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The Creation of Commodity Sokasi using Local Products in Bali Made from Bamboo Stem Fiber Composite

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Abstract

The aim of this study is to identify the best combination for a blend comprising bamboo fiber and polyester resin, enhanced by the addition of coconut fiber as a filler. The study primarily focuses on analyzing tensile tests to pinpoint the optimal strength parameters. Furthermore, this investigation seeks to assess the extent to which variations in specific parameters influence the tensile properties of composite materials. These parameters encompass the volume ratio between the matrix and coconut fiber, the alkali concentration percentage, and the length of the coconut fiber. During the composite fabrication phase, the hand lay-up method in conjunction with the Taguchi Method was employed. The L4(23) orthogonal experimental design was selected due to three process parameters, each with two levels. The experiment was replicated five times. The pivotal process parameters under scrutiny encompassed the volume ratio between the matrix and coconut fiber, alkali concentration, and coconut fiber length. The findings of this study reveal that the optimal composition for achieving maximum tensile strength consists of a 60% matrix to 20% coconut fiber volume ratio, a 5% alkali concentration, and a coconut fiber length of 30 mm. This specific composition yielded a tensile test value of 54.34 MPa. Additionally, the most influential parameter contributing to tensile strength was the length of the coconut fiber, contributing 42.560%.

Keywords: Bali, Bamboo, *Sokasi*, Tensile Strength of Composite.

INTRODUCTION

Natural fiber composites, such as bamboo fiber, offer various advantages, including renewability, recyclability (Zharvan et al., 2013), biodegradability in the environment (Kadir et al., 2014). Additionally, natural fibers possess commendable mechanical properties and are more cost-effective than synthetic fibers (Zimmermann et al., 2004). However, bamboo fiber does have inherent weaknesses, including a high sugar content of 42.4-53.6%, lignin content of 19.8-26.6%, and a moisture content of 15-20%. Consequently, bamboo fiber is prone to tangling and has a propensity to absorb water (hygroscopicity).

Bamboo plants fall within the order Graminales, the family Gramineae, and the subfamily Bambusoideae (Rofii et al., 2017). These plants are found in tropical regions across Asia, Africa, and the Americas, with Asia being the primary distribution area. Bamboo plants typically exhibit a clump-shaped growth pattern, reaching heights ranging from 0.3 m to 30 m, stem diameters of 0.25-25 cm, and stem wall thicknesses of up to 25 mm. While these plants have an extended lifespan, they usually perish without flowering.

Bamboo boasts an impressive tensile strength of up to 200.5 N/mm^2 and an impact strength of up to 63.4 $Joule/m^2$. It possesses a density of 0.8 g/cm^3 and exhibits a creep strength of up to 230.9 N/m^2 (Morisco, 1999). When combined with resin and a matrix, bamboo fibers can yield an alternative composite well-suited for applications such as car bumpers.

Previous research conducted by Arma (2011) involved experiments using polyester resins reinforced with varying volumes of bamboo fibers: 30%, 35%, and 40%. The study's findings revealed that an increase in the volume fraction of bamboo fiber led to an enhancement in tensile strength. The optimum tensile strength value was observed in specimens with a 40% volume fraction, measuring 46.3 MPa, while the lowest tensile strength value was recorded in specimens with a 30% volume fraction, measuring 19.68 MPa.

In recent years, the global focus has shifted towards bamboo materials, especially as tropical forests, once a source of wood, face a crisis. Bamboo is recognized as a sustainable material (Hastuti, 2015), gaining increased attention from developed nations for construction purposes. The concept of green design (eco-friendly) has driven research into bamboo composites, utilizing waste wood and bamboo components. Bamboo composites offer potential as raw materials for crafts, space-filling elements, aesthetic and interior accessories (Komarudin et al., 2021).

Bali is renowned for exporting a variety of handicrafts, including woven crafts, bamboo, rattan, wood, and more (Antara, 2015). In 2022, Balinese handicraft exports had a substantial impact, with notable categories such as wicker crafts ($3.1 million), bamboo crafts ($2.6 million), furniture ($21.4 million), and others, culminating in a total export value of $116.6 million. Craft exporters from Bali anticipate government incentives or assistance, particularly for Micro, Small, and Medium Enterprises (MSMEs), amidst global uncertainty in 2023. The desired support includes facilitating access to domestic and international exhibitions, thus expanding the market for Bali's handicrafts.

Given the significant value of wood and bamboo handicrafts in enhancing craftsmen's income and benefiting the region, bamboo composite materials hold promise not only for exhibition booth construction but also as viable interior accessory craft materials. This aligns with the top 13 export commodities, and the data underscores the feasibility of such endeavors.

METHOD

The research conducted is an experimental nature. The independent variables employed in this study encompass:

1. The ratio of coconut fiber volume to resin volume.
2. Alkali concentration.
3. Length of coconut fiber.

The response variable chosen for this study is tensile testing. Tensile testing involves a procedure aimed at determining the characteristics and state of a material. This test entails gradually applying a load, inducing a change (increase) in the material's length in correspondence with the applied force.

