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Research Article

Comparative Study of the Effects of Treatment Methods on the Tensile Performance of Bamboo

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Keywords

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Abstract

Bamboo is a rapidly replenishing resource that is used as a practical building material in many nations. However, it is not commonly used in the United States or other western nations, in part because building codes and safety standards have not yet included it. The mechanical characteristics of bamboo must be thoroughly comprehended and recorded in order to develop these. Major variables, including age, bamboo species, density, moisture content, post-harvest treatment, and the testing standards used, affects its properties greatly. This work presents a comparative study of the effects of treatment methods on the tensile performance of bamboo. In this research, bamboo samples of size 12x12mm, 14x12mm, 16x12mm and 20x12mm were prepared, some of the samples were treated with epoxy, bitumen emulsion, binding wire and some were treated by combining binding wire and either of epoxy or bitumen emulsion while few were untreated. Tensile strength test was carried out on both samples and the results shows that the tensile strength of bamboo samples was greatly increased in all the treatment methods used. Tensile strength of bamboo is also a function of size, from the research, it was observed that size 20mmx12mm possess higher strength. Hence, it is recommended for construction works, bamboo treated with epoxy has higher strength other treatment methods. However, a combination of binding wire and other treatment techniques give superior strength, epoxy was observed to have demonstrated higher strength than bitumen and binding wire alone.

1. Introduction

Concrete is widely used for infrastructure reasons in many countries. Due to its affordability, accessibility, and ability to withstand high levels of compressive force, it is often employed in construction projects [1]. Carbon fiber, aramid, glass, and bamboo are some of the other options for reinforcing a structure. Bamboo is one of the most cost-effective options, and it also has a high level of tension resistance. Because of its tensile strength, bamboo is being considered as an alternative to steel by our cutting-edge researchers and engineers [2]. When exposed to tensile pressures, a material's tensile strength measures its resistance to breaking or splitting. There are several downsides to the use of metal in concrete, including environmental deterioration and air pollutants. There are various environmental advantages to using bamboo, which may be produced with few emissions. However, despite the fact that bamboo has been shown to be more robust and stiffer than rebar, the plant is prone to insect attack and may decay when exposed to dampness. As a result, we cannot immediately utilize bamboo in lieu of rebar [3]. It's crucial to think about the material's durability and shrinking propensity, as well. There is a lot of work that needs to be done to address many of these issues and improve the technical qualities of bamboo. There are several varieties of bamboo are cultivated across the globe. Bamboo has a reputation for being the fastest-growing plant in the world. Depending on the species, it may grow to more than three feet in 24 hours and mature in three to five years [4].

Due to its high cost, the use of steel bar as reinforcement has recently been severely constrained and made challenging to acquire. Additionally, the manufacture of steel bars uses a lot of energy and contributes to global warming. Due to its low cost, quick growth, environmental friendliness, and most importantly, its strength in tension, bamboo is one of the alternative materials that can replace steel bar in concrete beams. As stated in [5, 37, 38, 39], bamboo's strength is greater than many types of wood products, but it is considerably lower than the tensile strength of steel.

Experimental research has shown that some species of bamboo have ultimate tensile strengths that are equal to those of mild steel. These strengths range from 140 N/mm2 to 280 N/mm2, and they can even exceed 370 N/mm2 [6], the ultimate tensile strength of moso type bamboo species is only half that of mild steel, despite the fact that bamboo behaves similarly to steel under tensile and compressive strength. Due to a lack of knowledge about the viability and potential of using bamboo in structures, as well as its behavior when exposed to certain conditions, bamboo is rarely utilized as reinforcement in structural elements such as columns, beams, and foundations in Malaysia. Because the bamboo structure beam is intended to withstand greater loads, it is crucial to thoroughly understand the factors that determine the material's strength. The strength information for bamboo from Malaysia is not yet available. Therefore, testing on bamboo should be carried out to obtain accurate results. But the tensile process for specimen preparation recommended by several codes results in inaccurate failure modes, with the majority of tensile tests failing at the grip rather than the gauge length or between the grips [7]. To ensure that the right failure modes are achieved, a detailed analysis of the specimen shape is therefore required. In order to employ the suitable forms for tensile tests, guidelines have been given.

In order to consume fewer fossil fuels and lessen environmental damage, there has been an increase in recent decades in the endeavor to utilize renewable raw resources to create sustainable products.

