Hybrid-Bamboo Rebars: Bamboo Trunks (Bambusa Vulgaris) with Polypropylene Attached as an Alternative to Typical Bamboo Rebars in Concrete Beams

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Abstract*: Various past studies suggest that utilizing this sort of rebar is viable for economical and low-rise residential structures where steel is hard to obtain and the ductility demand of the loads is low. Bamboo rebars show a competitive flexural strength that can be used in structural applications like concrete beams. Furthermore, polypropylene fibers can be used in the construction field. It can be mixed with concrete or used with concrete structures to further enhance the strength, as it offers enough tensile strength. The researchers utilized bamboo rebars as a control sample, and a bamboo with polypropylene attached as an experimental sample to compare whether the experimental sample exhibits a notable variation in flexural strength when incorporated into concrete. There are a total of 18 samples divided into (2) specifications: first, the concrete beams with traditional bamboo rebar (16mm); second, the concrete beams with bamboo coated with polypropylene plastic (16mm, with an additional 4mm of coating). The testing utilized a Universal Testing Machine to obtain the modulus of rupture (MOR) of the concrete beams. The findings indicated that bamboo with polypropylene coating has better flexural strength results compared to normal bamboo, for all 7-day, 14-day, and 28-day curing times. The results show as follows: in the 28th day curing time, experimental samples showed an average flexural strength of 7.52 MPa, whereas the control samples exhibited an average flexural strength of 5.51 MPa. With the utilization of the one-way ANOVA hypothesis testing, it shows a drastic difference between the flexural strength of both groups. Furthermore, the study found that bamboo with polypropylene coatings exhibits greater flexural strength than conventional bamboo rebar.

***Keywords*: Bamboo Rebars, Concrete Beams, Engineering, Flexural Strength, Polypropylene Coating.**

1. Introduction

In tropical and subtropical nations like the Philippines, the significance of bamboo to both environmental and economic factors is indisputable. The growing overall awareness of the usage of the material is also increasing. Several agencies inspect how to fully utilize bamboo, not just for its traditional uses.

Novicio (2024), in its statement, presented Executive Order 879, which issues to improve and enhance the bamboo industry in the Philippines, which will create widespread and long-term research development of the bamboo resource. These orders undeniably helped the bamboo industry to sprout in terms of its usability in both the market and other applications.

When it comes to concrete, several houses are built with bamboo rebar. As supported by the study carried out by Govindan et al. (2022), bamboo can be compared to steel rebar. They tested the bending strength and moment capacity of concrete with bamboo reinforcing material. The structural capacity of the bamboo rebars validates the anticipated bamboo's load-bearing capacity. The study also suggests that utilizing this kind of rebar is viable for low-cost and low-rising houses where steel is hard to obtain and the ductility demand of the loads is low.

On the other hand, plastics are also one of the main issues that need to be focused on. These wastes are continuously produced, yet there is no strength to eliminate these wastes. They may be eliminated but with the cost of producing more pollution. Burning plastics may eradicate the pile of plastics, but it will produce a vast amount of smoke with harmful effects that can deteriorate the environment. Ericson et al. (2021) stated that solid waste management needs to be issued as soon as possible to mitigate the effects of global warming. He also stated that sustainable uses of plastics may be a solution to the growing amount of plastic.

Polypropylene, one of the major plastics produced in the world, mostly takes the form of a plastic cap. This polypropylene takes around 450 years to decompose (Malek et al., 2021). Therefore, the re-usage of these materials must be addressed so that it will not produce any harmful effects on the environment. One of the solutions to the growing problem of polypropylene materials is to reuse them in various applications of numerous industries.

According to the study of Lafiti et. al. (2022), polypropylene fibers can be used in the construction field. Furthermore, it can be combined to further enhance the concrete mix. According to the tests, distributing polypropylene fibers in concrete formulation resulted in the following: a boost in the concrete's strength and resistance, and a redule dimensional growth. Improvement on the durability characteristics of the concrete, the overall cost reduces, while the energy absorption capacity of the concrete blends enhances. This proves that these plastic fibers can be mixed with concrete.