The constants in this study are as follows:

1. Bamboo volume (20%).
2. Duration of alkali soaking (2 hours).
3. Resin and catalyst ratio (100:1).
4. Bamboo fiber length (60 mm).
5. Fiber orientation direction (parallel).

Prior to commencing the fabrication of composite specimens through the hand lay-up method, several preparatory steps need to be undertaken for this study.

RESULTS AND DISCUSSION

Comparison of Matrix and Fiber Volume Ratio

In the creation of tensile test specimens, calculations are essential to establish the matrix and fiber volume ratios. The pertinent data for computing the tensile test specimen involves the mold volume of 9.78 cm^3. Following the acquisition of this data, weight calculations are performed for both the fiber and the matrix, as outlined in Table 1.

Table 1 Volume Ratios

Experimental Specimen	Volume ratio of matrix and fiber	Alkali concentration	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*

Weight of Test Specimens

The weight of the test specimens was determined through measurements conducted using digital scales. The resultant specimen masses are presented in Table 2.

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

Tensile Testing Results

The outcomes of the tensile tests were acquired through testing on a tensile testing machine at the Bangka Belitung State Polman Material Laboratory, following the guidelines stipulated in the ASTM D-638 standard. The findings from the tensile test have been tabulated in Table 3.

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

Based on the data presented in Table 3 above, it can be deduced that there exists a correlation between the length of coconut fiber and the resultant tensile strength. Furthermore, the aforementioned data indicates that a coconut fiber length of 30 mm yields the most substantial tensile strength. On average, the combination of a matrix with a 60% fiber volume:20%, 5% alkali concentration, and a 30 mm coconut fiber length exhibits the highest average strength, measuring 54.34 MPa.

Following the completion of the aforementioned four-step process, the outcomes of the experimental calculations pertaining to the tensile test response are detailed 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	

From the information presented in Table 4, it can be inferred that the optimal value for the tensile test of composite fibers is achieved through the 4th combination experiment, yielding a value of 54.34 MPa. As a result, it can be concluded that this experimental outcome yields a composite fiber tensile test value that falls within the range of a matrix volume ratio and coconut fiber volume of 60:20. Moreover, an assessment is conducted to determine the impact of factor levels on the average value of the composite fiber tensile test, considering factors A, B, and C.

Furthermore, an examination is performed to ascertain the influence of factor levels on the average value of the composite fiber tensile test. The relevant factors encompass the ratio of matrix volume to coconut fiber volume, alkali concentration, and coconut fiber length. Illustrated below are examples and outcomes detailing the calculation of the average tensile test value for each factor:

Determination of Variable Combination for Response

In order to establish the optimal combination of response variables, it is imperative to compute the averages for the utilized variables. Calculation of the overall average for the three variables has been conducted and is outlined in Table 5.

Table 5 Average Values 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 (%)	45,05	49,17
C	Coconut Fiber *(mm)*	53,67	40,55
Total average value of Tensile Test		**47,11**	

Data Normality Test

In accordance with the rejection criteria, the outcomes of the normality test conducted on the tensile test data are presented in the subsequent Table 6.

Table 6 Results of Data Normality Test

Response	*p-value*	H0 condition	Data
Tensile Test	0.150	Failure rejected	Normally distributed

The data normality test conducted on the tensile test response yielded a p-value of 0.150, which is greater than the significance level (α) of 0.05. As a result, the null hypothesis (H0) is not rejected, indicating that the data follows a normal distribution.

Mean Similarity Test

This can be observed in the image depicting the results of the average data testing software, which includes the outcomes of the average similarity test as presented in Figure 1 below:

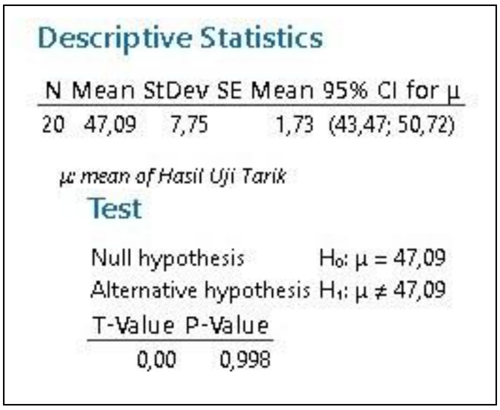

Figure 1 Average Similarity

Based on the rejection criteria, the results of the tensile test response mean similarity test are shown in Table 7 below:

Table 7 Results of Mean Equality Test

Response	*p-value*	H0 condition	Mean
Tensile Test	0.998	Failure rejected	Software Result > significant

Presenting the findings of the mean similarity test for the experimental response results, the calculated p-value is 0.998 > 0.05. Consequently, the null hypothesis (Ho) remains unaltered and is not rejected. This signifies that the statistical means align with the significance value, implying the suitability of the conducted test.

