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BAMBOO AS A SUSTAINABLE BUILDING MATERIAL

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Abstract:

Recently, the demonstrable alternative material to conventional material in the construction field becoming very popular due to global warming and other environmental issues. Steel is one of the considerable materials in construction which results in economical and non-renewability. So, it is suggested that an isotropic material called bamboo material as a reinforcement in concrete. As a building material bamboo fiber shows a promising result and caught attention around the world due to its strength, unavoidable brittle failure, advantages in energy conservation, and environmental protection. Bamboo has a fast-growing nature and its tensile strength is 1.5 times greater than steel. Bamboo reinforced concrete construction follows the same mix design, mix proportions, and construction techniques as used for steel. The durability and properties of bamboo can be improved by mechanical and chemical treatments. In this paper, the performance of bamboo-reinforced concrete, and its durability, are discussed.

1. INTRODUCTION

The construction of buildings is one of the major fields that play a great role in the emission of greenhouse gases in addition to the consumption of energy, land, and raw materials. The World Commission on Environment Development has defined sustainability as meeting the demands of the present without disturbing the demand of the future generation to meet their needs. To ensure sustainability in construction we can use renewable materials and industrial by-products. Construction using natural fibers, especially bamboo is considered as one of the sustainable construction methods.

Fiber-reinforced concrete shows superior ductility, flexural tensile strength, impact resistance, fatigue strength, and toughness when compared to normal concrete. Bamboo is considered the fastest growing natural construction material with more than 1250 species. *Bambusa bambos* is one of the common varieties seen in Kerala. The production of bamboo is around 20 million tons worldwide and India is the 2nd largest producer of bamboo. Even though there are various varieties, all species cannot be used for construction. To use it as a construction material it should satisfy some physical and mechanical properties. Bamboo is naturally distrusted in the tropical and subtropical belt between approximately 46^0 north and 47^0 south latitude and some species are also grown in mild temperature zones.

Bamboo is naturally renewable and biodegradable. Due to its natural origin and environmentally sustainable design, it is energy efficient. For ages, these qualities have made it necessary to employ this in the construction industry. In the majority of developing nations, steel demand is growing daily. There are instances where the output of steel is insufficient to meet demand. Therefore, it is crucial to have a worthwhile steel alternative. Since bamboo is plentiful and tough, it can meet the demand for reinforcing materials and make a great alternative to steel.

Index Terms: Bond strength, Shear strength, Water absorption, Durability, Flexural strength, Elastic modulus, Toughness, Impact resistance

Figure 1 Different types of bamboo

1.1 Structure of bamboo

Bamboo is not a hollow circular tube-like structure. It is divided by transverse diagrams at various locations which are known as nodes. The distance between two consecutive nodes is termed an inter-node. Moving from bottom to top the inter-nodal distance starts to increase at the same time the diameter of bamboo decreases. The node points are considered the weakest point since most of the failure occurs at node points. Bamboo is fast fast-growing perennial plant that grows only vertically over a height of 100 feet within six months.

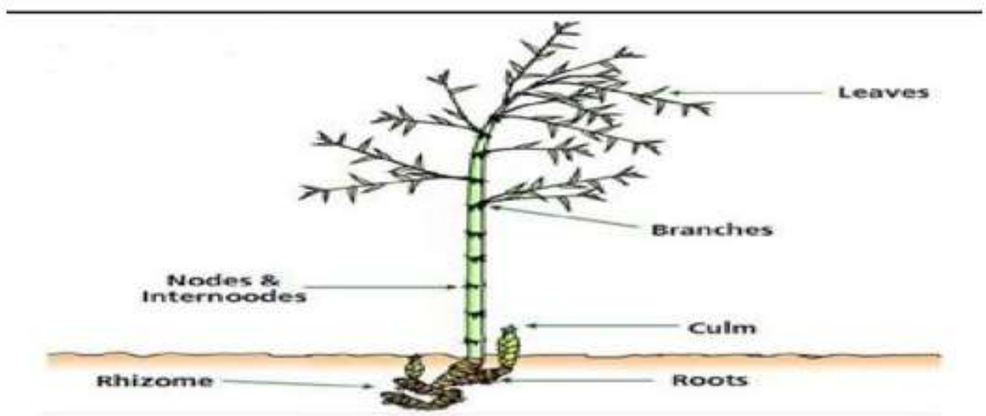

Figure 2 Bamboo and its parts

2.SELECTION OF BAMBOO

The material used as reinforcement in construction should have all the fundamental characteristics required for an element to remain structurally active under load. In the case of steel, the material is produced in the correct proportion and thoroughly tested for a fundamental strength check.

Bamboo, which comes in several species, should also be properly tested before being utilised as reinforcement. Each species varies in terms of thickness, texture, and strength. Knowing the precise species that can be utilized as reinforcement is therefore crucial.