Combining the two issues, the research gap formed concludes that there is a study to be conducted. This study will aim to focus on producing hybrid bamboo rebar as a substitute for conventional bamboo rebar. This will seek to improve the capacity of normal bamboo rebar by applying polypropylene fibers to bamboo.

2. Objectives of the Study

The researchers will investigate if the eco-friendly bamboo-polypropylene fiber plastic can be an alternative to traditional bamboo reinforcements in concrete beams. This research is focused on accomplishing the subsequent objectives:

- The characteristics of bamboo and polypropylene fiber plastic composite materials are suitable as an alternative for bamboo beam reinforcement.
- The difference in flexural strength between bamboo-polypropylene fibers plastics to traditional bamboo rebar.
- The efficiency of bamboo-polypropylene fiber plastic as another structural reinforcement material to bamboo in concrete elements.

A. Statement of the Problem

In this paper, the researchers will present an eco-friendly material bamboo-polypropylene fiber plastic as the alternative to traditional bamboo reinforcements in concrete beams. Additionally, the researchers will aim at the following specific objectives:

- Do bamboo and polypropylene fiber plastic composite materials have the characteristics and are suitable as an alternative for bamboo beam reinforcement?
- What is the variation in flexural strength among bamboo-polypropylene fiber plastics and traditional bamboo rebar?
- How efficient is bamboo-polypropylene fiber plastic as another structural reinforcement material to bamboo in concrete elements?

B. Scope and Delimitation

The thesis will introduce a breakthrough bamboo-polypropylene fiber-reinforced plastic that can be deployed instead of traditional bamboo reinforcement elements used in concrete beams. The research will further seek to establish the characteristics of bamboo-polypropylene fiber plastic. Besides, the thesis will also assess the proposed bamboo-polypropylene fiber plastic as an effective and strong reinforcement in concrete beams.

The research will not involve other materials and substances apart from the bamboo trunks and the polypropylene plastics used to construct the bamboo-polypropylene fiber plastic reinforced concrete beams. The study to be undertaken will only underscore and demonstrate that bamboo-polypropylene fiber plastic rebar can be used as substitutes for conventional bamboo rebars, and will not be centered on demonstrating their efficacy as substitutes for both conventional bamboo and steel rebars. Also, no further research will be conducted to determine whether it suits other structural elements such as columns. The study will also be constrained within a time frame of one year, as this is the period within which it is possible to complete it.

3. Methodology

A. Research Method

The study will use a quantitative method of research. Quantitative data are critical to the review and interpretation of the study findings. These data will be gathered for experiments and tests of variables present in the study. With this, the study will test if bamboo-polypropylene fiber rebar can be a sustainable alternative to conventional bamboo rebar.

B. Research Design

This study will utilize experimental design in analyzing the required data of the study, which is quantitative data, to determine if bamboo-polypropylene fiber-plastic can be used as another option for bamboo reinforcement in concrete beams. The study will focus on gathering data through laboratory experiments and tests to analyze the variables.

C. Research Instrument

The study will use observation logs as a research instrument in collecting the needed data for the study. The observation logs will include the sample numbers of the concrete beams, the sample type, their specific time of curing, and their respective tensile strength capacity during their testing via a Universal Testing Machine.

D. Locale of the Study

The research's locale will be determined from its convenience and significance to the researchers and the study itself. The researchers decided to conduct the study at the University of the Assumption, located in Unisite Subdivision, Del. Pilar, City of San Fernando, Pampanga due to the following considerations: (1) The researchers are presently enrolled at the University of the Assumption as a partial fulfillment into their Bachelor's Degree in Civil Engineering; (2) There is a competent engineering laboratory inside the campus that has sufficient tools and materials that will be needed during the data collection and experimentation process; (3) Finally, the university has a Universal Testing Machine, which is much needed for the concrete strength analysis of the beam samples of the study.