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Given their abundance in nature, natural fibers have increasingly replaced synthetic fibers as a primary raw resource. Natural fibers have a wide range of possible uses, including in textiles [8]. Numerous studies on the mechanical characteristics of natural fibers have been conducted, including those of wood (9). According to the Society of Bamboo Industry, the bamboo industry in Jiangxi province, China, supports 0.86 million employment related to bamboo pulp, textile, composites, furniture, etc., and generated around 4.6 billion US dollars in revenue in 2014. However, only around 40% of bamboo material is currently being used [11, 12, 13, 14]. The potential of textiles made from bamboo has not yet been fully realized. According to reports, the majority of bamboo fabric now on the market is produced utilizing the viscose technique [15, 16, 17, 18]. As a result, the majority of bamboo textiles on the market are made from natural materials rather than synthetic ones [18]. According to Liu et al. [19, 20, 2], natural bamboo fibers have antibacterial characteristics.

However, the intrinsic roughness and stiffness of bamboo fibers limited their use in the textile industry; fine and soft fibers are much more preferred [22, 23, 24]. Chemically altering natural fibers has been done effectively using a variety of methods. Natural fibers' microstructures and performances changed in response to several treatments, including benzoate [25]. According to Liu et al. [26], alkali treatment is one of the most common and economical ways to produce high-performance natural fibers. The size, morphology, and mechanical characteristics of bamboo strips and bamboo dusts were altered by alkali treatments at various concentrations [27, 28, 29]. According to Liu and Hu [3], bamboo fiber bundles treated with NaOH at varied concentrations and periods have a variety of structural types. Since natural individual bamboo fiber is much smaller and harder than many plant fibers (average hardness is almost 0.5 GPa), there are no reports on the microstructure and mechanical properties of alkali treated individual bamboo fiber to my knowledge. As a result, it is challenging to describe the microstructure and mechanical attributes of certain bamboo strands, hence, chemically altering bamboo fibers is crucial for extending the textile industry's use of this material. Huang and Young [31] look at how different NaOH concentrations affect the mechanical and microstructural characteristics of individual bamboo fibers. Neosinocalamus affinis, a species of bamboo growing in Chengdu, Sichuan Province, China, served as the source of the raw materials. Bamboo with an initial moisture level of 8–12% was harvested from culms that were 2 meters high from the ground. Small strips of bamboo (30 mm long and 29.2 mm wide) were cut from the material. Small bamboo strips were submerged in a chemical solution (one part 30% hydrogen peroxide and one-part glacial acetic acid) at 650C for 18.5 hours to extract individual bamboo fibers [32, 33, 34, 40].

Individual bamboo fibers were neutralized by being rinsed in deionized water before being immersed in 6, 8, 10, 15, and 25% NaOH solutions for 2 hours at room temperature [35]. After the treatment, each bamboo fiber was thoroughly cleaned with deionized water to remove the NaOH and bring the pH level of the fibers down to 7. The fiber suspensions, both untreated and treated, were both frozen in liquid nitrogen and then dried for 24 hours in a freeze drier. The approach described in Trujillo et al. [36] was followed while testing the mechanical characteristics of the individual bamboo fibers. Individual bamboo fibers longer than 2 mm were first chosen. Then, using one drop of glue at each end, fibers were adhered to an organic, channeled glass plate, which was then left in ambient conditions (25 20C, 35 5% RH) for at least 24 hours. Individual fibers' tensile strength was tested using a high resolution commercial mechanical tester with 0.005 N measurement precision. In this study, effects of treatment methods such as, use of epoxy, bitumen emulsion and binding wire was investigated for various bamboo sizes of 12x12mm, 12x14mm, 12x16mm and 12x20mm.

2. Testing process

2.1. Test specimens and properties

Materials

Bamboo, epoxy, binding wire, hydrogen peroxide and glacial acetic acid were used in this work

Sample preparation and treatment: Bamboo use for this work were treated with bitumen emulsion coating, epoxy and binding wire to prevent it from absorbing water, insect's attacks and improve it bond strength with concrete.

Apparatus: Universal Testing Machine, Ruler, Bamboo, Weighing balance

2.2. Theory

The tensile test is probably the most well-known material testing procedure. Material tensile strength is one of the most critical attributes to consider while designing a product. Loading of the sample is gradually increased until it fails to assess the material's strength. The material's tensile strength may be gauged by how much force is applied during the test. The highest test force and the sample's starting cross-section are used to arrive at a final value in terms of tensile strength. The stress-strain diagram is especially good at demonstrating the differences in behavior between the various materials. Stress and strain patterns are unique to each material.

