Journal of Civil Engineering and Construction 2024;13(4):170-178
https://doi.org/10.32732/jcec.2024.13.4.170

Bamboo Reinforcement: An Eco-Friendly Composite to Steel Reinforcement

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Received: 22 May 2024; Accepted: 7 August 2024; Available online: 30 August 2024

Abstract: The use of steel material has increased in developing countries causing surges in prices and affecting the environment. Researchers are endeavouring to find better and eco-friendly materials like bamboo as a better alternative to be used as reinforcement in concrete construction. This research purpose is to examine bamboo as a reasonable substitute for conventional steel serving as a reinforcement in concrete beams. Nine concrete cubes and prisms, and nine Bamboo-Reinforced Concrete Beams (BRCB) designed are subjected to compression testing. For longitudinal reinforcement, T12 steel rebars are utilized while for shear reinforcement R3 bars are used. Also, Bamboo-Reinforced Concrete Beams BCRBs are experimented with using longitudinal bars having a diameter of 20 mm and 8 mm thick steel bars. The results obtained show that bamboo is a viable alternative material and can be efficiently used as reinforcement in concrete beams in place of steel bars average strength is 34 Mpa. However, bamboo poles should be utilized in concrete construction rather than using bamboo slats because of severe durability concerns. There is a need to further investigate bamboo material to enhance its strength and durability while it is being used as a reinforcing material in concrete beams. This could be done by improving the treatment processes, examining the composite materials, or exploring new ways to improve bamboo efficiency and lifespan in concrete construction.
Keywords: Bamboo sticks; Reinforcement; Steel bars; Concrete; Composite.

1. Introduction

Since the 1960s, scientists have been looking for new materials to improve the mechanical qualities of plain concrete. Bamboo and other naturally occurring fibers have been utilized in conjunction with concrete. Particularly bamboo is regarded as a rapidly expanding, renewable, durable, and environmentally beneficial material. It's interesting to note that each culm of bamboo takes up around 1 ton of CO2 throughout the growth phase. This quality makes bamboo a very sought-after material, especially because tropical regions, where many impoverished nations are situated, are where it is most readily available [1-4]. Numerous researchers have studied the engineering qualities of bamboo and found that, while having somewhat less strength than steel, it is a viable alternative to steel. Bamboo has advantageous properties such as high tensile strength, good durability, and acceptable stiffness, making it a viable alternative reinforcing material in a variety of building applications. The study's findings emphasize bamboo potential as a sustainable and cost-friendly substitute for steel reinforcement in certain structural parts [5-7]. In a study of various scientific investigations on bamboo-reinforced concrete beams, the author Srimathi and others [8] as showed that Figure 1 beams reinforced with square bamboo cross-sections demonstrated appropriate load-bearing capacity, deflection behavior, and sufficient flexural and shear strength. These results delineate bamboo capacity to enhance the structure performance and strength of concrete beams, demonstrating bamboo promise as a dependable and efficient reinforcing material. Bamboo has a tensile strength and elastic modulus that are around half and a third of that of steel, respectively.

In order to guarantee sustained economic surge, efficiency, and the general well-being of a country, building technologies must be effective, consistent, and durable. The increased incidences caused due to structural flaws and utility decline in the built environment can be linked to the component materials utilized in addition to environmental elements and operating circumstances [9]. There is a rising need for substitute materials that may be used instead of steel in some components of civil construction because of the increased demand for steel reinforcement in the construction industry [10]. As a result, scientists have started looking into the qualities of new materials that may take the place of steel without compromising the stability and security of structures. The demand for steel substitute materials in the building sector is also significantly influenced by the rising price of steel. The enormous environmental harm that traditional building materials like steel and cement create during manufacture is one of their biggest downsides. Along with other dangerous fluids, the emission of CO_2, which emits 1.83 tons of each ton of steel produced, adds significantly to the massive destruction of the natural atmosphere [11]. Based on these features, studies by Naznin and Chetia [12] demonstrated that bamboo beams perform better under flexural forces when certain parameters are taken into consideration. The study found that adding shear connections, increasing the diameter of the rebars, and increasing the number of reinforcements improved the performance of bamboo-reinforced beams. These findings suggest that by employing the proper reinforcing procedures, bamboo-reinforced beams' flexural behaviour and overall strength may be enhanced. Bamboo stem and culm, along with the remainder of the plant, are very adaptable and may be utilised to create a wide range of products for use in both domestic and commercial environments. Everything from everyday household goods to applications in other industries [13] Bamboo is widely used in the building of bridges and scaffolds, which has made it very popular among developers in China and Hong Kong. Because of its inherent strength and longevity, bamboo is a trustworthy and cost-effective replacement for traditional materials in these kinds of applications. Owing to its wide availability in these regions and its advantageous mechanical properties, it is often utilised in the construction of scaffolding systems and bridges [14].