The following factors can be used to choose bamboo for bamboo-reinforced concrete:

- Species:

The particular species of bamboo ought to be reinforced. About 1500 different species of bamboo exist. It needs to be examined for its traits, thickness, texture, strength, and other qualities that meet the specifications for a material for reinforcing, among others.

- Age and Color:

The bamboo used as reinforcement should be clearly brown in color, indicating that it should be at least three years old.

- Diameter:

Although it has been determined that the chosen bamboo should have long, broad culms, there is no precise diameter to choose a bamboo for reinforcement.

- Harvesting:

It is best to steer clear of using bamboo that has been harvested in the spring or summer as reinforcement.

3. STRENGTH PARAMETERS OF BAMBOO REINFORCED CONCRETE (BRC)

The construction using steel and concrete became very popular due to its strength durability and easy handling. But it may lead to an increment in production costs also damage to the environment by the emission of CO_2 during manufacturing processes. One of the solutions to this problem is using natural or synthetic fibers such as bamboo in construction instead of steel. Bamboo is a type of natural fiber that gives more accurate results. Bamboo is by its origin an orthotropic material. It possesses fibers within it. It gains high strength along the fibers and low strength in the transverse direction. The bamboo has a structure of a composite material with cellulose fibers aligned across the length. It has high thick fibers near the outer length of the bamboo, which is the main reason why it resists huge wind forces.

3.1 Bond strength

The bonding property is based on the adhesive property of cement and compressive forces that are formed on the surface of the reinforcing bars. The bamboo culms are treated with some chemicals (boric acid) for 72 hours to avoid the attack by insects and pesticides. The bond strength can be improved by treating it with different chemical coating, sandblasting, and steel wire wrapping. The treated bamboo has shown 6-16 times more strength than untreated bamboo. According to Jung, the feasibility of the use of bamboo as a substitute for steel should be evaluated by a pull-out test. Based on the results the bond strength of bamboo reinforcement is lower than steel. An untreated bamboo affects the bonding strength in the following manners

- By pushing the concrete away, by swelling of bamboo material
- By the formation of cracks as the products of voids formation
- By the formation of voids within the concrete

3.2 Shear strength

Xing (2019) studied about flexural behavior of bamboo fiber reinforced mortar laminates. They are five different types of adhesive are used, emulsion polymer iso-cyanate (EPI), polyurethane (PUR), melamine-urea formaldehyde (MUF), hybrid polymer adhesive (HPA), and polyvinyl lactate (PVA). The shear strength of bamboo depends on the two configurations one is laminated bamboo and the other is bamboo scriber. The general physical features of bamboo are shown in Figure 3. The performance of laminated bamboo boards is influenced by several factors such as the layer structure adhesive type, adhesive spreading rate and clamping pressure, and time. The type of adhesive has a significant impact on the shear bond strength of bamboo materials. The penetration of the adhesive into the bamboo cell walls alters the bonding mechanism and has a significant impact on the mechanical properties of laminated bamboo materials from various bamboo species and densities.

The shear strengths of the glue lines of the laminated bamboo boards produced in this study were evaluated based on British Standard (BS) EN 392: 1995—Glued laminated timber—Shear test of glue lines. Samples with dimensions of 40 mm wide × 40 mm long with various thicknesses were prepared. Prior to testing, the samples were conditioned at a temperature of 20 ± 2 °C and relative humidity 65 ± 5% until contact mass was achieved. The conditioned samples were placed on a shear machine and load was applied at the glue line between the laminations of the laminated bamboo until failure occurred (Figure 3). The load was applied under a displacement control rate of 3 mm/min, ensuring failure after no less than 20 s. The shear strength fv was determined for every tested glue line and was calculated in accordance with the following formula:

$fv = k \times (Fu/A)$

- Fu is the ultimate load (in N);
- A is the sheared area (in mm^2);
- k is factor: $kv = 0.78 + 0.0044\, t$
- t is thickness (in mm)

The shear strength of the laminated bamboo in the horizontal and mixed arrangements is affected by the species ($p \leq 0.05$). The bamboo species did not affect shear strength in the vertical arrangement. Meanwhile, the shear strength of the laminated bamboo in all arrangements is significantly affected by the adhesive type and lay-up ($p \leq 0.01$). On the other hand, the adhesive type was discovered to have a significant effect on bamboo failure, whereas species did not influence bamboo failure. Only the bamboo failure of laminated boards manufactured in a mixed arrangement was significantly influenced by the lay-up pattern