2.3. Procedure for Tensile Testing of Bamboo

Three samples of bamboo will be selected and weighed. A ruler will be used to measure the length, breadth and height of each bamboo sample. A graph sheet will be placed on the universal tensile testing machine adjusting the ink on the edge of the sheet and then the machine will be powered. The bamboo sample will be placed between the lower and the upper jaw of the machine. The load key will be hit on the machine in order to start the process of crushing, the reading will be taken when the bamboo reaches it limit.

Yield Stress = Yield load/Area (N/mm2)

Maximum Stress = Maximum load/Area (N/mm2)

Area = lb(mm2 where l is length and b is breadth

%Elongation = Gauge length/Actual x 100

%Reduction = Original area – Reduced area/Original * 100

2.4. Failure Modes

The bamboo tensile test specimens showed a variety of specimen failure categories, depending on the specimen's form. The test specimens following failure are shown in Figures 7 through Figures 10. According to the observation, each specimen needs to be tested for between three and six minutes, and failure rates for each set of specimens varied both during and after the test. According to the above-described figure, bamboo generally fails more frequently at the grips than in the gauge length region that is located in between the grips. This scenario is comparable to the research done by [9]. When compared to SS, DC, and SC, it is obvious that the S shape failure was exactly where the grips appeared. While SS and DC shape mode failures were regarded as "preferred" failures since they were largely unaffected by the grasping process. Failure of the SC and S forms did occur at the grips, but the specimens broke in completely different ways. According to the observations, testing bamboo cannot avoid three significant elements that may affect all of these failure possibilities. The most significant factors that might cause specimen failure include uneven grip pressure, cutting shapes, and specimen location when being gripped.

3. Testing Results

The results of the tensile strength test are tabulated in table 1.0 to 6.0

Table 1. Results of Tensile Strength Test for Untreated Bamboo Samples

Bamboo Size mm	Bamboo Area mm^2	Treatment Method	Maximum Tensile Force kN	Tensile strength N/mm^2
12X12	144	Untreated	12.00	83.33
14X12	168	Untreated	14.00	83.33
16X12	192	Untreated	16.10	83.85
20X12	240	Untreated	20.20	84.17

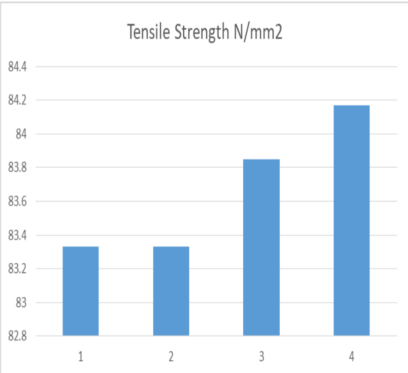

Figure 1. Bar Chart of Tensile Strength for Untreated Bamboo Samples

Table 2. Results of Tensile Strength Test for Binding Wire Treated Bamboo Samples

Bamboo Size mm	Bamboo Area mm^2	Treatment Method	Maximum Tensile Force kN	Tensile Strength N/mm^2
12x12	144	Binding Wire	14.40	100.00
14x12	168	Binding Wire	16.70	99.40
16x12	192	Binding Wire	19.20	100.00
20x12	240	Binding Wire	24.30	101.25

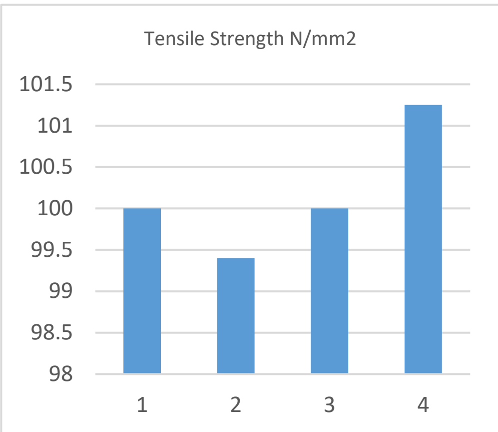

Figure 2. Bar Chart of Tensile Strength for Binding Wire Treated Bamboo Samples

Table 3. Results of Tensile Strength Test for Epoxy Treated Bamboo Samples

Bamboo Size mm	Bamboo Area mm^2	Treatment Method	Maximum Tensile Force kN	Tensile Strength N/mm^2
12x12	144	Epoxy	14.40	100.00
14x12	168	Epoxy	16.90	100.59
16x12	192	Epoxy	19.40	101.04
20x12	240	Epoxy	24.35	101.46