E. Process Flow Chart

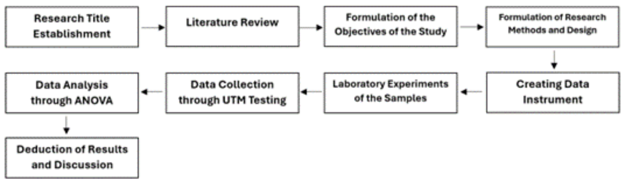

Fig. 1. Process flow chart

Figure 1 displays the Process Flow Chart of the study. It outlines the study's step-by-step methodology. It starts with establishing the research title followed by a literature review to gather relevant information. Then, the proponents formulate objectives for the study that help to identify the research method, design, and data instrument for data collection. The study conducts laboratory experiments on samples through UTM Testing. The collected data was analyzed through ANOVA and then the proponents summarized the data and interpreted the findings.

F. Material Preparation

Table 1
Material preparation

Material Preparation	
Bamboo Stick	
Average size	16mm⌀
Length	450mm
Polypropylene	
Average thickness	4mm
Stirrups	
Steel bar diameter size	9mm⌀
Hook size	50mm on each side
Water-Cement Ratio	
For Class A mixture	0.6 to 0.7
Concrete Mixture	Proportions (C:S:G)
Class A	1:2:4
Compressive Strength (28 days after)	3,000 psi

In summary, the bamboo stick dimensions used were 16mm⌀ with a length of 450mm. For the polypropylene attached, the average thickness on both sides is 4mm. Next, the stirrups used a diameter size of 9mm⌀ with a hook size of 50 mm on each side. For the water-cement ratio, the researchers used 0.6 to 0.7. Lastly, for the concrete mixture, the researchers utilized Class A mixture.

1) Bamboo Stick

Bamboo is an unusual natural retrofit material that grows throughout developing nations and is now artificially planted for various reasons. Bamboo can be used for both structural and decorative purposes. Bamboo sticks have been utilized in beam reinforcement due to their excellent crack resistance and load deformation, as well as their tensile strength and control. Bamboo, which is gathered from the local market, is utilized here as a retrofit material

2) Polypropylene

Polypropylene, which is primarily extracted from plastic cups, was gathered by the researchers for this investigation. The bamboo sticks were coated with melted PP. The bamboo stick's melted PP is 4 mm thick on average.

3) Stirrups

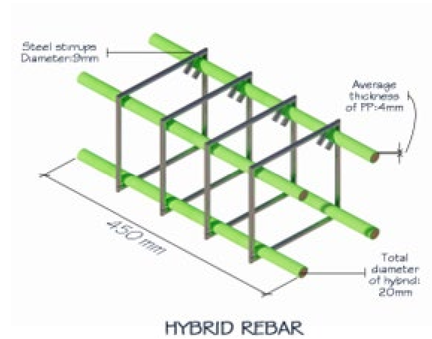

Fig. 2. Hybrid rebar

The most common type of reinforced concrete (RC) beams in practical engineering are those with stirrups. Numerous results consistently identified concrete strength and stirrup ratio as critical elements influencing RC beam impact performance.

For the stirrups in this instance, the researchers used steel bars that were 9 mm in diameter.

Figure 2 exhibits the hybrid rebars (bamboo with polypropylene attached before placing them into the concrete beam formwork. It has a total of 4 stirrups, 4 hybrid rebars, and a total length of 450mm.

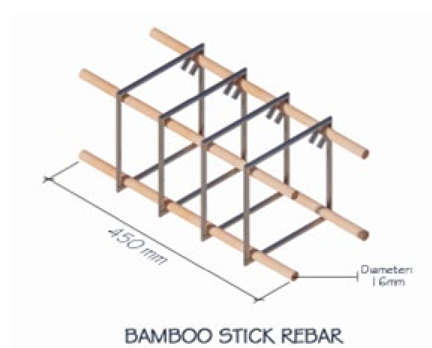

Fig. 2. Bamboo stick rebar

Figure 3 exhibits the traditional bamboo rebars before placing them into the concrete beam formworks. It has a total of 4 stirrups, 4 bamboo rebars, and a total length of 450mm.