(a) Bamboo Sticks/bars

(b) Steel bars

Figure 1. Some examples of steel bars and bamboo Sticks

Furthermore, bamboo is frequently thought of as one of the materials with the best sustainability and economic potential. Its application addresses the pressing demand for affordable housing options. Because of its rapid growth rate and capacity for renewal, bamboo is an abundant building material that may be used to assist meet the critical demand for cheap housing. Communities may attain sustainability and affordability in their housing endeavors by utilizing bamboo advantages. Having a growth rate that is quicker than thrice as that of other plant species, bamboo is remarkably one of the fastest-growing plants worldwide because of its special rhizome-dependent structure. Bamboo adaptability extends to its simplicity in cutting it into a variety of sizes, allowing for comfortable handling and repositioning without the need for specific skills or equipment. Bamboo is an eco-friendly material since it produces no hazardous byproducts throughout the growth process or when it is turned into usable items. This characteristic increases bamboo attractiveness as a long-lasting, environmentally beneficial material. Contrarily, Mahzuz, et al. [15] underlined the almost two tons of CO_2 that steel manufacturing emits each ton of steel produced, which raises environmental issues. The environment might be harmed by this enormous carbon footprint. When this is taken into account, bamboo becomes a very viable solution for the creation of composite materials and components. In addition to being more environmentally friendly than conventional steel production techniques, bamboo is also more affordable [3; 4]. Since bamboo is a lightweight building material, it offers advantages and ease while handling, procuring, shipping, and storage. It is distinguished by its hollow section and round form. Its minimal weight makes it simpler to transport and move around, which eases logistical difficulties. However, it is essential to use cutting-edge processing methods and make use of scientific developments in order to fully realize bamboo potential as a robust and sustainable construction material. Bamboo may be treated and enhanced using cutting-edge methods to increase its toughness, performance, and general durability. This guarantees that bamboo may be used as much as possible in the building sector as a durable and sustainable alternative [16-17].

Bamboo is frequently acknowledged as a very resilient and strong substitute for lumber. It is an extraordinarily renewable resource due to its high growth rate and quick regeneration after harvesting. Additionally, bamboo has remarkable tensile strength and durability that rival or even surpass some forms of lumber. Due to these characteristics, bamboo is now a viable substitute for conventional timber in a number of applications, offering the building industry and other sectors a green and sustainable solution [16]. Bamboo is sometimes referred to be a "strong-as-steel" reinforcing material for concrete structures. The amazing strength and structural adaptability of bamboo as a reinforcing material in concrete construction are highlighted in this section. Bamboo is a viable alternative because to its favourable mechanical properties, particularly in applications where a high tensile strength is not strictly required. While bamboo lacks the identical strength characteristics of steel, it does offer advantageous mechanical properties. The term "strong-as-steel" refers to bamboo ability to provide additional environmental advantages in addition to reliable reinforcing [5]. Extensive research investigations have highlighted bamboo enormous potential for both structural and non-structural purposes in the building industry. Due to its exceptional mechanical properties, most notably its great tensile strength, bamboo has long been used as a main reinforcing material in the structural components of low-cost residential buildings. Bamboo is an inexpensive, sustainable, and long-lasting building material that may be used to create safe and reasonably priced dwellings. solutions in a range of areas [3]. Bamboo has a very high tensile strength when compared to other natural materials. Bamboo frequently has a tensile strength of 370 MPa. It is an excellent choice for usage as a reinforcing material in construction because of its ability to withstand tensile forces and enhance the overall structural integrity of various components. Because of its incredible tensile strength, bamboo has the potential to be a strong and durable material in the building industry [7,8].

However, bamboo tensile strength might change depending upon its kind, species, and region of cultivation. The mechanical qualities of bamboo can be impacted by various climatic conditions and growing situations. The normal bamboo culm contains diaphragms or nodes spaced evenly throughout its height and a hollow, round cross-section. From the bottom to the top end of the culm, bamboo has a varying wall thickness, intermodal distance, diameter, and fiber density. The culm's strong tensile strength along the grain is a result of its fibrous nature. Bamboo has a high strength-to-weight ratio that can be up to six times greater than traditional reinforcing steel. By the time they are three to four years old, bamboo culms are at their strongest and are completely grown. As shown in figure 2 Bamboo differs from many other natural materials in that it can bear both tension and compression load due to its strong fibrous structure [15].