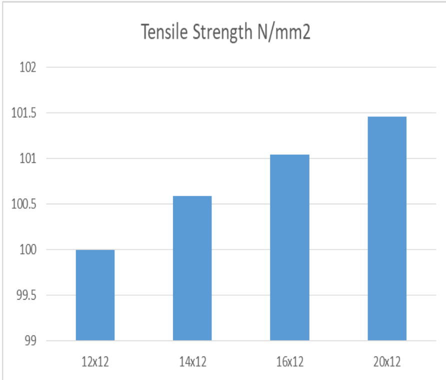

Figure 3. Bar Chart of Tensile Strength for epoxy Treated Bamboo Samples

Table 4. Results of Tensile Strength Test for Bitumen Treated Bamboo Samples

Bamboo Size mm	Bamboo Area mm^2	Treatment Method	Maximum Tensile Force kN	Tensile Strength N/mm^2
12x12	144	Bitumen Emulsion	14.00	97.22
14x12	168	Bitumen Emulsion	16.10	95.83
16x12	192	Bitumen Emulsion	18.90	98.43
20x12	240	Bitumen Emulsion	23.85	99.38

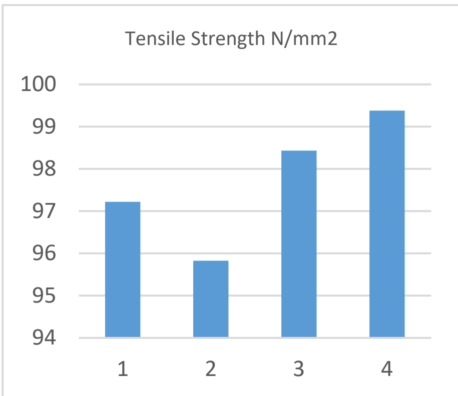

Figure 4. Bar Chart of Tensile Strength for Bitumen Emulsion Treated Bamboo Samples

Table 5. Results of Tensile Strength Test for Epoxy and Binding Wire Treated Bamboo Samples

Bamboo Size mm	Bamboo Area mm²	Treatment Method	Maximum Tensile Force kN	Tensile Strength N/mm²
12x12	144	Epoxy and binding wire	17.20	119.44
14x12	168	Epoxy and binding wire	20.20	120.34
16x12	192	Epoxy and binding wire	23.25	121.09
20x12	240	Epoxy and binding wire	29.30	122.08

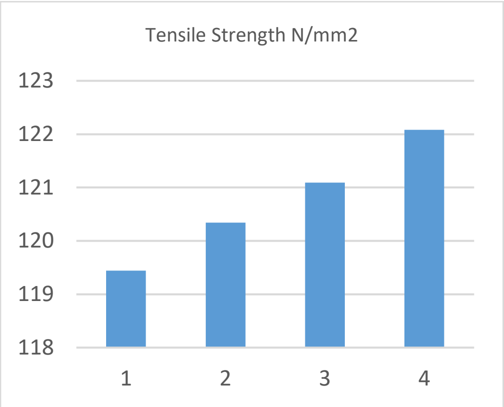

Figure 5. Bar Chart of Tensile Strength for epoxy and Binding Wire Treated Bamboo Samples

4. Discussion

The tensile strength of untreated bamboo varies with bamboo sizes. The size 12mmx12mm (144mm2 area) and size 14mmx12mm (168 mm2 area) bamboo specimens both possess a tensile strength of 83.33N/mm2, size 16mmx12mm (192 mm2 area) possess a tensile strength of 83.85N/mm2 slightly higher than size 12mmx12mm and 14mmx14mm while size 16mmx12mm (240mm2 area) possess a tensile strength of 84.17N/mm2 higher than all other sizes. The tensile strength of bamboo treated with bonding wire vary with bamboo sizes. The size 12mmx12mm (144mm2 area) and size 16mmx12mm (192 mm2 area) bamboo specimens both possess a tensile strength of 100.00N/mm2, size 14mmx12mm (168 mm2 area) possess a tensile strength of 99.40N/mm2 slightly lower than size 12mmx12mm and 16mmx14mm while size 16mmx12mm (240mm2 area) possess a tensile strength of 101.25 N/mm2 higher than all other sizes. The tensile strength of bamboo treated with epoxy vary with bamboo sizes. The size 12mmx12mm (144mm2 area) bamboo specimens both possess a tensile strength of 100.00N/mm2, size 14mmx12mm (168 mm2 area) bamboo specimens possess a tensile strength of 100.59N/mm2, size 17mmx12mm (192 mm2 area) possess a tensile strength of 101.04 N/mm2 slightly higher than size 12mmx12mm while size 16mmx12mm (240mm2 area) possess a tensile strength of 101.46 N/mm2 higher than all other sizes.