4) Preparation of Samples

The preparation of samples began with determining the precise mixture of concrete design, which is concrete mixture Class A, and casting the concrete beams using the designed formworks/molds. The experiment will include three (3) tests on the seventh(7th), fourteenth(14th), and twenty-eighth(28th) days of the curing process.

5) Preparation of Formworks/Molds

The beam formwork or mold will be built using a phenolic board with a dimension of 200mm x 200mm x 500mm. A Universal Testing Machine (UTM) can be used to test a beam specimen measuring 200 mm x 200 mm x 500 mm, as long as the machine's specifications match the specimen's sizes and testing requirements. Yoo (2022) investigated enhanced concrete beams with cross-sectional dimensions of 200 mm width x 500 mm height and a length of 4000 mm. The study's goal is to assess the functionality of various shear reinforcements under four-point loading conditions. The study shows that beam specimens with dimensions close to 200 mm x 200 mm x 500 mm have been used in experimental research, indicating the feasibility of using such dimensions for testing.

6) Molding of Concrete Beams

The concrete beam is filled with concrete mixtures (Class A concrete mix). A total of 18 samples (9 for bamboo-reinforced concrete beam and 9 for bamboo with polypropylene reinforced concrete beam) will be prepared.

7) Curing of Concrete Beams

Following the molding of the concrete beams, the specimens will be cured for 7, 14, and 28 days and tested accordingly. Throughout the curing method, the concrete beams should be sprayed with water consistently.

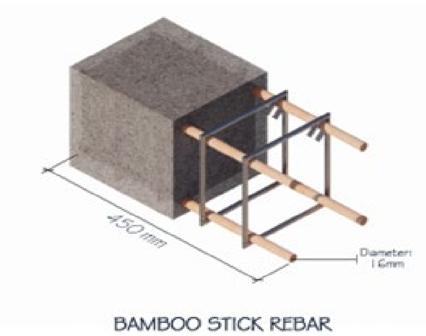

Fig. 3. Bamboo reinforced concrete beam

Figure 3 illustrates the exhibit of a traditional bamboo-reinforced concrete beam after pouring. The concrete beam is cut transversely half to show the content of the concrete beam inside.

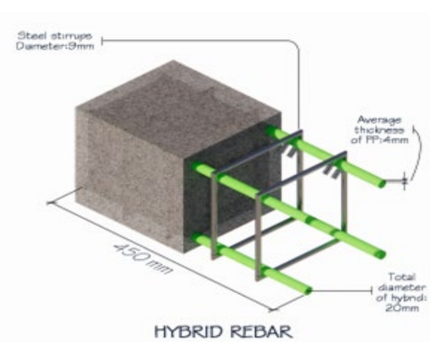

Fig. 4. Hybrid reinforced concrete beam

Figure 4 shows the exhibit of hybrid bamboo reinforced concrete beam after pouring. The concrete beam is cut transversely half to show the content of the concrete beam inside.

8) Testing of Concrete Beam Samples

Concrete beam prototypes will be assessed on the 7th, 14th, and 28th days of curing. The flexural strength test will be performed in the University of the Assumption's Laboratory and Testing Room, located in the Unisite Subdivision, Brgy. Del Pilar, San Fernando, Pampanga, under the supervision of a Licensed Engineer.

G. Data Gathering Procedure

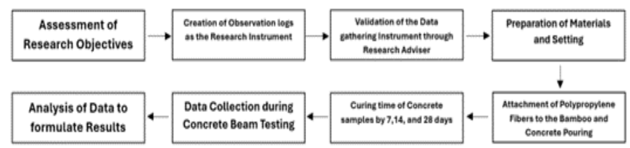

Fig. 5. Data gathering procedure

For the process of data gathering of the study, the research firstly assessed the research objectives. Then, an observation log was made for tallying the results in experiment testing. Furthermore, the research instrument has been validated through the research adviser, checking if it is viable enough to answer the research questions. Then, the researchers prepared the materials and setting of work. After that, the researchers attached polypropylene to the bamboo before setting them in the concrete beams. Then, curing time was set for 7, 14, and 28 days. Furthermore, data collection has been acquired through concrete beam testing in UTM. Lastly, the data has been acquired and the researchers analyzed the data through a data analysis method.