Figure 2. A practical example of developing countries using bamboo-reinforced concrete

The use of bamboo in concrete composites does have certain limits in terms of durability despite its numerous benefits. Bamboo is an organic and natural material, making it prone to deterioration over time, especially when exposed to dampness, fungi, and situations with alkaline concrete. These elements may cause the bamboo in the concrete composite to deteriorate, sometimes losing strength or performing less well due to rot. To overcome these restrictions, bamboo must be properly handled and protected, such as by the application of safeguarding treatments and sufficient concrete cover, to increase its longevity and guarantee long-lasting productivity in concrete buildings. Research is being done to increase bamboo resilience as a reinforcing material in concrete composites and lessen its vulnerability to deterioration.

The objective of this study entails investigating at the potential application of bamboo as reinforcement in structural concrete elements. The factors investigated were bamboo reinforced beam performance, compressive properties, and the strength-to-cost ratio of bamboo reinforced construction.

2. Materials and methodology

2.1 Cement

ASTM C150-51 is a building materials standard that focuses on employing cement as a chemical binder for setting, hardening, and establishing cohesive connections between materials. Cement is frequently used as a binding agent to unite materials such as sand and gravel to form concrete. Masonry work also uses mortar, which is created by mixing cement with fine aggregate. The primary ingredients of the majority of inorganic cement are calcium silicate or lime. Cement is categorised as hydraulic or non-hydraulic depending on how well they set in the presence of water. Popular hydraulic cement Ordinary Portland Cement (OPC) Type-1 is suitable for many building applications because of its setting and hardening properties.

2.2 Coarse aggregate

Coarse to medium-grained particle materials are widely used in construction projects, and the phrase "coarse aggregate" describes a broad group of these materials. This group of materials includes geosynthetic aggregates, recycled concrete, slag, crushed stone, and gravel. These components provide the construction material with structural support, strength, and mass, and are commonly employed as the main ingredient in concrete mixtures. Coarse particles significantly increase the lifetime and performance of concrete structures. Indeed, coarse aggregates have a multitude of purposes beyond just being a component of concrete. They are widely employed as the base material for several construction projects, including the construction of railroads and highways. In a variety of applications, coarse aggregates provide stability, load-bearing capacity, and settling resistance.

Assuring the long-term stability and endurance of the entire construction, they act as a solid and trustworthy foundation, distributing the loads from the buildings or transportation systems above. Coarse aggregates must be used to create a strong and sturdy foundation for these sorts of infrastructure projects. Additionally, aggregates can function as a low-cost extender, effectively combining more expensive materials like cement or asphalt to form concrete. For the specific inquiry that was required, crushed stone in the form of normal-weight coarse aggregate was utilised. The aggregate was neither completely dry or very wet when it was created; rather, it was in a condition known as saturated surface dryness (SSD). The size distribution of the aggregate used in this experimental study ranges from 4.75 mm to 19 mm, which is thought to be typical for coarse aggregates.

2.3 Sand (Fine aggregates)

Aggregate with particles so tiny they may pass through a 4.75 mm mesh screen is known as fine aggregate. One type of particle utilised in the making of concrete is fine aggregate. The tiny particles used as structural filler make up the majority of the volume in the formulas used to make concrete mixes. Fine aggregates are the filler that takes up the most area in concrete. The size, form, and composition of minute particles can have a big influence on the outcome.

2.4 Water

Compressive One of the most important features of concrete is strength, which is greatly influenced by the water quality that will be used in the casting of the samples. Researching the chemical properties of water in relation to its suitability for producing concrete is significant since water quality affects not only the strength of concrete but also the quality of concrete after construction. We used regular drinking water for this experiment.

2.5 Bamboo

Solid transverse diaphragms called bamboo culms have nodes that categorize them into cylindrical shells. The strength distribution of bamboo is more uniform there than at the top or in the center, where wind bending power is at its greatest. When selecting bamboo culms (whole plants) to be utilized as reinforcement in concrete structures, the following considerations should be made:

1) Plants should be well-defined brown in color and at least three years old.
2) The largest, longest culms that are nearby are the finest choices.
3) You shouldn't utilize whole culms of unseasoned, green bamboo.
4) The ideal time to avoid chopping bamboo is in the early spring or summer.