The tensile strength of bamboo treated with bitumen emulsion vary with bamboo sizes. The size 12mmx12mm (144mm2 area) bamboo specimens both possess a tensile strength of 97.22 N/mm2, size 14mmx12mm (168 mm2 area) bamboo specimens possess a tensile strength of 95.83 N/mm2, size 17mmx12mm (192 mm2 area) possess a tensile strength of 98.43 N/mm2 slightly higher than size 12mmx12mm while size 16mmx12mm (240mm2 area) possess a tensile strength of 99.38 N/mm2 higher than all other sizes. The tensile strength of bamboo treated with bitumen emulsion and binding wire vary with bamboo sizes. The size 12mmx12mm (144mm2 area) bamboo specimens both possess a tensile strength of 115.97 N/mm2, size 14mmx12mm (168 mm2 area) bamboo specimens possess a tensile strength of 114.29 N/mm2, size 16mmx12mm (192 mm2 area) possess a tensile strength of 117.97 N/mm2 slightly higher than size 12mmx12mm while size 16mmx12mm (240mm2 area) possess a tensile strength of 119.17 N/mm2 higher than all other sizes. The tensile strength of bamboo treated with epoxy and binding wire vary with bamboo sizes. The size 12mmx12mm (144mm2 area) bamboo specimens both possess a tensile strength of 119.44 N/mm2, size 14mmx12mm (168 mm2 area) bamboo specimens possess a tensile strength of 120.34 N/mm2, size 17mmx12mm (192 mm2 area) possess a tensile strength of 121.09 N/mm2 slightly higher than size 12mmx12mm while size 16mmx12mm (240mm2 area) possess a tensile strength of 122.08 N/mm2 higher than all other sizes.

Table 6. Results of Tensile Strength Test for Binding Wire and Bitumen Emulsion Treated Bamboo Samples

Bamboo Size mm	Bamboo Area mm²	Treatment Method	Maximum Tensile Force kN	Tensile Strength N/mm²
12x12	144	Bitumen Emulsion and binding wire	16.70	115.97
14x12	168	Bitumen Emulsion and binding wire	19.20	114.29
16x12	192	Bitumen Emulsion and binding wire	22.65	117.97
20x12	240	Bitumen Emulsion and binding wire	28.60	119.17

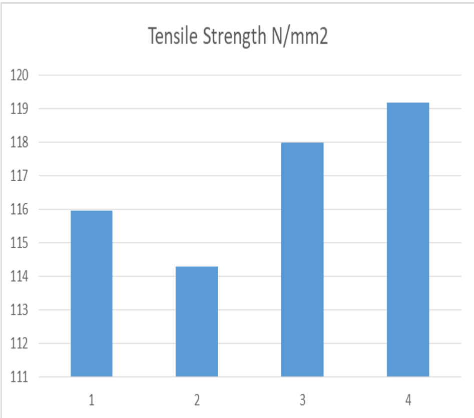

Figure 6. Bar Chart of Tensile Strength for epoxy and Binding Wire Treated Bamboo Samples

5. Conclusion

From the research findings, the following conclusions were made

- Bamboo possess a significant tensile strength of up to 84.17 for untreated and 122.08 for treated samples and as such, it can be considered a potential reinforcement material
- Treatment techniques improve the tensile strength of bamboo and increase it durability

- Tensile strength of bamboo is also a function of size, from the research, it was observed that size 20mmx12mm possess higher strength. Hence, it is recommended for construction works.
- Bamboo treated with epoxy has higher strength other treatment methods such bitumen emulsion and binding wire.
- Combination of binding wire and other treatment methods gives higher strength than all the single treatment techniques, hence, it can be adopted for bamboo construction

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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