H. Data Collection

The collected data in this study will be in terms of flexural strength tests carried out in the testing facility at the University of the Assumption's Laboratory and Testing Room, which is situated in the Unisite Subdivision, Brgy. Del Pilar in San Fernando, Pampanga. A total of 18 tests (9 tests for beam made of concrete reinforced with bamboo, and 9 tests for bamboo with polypropylene reinforced concrete beam) will be evaluated at intervals of 7th, 14th and 28th day.

4. Results and Discussion

Chapter IV of this study provides a thorough interpretation of the data obtained from the experiments conducted by the researchers. It concentrated in investigating and reviewing the

Table 2
Flexural strength results (MPa) at 7-day curing time

Sample Type	Actual Loads (in kN)	Flexural Strength (in MPa)	Average Flexural Strength (in MPa)
Bamboo (Control Sample)	30.49	3.07	3.20
	33.45	3.37	
	31.27	3.15	
Bamboo with Polypropylene	49.32	4.96	5.23
	55.87	5.62	
	50.75	5.11	

data outcome from the preceding chapter. The study assessed the capability of beams with conventional bamboo rebar as examined against those reinforced with polypropylene bamboo rebar. The flexural capacity tests in UTM will be assessed to evaluate the impact of hybrid rebars on the concrete beam's flexural strength to ascertain its feasibility as a sustainable substitute rebar material.

Researchers made two different samples: the concrete beam with polypropylene bamboo rebar and the concrete beam with typical bamboo rebars as the control sample. Then, the researchers made at least (9) concrete samples. Each type of sample will be separated into batches of 3 to test their strength based on their curing time of conventional time period of 7, 14, and 28. Furthermore, the testing is conducted with the guidance of Engr. Ronald Erwin Calma approved the results shown by the UTM.

Table 3
Flexural strength results (MPa) at 14-day curing time

Sample Type	Actual Loads (in kN)	Flexural Strength (in MPa)	Average Flexural Strength (in MPa)
Bamboo (Control Sample)	51.71	4.03	3.76
	47.58	3.71	
	45.33	3.54	
Bamboo with Polypropylene	68.93	5.5	5.80
	74.57	5.95	
	74.66	5.95	

A. Results of Curing Time in 7-Day Period

Table 2 shows the raw results of the samples regarding its flexural capacity, both bamboo (control sample) and bamboo with polypropylene (test setup) in 7 days of curing time. Bamboo with polypropylene exceeds the flexural capacity of the traditional bamboo samples, resulted in 5.23 and 3.2 (both in MPa), respectively. This indicates that polypropylene plastics have a considerable effect on the concrete beam's flexural capacity.

B. Results of Curing Time in 14-Day Period

The 3 Table shows the raw results of the samples' flexural strength, both bamboo (control sample) and bamboo with polypropylene (test setup) in 14 days of curing time. Bamboo with polypropylene exceeds the flexural strength of the control samples, resulted 5.8 and 3.76 (in MPa), respectively. This indicates that polypropylene plastics have a considerable effect on the concrete beam's flexural strength. Furthermore, both results are higher in comparison to the results during the curing period of prior time.

C. Results of Curing Time in 28-Day Period

The 4 Table shows raw the results of the samples' flexural strength, both bamboo (control sample) and bamboo with polypropylene (test setup) in 28 days of curing time. Bamboo with polypropylene exceeds the flexural strength of the samples, resulted 7.52 and 5.51 (in MPa), respectively. This indicates that polypropylene plastics have a considerable effect on the concrete beam's flexural strength. Furthermore, both results are higher in comparison to the results during the curing period of prior times.