2.6 Bamboo fibers

The bamboo sticks were gathered, the loose material was scraped off of their surfaces, and then all of the bamboo sticks were torn into very thin strips, which were then cut into one-inch lengths.

3. Experimental sample preparation

3.1 Bamboo sticks

Bamboo sticks, as opposed to whole culms, are often more popular in construction projects as shown in figure 3. After the bamboo plant has been cut, three to four weeks should elapse before using it. The tensile strength test couldn't be performed until the bamboo sample was available. To make the sample, bamboo sticks with a diameter of no more than 20 mm and a length of 1 m were cut, dried, and seasoned for 30 days. Since bamboo is a natural material, its properties cannot be precisely controlled, hence the sample's thickness fluctuates throughout its length. Five separate points along the length of the sample were measured to estimate its average dimension. Throughout the season, all bamboo sticks were supported at regular intervals to prevent warping.


(a) Bamboo sticks


(b) beam Configuration


(c) beam Casting

Figure 3. Preparation of the sample of concrete.

3.2 Steel bar

The steel bars were carried into the lab in bundles after being purchased from a nearby market. The steel bundle was untied first, then it was positioned straight. The bars were then cut to length and further straightened by being pounded with a hammer after being marked with the required length. The bars were then equipped with hooks on each side and end. The stirrups' length was also measured, and it was bent to fit the size of the beam.


(a) concrete maximum capticty


(b) Cracks appears


(c) Side view

Figure 4. Loading observation of beam experiments.

3.3 Sample preparation and mix design

A single mix design proportion was used to create concrete utilizing a cement, sand, and aggregate combination as the foundation. This study experiment made use of the 1:2:4 mix ratio. The water-cement ratio was kept constant for both forms of beam preparation at 0.55. It should be emphasized that just drinking was used to prepare the concrete at a time, and neither type of beam preparation concrete mix included any chemicals. The elements were blended in a concrete mixer after being individually weighed in separate trays, following the American Society for Testing and Elements (ASTM C192-98) guidelines. A trowel was used to smash the concrete mixture after the usual 5-7-minute mixing time. The concrete's workability was determined using the slump test, which was then used to determine how the water sample influenced that workability. The slump test was carried out to evaluate the workability of the concrete and then to examine how the water sample affected that workability. As shown in figure 4 the specimens were taken out of the mold, cured in water, and tested for the required amount of time at room temperature after 24 hours. 150 mm x 150 mm x 150 mm prisms or beams were cast to measure the compressive and tensile strength, and 150 mm 150 mm 700 mm prisms or beams were made to measure the flexural strength (modulus of rupture). After 7, 14, and 28 days of curing, all samples for compressive strength were evaluated, and prisms were tested after 28 days of curing.

4. Experimental results

4.1 Analysis of fresh concrete properties

A concrete slump test, often referred to as a slump cone test, is used to gauge how workable or consistent a concrete mix is after it has been made in a lab or while it is being built on a building site. Testing on the concrete slump is done batch by batch to ensure that the quality of the concrete remains constant during construction. Because of its low cost and rapid results, the slump test is the most basic and basic workability test for concrete. Because of this, workability tests have been frequently used since 1922. The slump is carried out in accordance with ASTM C143 specifications in the US. Below, in Table 1, are the slum values. The findings show that the slump obtained from a 1:2:4 mix ranges from 55mm to 66mm for a combination made with 10% bamboo fibers by weight of cement and from 65mm to 75mm for cubes, cylinders, and prisms cast with ordinary or plain concrete. The same water resources used for all types of combinations resulted in the same fresh concrete qualities.

Table 1. Normal and fibrous concrete compressive strength.

	Plain concrete Compressive Strength				Bamboo fibers Concrete Compressive Strength			
Days	Cube 1 (MPa)	Cube 2 (MPa)	Cube 3 (MPa)	Av. Comp. (MPa)	Cube 1 (MPa)	Cube 2 (MPa)	Cube 3 (MPa)	Av. Comp. (MPa)
7	10	11	15	12.1	15	16	17	14
14	20	21	19.1	20	25	27	28	28
28	24	26	25	25	32	38.2	36.1	34

4.2 Mechanical strength properties of concrete analysis

Compressive strength was utilised in this experimental inquiry to identify the properties of plain concrete and bamboo fibres that affect compressive strength. The flexural strength of concrete was assessed using bamboo and steel rods, and all of the concrete samples' features and attributes were constructed from easily accessible materials. The samples were cured for 7, 14, and 28 days for the compressive strength of the concrete, and for 28 days for prisms, by being immersed in a curing tank.