Ratio of Matrix Volume and Coconut Fiber Volume in Relation to Response

It is evident that the tensile strength of the composite increases with the rise in the volume fraction of coconut fibers. In the Response Table for Means, the volume fraction of 70% : 10% exhibits the highest average tensile strength value of 53.00 MPa, while the volume fraction of 60% : 20% demonstrates the highest average tensile strength value of 54.32 MPa. The 70% : 10% fraction experiences a reduction in tensile strength compared to the 60% : 20% volume fraction due to the latter having the highest average tensile strength of 54.32 MPa. The disparities in the two volume fractions' average tensile strengths are not significantly different, as the volume fraction variable exerts a limited impact on the composite's tensile strength.

Effect of Alkali Percentage on Response

At concentration percentages of 2% and 5% NaOH, there is an observable influence on the fiber surface, where a 5% NaOH concentration yields composites with optimal tensile strength values (Napitupulu et al., 2022). In composites with 2% alkali-treated fibers, the bonding between the fiber and resin is not yet fully established due to the presence of a wax-like layer on the fiber's surface. Consequently, during tensile testing, the decrease in tensile strength is predominantly attributed to the disruption of the bond between the fiber and matrix caused by shear stress on the fiber's surface, commonly referred to as "fiber pull-out." Even as the tissue/filler and fiber retain the ability to endure greater loads and strains during reduced tensile strength, the bonding failure between the fiber and filler leads to a decline in the composite's tensile strength.

Coconut Fiber Length in Relation to Response

Composites featuring a fiber length of 30 mm exhibit greater tensile strength when compared to those with a fiber length of 60 mm. This disparity arises from the effective and uniform distribution achievable with the 30 mm fiber length during the composite manufacturing process. This even distribution facilitates a robust bonding between the reinforcement elements, namely bamboo fiber and coconut fiber, and the matrix component, polyester resin. Consequently, the tensile strength of the composite, reinforced by bamboo and coconut fibers, experiences a direct enhancement. The peak strength is achieved at a composite fiber length of 30 mm due to the higher water absorption in the 60 mm composite. The greater water absorption leads to higher tensile stress values, thus enabling more efficient load distribution. This, in turn, results in a higher frequency of bonding occurrences between the matrix and the fiber. As a consequence, the composite's tensile strength is significantly elevated.

Based on the analysis of the aforementioned research, the results of the tensile test for the composite material comprising bamboo fiber with coconut fiber filler manifest favorable outcomes. These results are evident in the tensile test parameters derived from histograms, specifically the matrix volume ratio and the volume of coconut fibers, which illustrate a volume fraction of 60%:20%. Additionally, the histogram depicting a 5% alkali percentage and the histogram of coconut fiber length set at 30 mm both contribute to achieving a composite material composition with the utmost tensile strength. The congruence between the histogram outcomes and the direct research findings conducted by researchers is noteworthy. The volume ratio of matrix to coconut fiber volume at 60%:20%, the 5% alkali percentage histogram, and the 30 mm coconut fiber length histogram consistently yield the maximum tensile strength. This trend is exemplified by the normal curve formation within the histogram results, with a majority of bars positioned beneath the curve.

Hence, the optimal variables include the 60% volume fraction:20%, the 5% alkali percentage histogram, and the coconut fiber length histogram set at 30 mm. These variables collectively contribute to a composite material composition yielding the highest average tensile strength value of 54.34, as depicted in Figure 2 below.

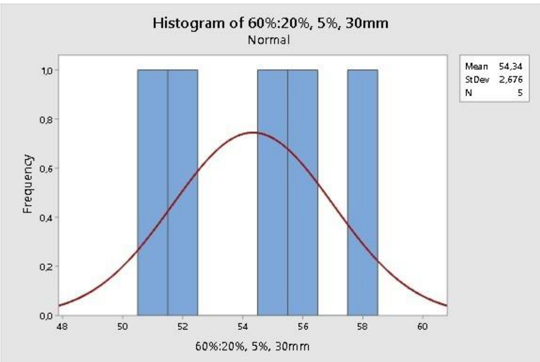

Figure 2 Average highest tensile strength

CONCLUSION

Based on the analysis of tensile test data for bamboo fiber composites with coconut fiber filler, several important conclusions can be drawn. Firstly, a significant influence exists between the volume ratio of matrix and fiber on the tensile strength of the composite. In this case, a volume ratio of 60% matrix to 20% fiber demonstrated the best results, yielding an average tensile strength of 54.34 MPa. Additionally, alkali concentration also played a role in influencing composite tensile strength, with a 5% alkali concentration resulting in superior tensile strength compared to the 2% concentration. Furthermore, the length of the coconut fiber showed a notable impact on tensile strength. A fiber length of 30 mm exhibited more optimal results compared to the 60 mm length. The results of the mean similarity test indicated that the optimal combination of variables included a volume ratio of 60% matrix to 20% fiber, a 5% alkali concentration, and a 30 mm coconut fiber length. Based on these findings, it can be concluded that this specific combination of variables provides the highest tensile strength for bamboo fiber composites with coconut fiber filler. The interaction among these variables also significantly influenced the results of the composite tensile tests. As a result, this study offers important insights into optimizing tensile strength in bamboo fiber and coconut fiber composites.

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