concentration also had an impact on the composite's tensile strength. Specifically, a higher alkali concentration of 5% yielded a stronger tensile strength when compared to the lower concentration of 2%. Moreover, the tensile strength was significantly affected by the length of the coconut fiber. The results were more favorable with a fiber length of 30 mm as opposed to a length of 60 mm. According to the mean similarity test outcomes, it was found that the best mix of factors comprised a volume ratio of 60% matrix and 20% fiber, a 5% concentration of alkali, and a 30 mm length of coconut fiber. These findings indicate that the highest tensile strength for bamboo fiber composites with coconut fiber filler can be achieved through this particular combination of variables. The composite tensile test results were notably impacted by the interplay between these variables. Consequently, this research provides valuable findings on how to enhance the tensile strength of composites made from bamboo fiber and coconut fiber.

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