4.2.1. Compressive Strength

Compression testing equipment was used to assess the compressive strength of eighteen cubes of 150 x 150 x 150 mm following seven, fourteen, and twenty-eight days of cure. The 18-cube compression result is shown in Table 1. After seven days of curing, the strength of the concrete has reached 70% of its maximum strength. At 28 days, the typical compressive concrete strength was 35 MPa. Additionally, the table below 1 provides a summary of each sample's compressive strength.

The data clearly show that the compressive strength of the concrete cubes rose at day 28 as opposed to days 14 and 7. Moreover, bamboo fiber-made concrete cubes demonstrated superior compressive strength in comparison to standard concrete cubes. At 28 days, figure 5 the compressive strength of concrete cast with bamboo fibres was 35 MPa for the mix design ratio M1 (1:2:4). Furthermore, plain concrete specimens were made and examined after 7, 14, and 28 days in order to investigate the compressive strength of concrete with mix proportion M1 (1:2:4). Figure 2 shows how bamboo fibers are used in concrete and compares the strengths of two different types of concrete.

4.2.2. Flexural Strength

On day 28, 9 beams were assessed after being treated in a water tank. As the load steadily increases, Table 2 displays the maximum flexural stress and displacement breadth. A load comparison of bamboo and steel-reinforced beams is shown in Fig. 5. The results show that the concrete beam reinforced with bamboo is 12% lighter than the concrete beam strengthened with steel. It proves that the weight of the beam is unaffected when bamboo is used in place of reinforcement in concrete beams. The outcomes also show that the stress capacity of the concrete beam was not considerably increased by employing bamboo as a replacement for reinforcement.

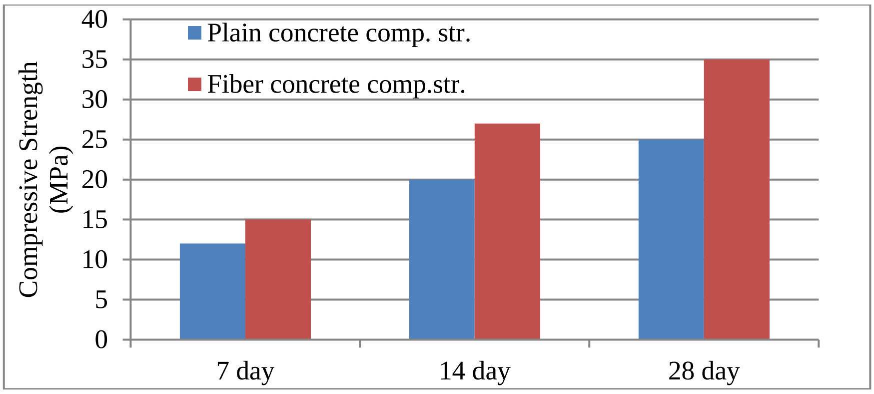

Figure 5. The compressive strength of conventional concrete and bamboo fibre concrete

Table 2. The Flexural Strength of Bamboo and Steel Beams

	4 Bamboo Bars	5 Bamboo bars	6 Bamboo bars	4 Steel Bars Beam	5 Steel Bars Beam	6 Steel Bars Beam
load (KN)	31	50.1	62	121	130.1	160.2
deflection(mm)	8.2	7.1	6	6.1	5.56	4.26

Figure 6 It has been well established that bamboo-reinforced concrete beams have a lower load capacity than steel-reinforced concrete beams. The normal ultimate load and displacement for concrete beams are 136kN and 5mm, respectively. In contrast, a bamboo-reinforced concrete beam has an average ultimate load of 48 kN and an average displacement of 16 mm. Bamboo little displacement indicates its limited shear capability. As a result, when compared to steel-reinforced concrete beams, bamboo-reinforced concrete beams have 35% less strength and 30% more displacement. The natural state of bamboo, which has substantial water absorption due to repetitive cycles of expansion and contraction, maybe the root of this issue. Additionally, bamboo may experience faster and bigger shrinkage than concrete, leading to a speedy debonding of the two materials. As a result, it is possible that bamboo is not a good option for reinforcement. The laboratory test Results indicated that the concrete beam with bamboo reinforcement attained around 35% of the load standard. Bamboo may be used as reinforcement in reinforced concrete buildings, especially in low-cost housing projects, as evidenced by the load capacity of bamboo-reinforced concrete structures that have shown high tensile strength [4]. Additionally, prior studies have suggested that using bamboo nodes while growing bamboo may increase its sustainability. The division or transverse wall can be strengthened by the bamboo nodes, which also allow for bending and avoid rupture when bent [2].