D. Hypothesis Testing

1) One Way Anova

An appropriate statistical tool for determining whether there is a considerable difference between the analytical data of two or greater than two groups is the analysis of variance (ANOVA) - one-way type. The test eliminates genuine group mean variations brought about either by chance or real population mean differences, and it quantifies the effect of a single independent factor to another related dependent variable. If the F-ratio yields a significant p-value, usually <0.05, suggesting that there is a significant difference in means across the groups examined, the null hypothesis (Ho), according to which all group means are equal, is rejected. (Mackenzie, 2024).

Table 4
Flexural strength results (MPa) at 28-day curing time

Sample Type	Actual Loads (in kN)	Flexural Strength (in MPa)	Average Flexural Strength (in MPa)
Bamboo (Control Sample)	71.50	5.58	5.51
	70.43	5.50	
	69.89	5.45	
Bamboo with Polypropylene	94.91	7.57	7.52
	92.76	7.40	
	95.12	7.58	

One-way ANOVA test for Flexural Strength

7-day timestamp ($f = 86.23407$, p-value $= 0.000748$) has a p-value less than 0.05 for the flexural strength test. As a result, the null hypothesis (Ho) is rejected by the study. Additionally, the p-value for the 14-day curing period ($f = 96.48223$, p-value $= 0.00602$) is likewise less than 0.05. As a result, the null hypothesis (Ho) is likewise rejected. Finally, the p-value for the 28-day curing period ($f = 831.2018$, p-value $= 0.0000862$) is likewise less than 0.05. As a result, the null hypothesis (Ho) is likewise rejected. The findings indicate that the setups after seven, fourteen, and twenty-eight days varied significantly in strength.

E. Cost and Benefit Analysis

Sample with bamboo-polypropylene rebars. It has a total cost of Php 345.00, and is made around 18 concrete beams, 9 with traditional bamboo rebar, and 9 with bamboo-polypropylene rebars. The benefit to obtain is the waste reduction cost and

Table 5
F-value, F-crit, and P-value

Curing Period	Fb Mean for Control Sample	Fb Mean for Experimental Sample	F-value	F-crit	P value
7 days	3.20	5.23	86.23407	7.708647	0.000748
14 days	3.76	5.80	96.48223	7.708647	0.000602
28 days	5.51	7.52	831.2018	7.708647	0.0000862

pollution savings which is estimated to be Php 5000.00. Secondly, there are utilities and other costs that include the equipment and consumables used such as coals, flint, etc.It has a total cost of Php 100.00. Lastly, the labor cost of the hybrid bamboo rebars is estimated to be 40% of the total product cost of making. Therefore, it is computed to be Php 178.00. The benefit to obtain is the strength to cost savings, which is estimated to be Php 655.00.

5. Summary, Conclusions and Recommendations

A. Summary

During the experimentation, the researchers made two setups: the control sample of typical bamboo rebars within a concrete beam sample, and bamboo-polypropylene rebars within a concrete beam sample. Throughout the 7th, 14th, and 28th days of curing, the samples made were determined to test their strength in terms of flexure. The research determined whether bamboo-polypropylene rebars exceed the flexural strength of typical bamboo rebars when they are placed in a concrete beam sample.

The concrete has undergone a slump test in assessing its consistency prior to testing and preparing the materials. The result has shown its slump of 55 mm and the concrete is both used for the concrete beam of typical bamboo, and concrete beam of bamboo-polypropylene.

Table 6
Mean & Difference each curing periods

Curing Period (in days)	Fb Mean for Control Sample	Fb Mean for Experimental Sample	Difference bet. Curing Periods for Control Sample	Difference bet. Curing Periods for Experimental Sample
7	3.20	5.23	-	-
14	3.76	5.80	0.56	0.57
28	5.51	7.52	1.75	1.72