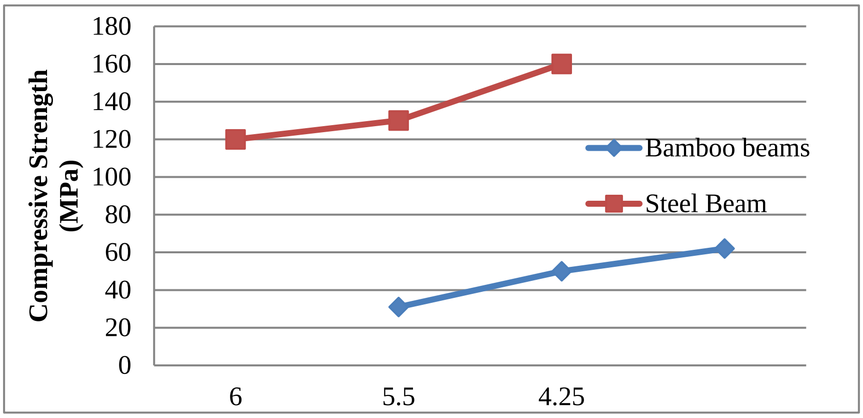

Figure 6. Flexural Strength of Steel Beam and Bamboo Beam

5. Comparison with previous research

5.1 Perioperative research Bamboo reinforcements should be used as recommended

Global experts found that within the next 60 years, the amount of steel produced will decline, requiring the use of natural and environmentally beneficial substitutes like bamboo. Round bamboo has a low shear strength and a compression strength that ranges from 47.9 to 69.9 Mpa [1]. Microcracks started to show on the surface of untreated bamboo and plain concrete columns at around 80% of their maximum axial force, indicating brittle behavior [4, 17].

When compared to steel-reinforced buildings, the use of bamboo as reinforcement may result in cost savings, reducing overall construction costs by 10–20% [18]. Compared to steel, bamboo has a strength-to-cost ratio that is more than nine times greater [19]. The experts' proposals for bamboo-reinforced buildings for moderate-strength construction are both economical and safe.

5.2 Limitations and potential solutions for bamboo reinforcements

The main problem with using bamboo reinforcing in concrete constructions is that bamboo absorbs a lot of water. It is recommended to use a waterproofing chemical to decrease continuous water absorption [4–10]. After collecting water from the concrete, the volume of bamboo expanded, thus decreasing the binding strength [15–19]. Compared to mild steel reinforcements, bamboo reinforcements have a substantially lower binding strength with concrete. It is therefore inappropriate for usage in high-rise buildings with heavy applied loads [20].

Bamboo housing has extremely low earthquake resistance as compared to existing housing systems [21]. because reinforcements made of mild steel are more stiff than this. Because bamboo has a lower modulus of elasticity than steel, concrete fractures more easily. Compared to steel-reinforced concrete, bamboo-reinforced concrete has a much lower design life. on stop water absorption, bamboo reinforcements can be used by applying a high-bonding waterproofing paint on concrete.

Steel wire was previously recommended by researchers as a way to increase binding strength. It takes three to four weeks for bamboo to dry after cutting for seasoning [22], thus delays in building are not always possible. The structure will be weaker if the seasoning was not done correctly. On the other hand, bamboo is vulnerable to insect and mold damage, as well as environmental deterioration [23]. Reinforcements made of bamboo are significantly less fire resistant. Concrete components reinforced with bamboo are therefore suitable for low-rise commercial buildings.

6. Conclusions

Bamboo, a natural material, can be used as a reinforcement in reinforced concrete structures, but its strength may be limited compared to steel bars. Semantan Bamboo, for instance, has a relatively low tensile strength compared to T10 steel bars, but is half as strong. To increase strength, bamboo structures should be constructed using 3-4-year-old bamboo. Bamboo cannot completely replace steel bars as the main structural element in buildings or heavy engineering tasks, as the flexural test for steel-reinforced concrete is thrice as strong as bamboo-reinforced concrete. However, it can be used in lightweight engineering construction and compound wall columns/beam due to its durability when compressed.

The physical and mechanical properties of bamboo can vary based on factors such as diameter, length, age, type, location along culms, and moisture content. Bamboo's rapid water absorption affects its adhesion to concrete and has a low fire resistance. To use bamboo as a reinforcement alternative, it must be treated to protect it from pests, extreme temperatures, and moisture.

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