Table 7
Cost and benefit analysis

COST					
Description	Current Year (CY)	CY +1	CY +2	CY+3	CY+4
1. Material Cost (Bamboo + Polypropylene)	₱345.00	₱362.25	₱380.36	₱399.38	₱419.35
Bamboo (₱20.00 /stick), Polypropylene (₱7.00/kilo)					
2. Utilities and Other Costs	₱100.00	₱105.00	₱110.25	₱115.76	₱121.55
Equipment and Consumables such as Coals, Flints, etc.					
3. Labor	₱178.00	₱186.9	₱196.25	₱206.06	₱216.36
Total Cost (Future Value)	₱623.00	₱654.15	₱686.86	₱721.2	₱757.26
Total Cost (Present Value)	₱623.00	₱654.15	₱686.86	₱721.2	₱757.26

BENEFIT					
Description	Current Year (CY)	CY +1	CY +2	CY+3	CY+4
1. Waste Reduction Cost and Pollution Saving	₱5,000.00	₱5,250.00	₱5,512.50	₱5,788.13	₱6,077.53
Garbage Plastic Collections and Dumping Expenses, and Lessen Labor for Extensive Plastic Cleaning Operations.					
2. Strength to Cost Savings	₱655.00	₱687.75	₱722.24	₱758.24	₱796.16
Proportionality of Expenses saved to the Strength added					
Total Benefit (Future Value)	₱5,655.00	₱5,937.75	₱6,234.64	₱6,546.37	₱6,873.69
Total Benefit (Present Value)	₱5,655.00	₱5,937.75	₱6,234.64	₱6,546.37	₱6,873.69

Before making concrete, steelworks, and formworks were ensured for the accurate acquaintance of test results. Stirrups were made and installed to the concrete steelworks, using 9 mm diameter. Furthermore, bamboo rebars were 16mm in diameter, and the bamboo-polypropylene rebars were 20 mm (16 mm bamboo, additional 4mm polypropylene coatings).

Then, a Universal Testing Machine (UTM) was used to examine the 200mm x 200mm x 500mm concrete beam's ability to withstand flexural stress. The applied loads were evaluated and converted into the Modulus of Rupture (Fb) that were presented by the UTM. The results of the mean bending resistance of both concrete and testing specimens during the 7th day curing period are in Table 4.1. The presented findings for the bamboo concrete beam and bamboo-polypropylene concrete beam were 3.20 MPa and 5.23 MPa, respectively. This presents that the concrete beams with bamboo-polypropylene exceeded the flexural capacity of the control specimen during the 7th day curing period. The results of the mean bending resistance of both concrete and testing specimens during the 14th day curing period are indicated in Table 4.2. The results shown for the bamboo concrete beam and bamboo-polypropylene concrete beam were 3.76 MPa and 5.8 MPa, respectively. This indicates that the concrete beams with bamboo-polypropylene surpassed the flexural capacity of the control sample during the 14th day curing period. Furthermore, the 7th day curing time results are exceeded by the 14th day curing time results as expected (0.56 MPa for the Control Sample and 0.57 MPa for Experimental Sample). The results of the mean bending resistance of both concrete and testing specimens throughout the 28th day curing period are indicated in Table 4.3. The results shown for the bamboo concrete beam and bamboo-polypropylene concrete beam were 5.51 MPa and 7.52 MPa, respectively. This shows that the concrete beams with bamboo-polypropylene surpassed the flexural capacity of the control sample throughout the 28th day curing period. Furthermore, the 7th day and 14th day curing time results were exceeded by the 28th day curing time results as expected (1.75 MPa for the Control Sample and 1.72 MPa for Experimental Sample).

For the hypothesis testing, the researchers utilized One-Way ANOVA and observed a meaningful difference in the flexural capacity or Modulus of Rupture between the control specimens and the experimental specimens. In all curing time spans, an experimental sample of the concrete beam with bamboo-polypropylene rebar has higher strength than the control samples.

B. Conclusions

The primary aim of this study is to determine the impact of eco-friendly material bamboo-polypropylene fiber plastic as the alternative to traditional bamboo reinforcements in concrete beams. Additionally, the study seeks to assess whether the flexural strength between bamboo-polypropylene fiber plastics and traditional bamboo rebars has significant differences.

For the first objective, based on their studies and experiments, the researchers figured out that bamboo and polypropylene fiber plastic composite materials have the characteristics required for bamboo beam reinforcement. Moreover, test results from the study of Martijanti (2021), incorporation of polypropylene demonstrates an increase in strength and suggests that the composite material improves bamboo's mechanical properties, particularly load-bearing capacity and durability. Furthermore, as stated by Fajardo (2021), polypropylene enhances the binding capabilities and moisture resistance of bamboo against natural conditions. Thus, it concludes that polypropylene has the characteristics to enhance the strength and capabilities of bamboo rebar.

For the second objective, the researchers determined that concrete beams with polypropylene attached to bamboo rebars have a meaningful difference in bending resistance to concrete beams embedded with bamboo rebars, derived from the findings and experimentations. In addition, the flexural capacity of concrete beams reinforced using polypropylene-bamboo rebars is better compared to concrete beams with bamboo reinforcement alone.

Regarding the third objective, we utilized cost-benefit analysis. There are two points: Firstly, there are material costs when procuring materials that will be used in a concrete sample with bamboo-polypropylene rebar. It has a total cost of Php 345.00 and is made around 18 concrete beams, 9 with traditional bamboo rebar, and 9 with bamboo-polypropylene rebars. The benefit to obtain is the waste reduction cost and pollution savings which is estimated to be Php 5000.00. Secondly, there are utilities and other costs that include the equipment and consumables used such as coals, flint, etc.It has a total cost of Php 100.00. Lastly, the labor cost of the hybrid bamboo rebars is estimated to be 40% of the total product cost of making. Therefore, it is computed to be Php 178.00. The benefit to obtain is the strength to cost savings, which is estimated to be Php 655.00. In conclusion, the aforementioned benefits outweigh the unique cost needed in applying bamboo-polypropylene rebar in a concrete beam. Not only does it support sustainability, but it also assesses the costs saved due to the benefits.

C. Recommendations

The researchers' recommendations are derived from previous research and tests. After analyzing the test results and taking into account all of the variables that could influence the data gathered, the researchers made some recommendations. First, repeated cyclic loading due to vibrations can cause failure due to fatigue in both concrete and reinforcement. The study authors recommend using cushioned supports at contact points, such as rubber pads, foam, or sandbags, to absorb shock, which can cause vibration in the sample concrete beams and significantly reduce structural integrity. Furthermore, beams should be placed horizontally to distribute stress evenly when transporting samples.

Second, one of the most difficult aspects of conducting the study is maintaining consistency in the size of the bamboo and the thickness of the polypropylene coating in the bamboo. Inconsistent bamboo sizes can result in unequal load distribution, affecting beam performance. The accuracy of experimental results is heavily reliant on the uniformity and conformity of bamboo sticks. Because the materials are primarily made by bare hands, proponents argue that finding a manufacturer of standardized bamboo reinforcement ensures precise and reproducible outcomes. A manufacturer can provide consistent diameters, lengths, and thicknesses, which reduces variation in results. Furthermore, manufactured bamboo sticks can meet or exceed engineering testing standards.

Third, the researchers suggest exploring alternative concrete mixtures. The use of different mixture classifications has a notable impact on performance outcomes, durability, and measurement accuracy. The bonding and structural integrity can improve by modifying the concrete mixture. Future researchers may adjust the water-cement ratio or aggregate size to prevent separating under load.

Fourth, in assessing the practical effectiveness of the hybrid-bamboo reinforced concrete beams, it is advised by the research to conduct additional structural testing. They should undergo extensive load testing to see how they react to seismic activity and large loads. This will offer insight into how they might be applied to structural applications such as disaster-resilient housing.

Lastly, the proponents suggest conducting additional research into the structural use of bamboo-polypropylene in other structural components such as slabs, columns, and wall footings. This will aid in determining whether the material is appropriate for various load-bearing components, as well as evaluating its structural behavior, longevity, and practicality in a range of construction applications. By broadening the scope of their investigation, Future researchers can gain a deeper insight of its potential as an environmentally friendly alternative to traditional reinforcements

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