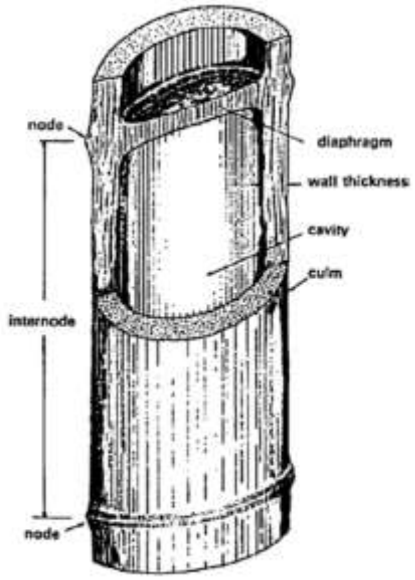

Figure 3 Physical features of bamboo

3.3 Water absorption

The main disadvantage of bamboo in concrete is water absorption. During the curing period, bamboo absorbs a large amount of water and starts to expand. This results in the formation of cracks. Once the curing period ends bamboo starts to shrink and loses its contact with concrete. This can be overcome by treating bamboo with chemicals before it is used as reinforcement. The bamboo can be treated with oil paint, bitumen kerosene, mixture paints, and readymade bituminous paints, they form an impervious layer over its surface which protects it from water absorption. This can be done by placing bamboo inside the water tank for about 24 hours. The crack development due to water absorption is illustrated in Figure 4

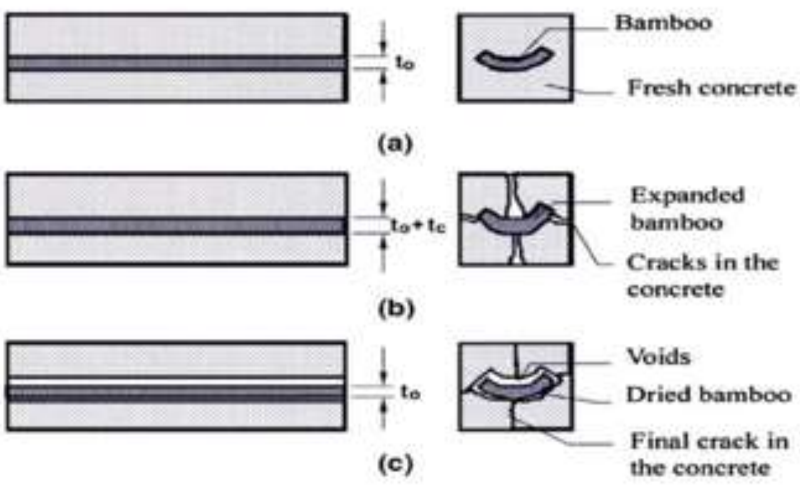

Figure 4 Water absorption

3.4 Durability

Lima et al. (2007) analyses the bamboo-reinforced concrete's durability. This research made use of 20 m long *Dendrocalamus giganteus* bamboo that was received from the Cascavel City Zoo (Brazil) and sample bamboo culms of around 500 numbers, which are three years old. With Brazilian type V Portland cement, river sand with a fineness modulus of 2.1, and coarse aggregate with a fineness modulus of 5.79, the mix proportion was determined to be 1:4.37:4.96:0.70. To increase the flexibility and durability, calcium oxide (CaOH2) was applied to the bamboo culms. Based on the findings, it can be said that bamboo has no effect on Young's modulus and that the tensile strength of concrete for bamboo nodes is 100 MPa and 240 MPa for concrete without bamboo nodes.

Its property of being a natural product makes it more exposed to environmental agents and insects. A remedy against this is to undergo bamboo curing. The curing process enables the treatment of humidity content and the starch within it, which is the main reason for insect attraction. The curing is effective only if the chosen bamboo is the right one. As mentioned in the selection of bamboo. The curing of bamboo can be done either by

1. Curing on spot
2. Immersion process
3. By heating
4. Smoke Curing

The treatment must be done when the bamboo is in a dry state so that the penetration is done in the right way. The preservation treatment done on bamboo to take care of the durability factor should not affect the chemical composition. The treatment itself should last, without being washed away under high water conditions if any. Durability is a major concern for bamboo materials. The physical and chemical properties of bamboo are found high with a low content of humidity within it. This low content would keep away molds in bamboo.

The pre-dried bamboo fiber was fine-grained and allowed to pass through a 50–60 micron size mesh before being tested isothermally for three hours and subjected to various treatments. Bamboo comes in two varieties: treated bamboo and untreated bamboo.

Bamboo fiber, both treated and untreated, has a high twin density. As a result, the chemical treatment of bamboo helps to reduce the water absorption of bamboo fiber and increases its durability. Bamboo reinforcement is found more durable than steel if it has undergone proper treatments.

3.5 Flexural strength

Researchers Schneider et al. (2014) examined how concrete beams with flexural and shear reinforcing behaved. To determine the mechanical characteristics of bamboo, the first tests, such as tensile and pullout tests, were carried out on Moso bamboo. In 3- and 4-point bending tests, monotonic gravity loading was applied to three different types of beams for shear control, flexural control, and lap splice control. According to the findings, bamboo offers an alternative to steel because it allows for large deflections and cracks that also serve as early warning signs of impending structural failure.

4. TREATMENTS

After being cut into pieces and having their backs scraped off, the bamboo sticks were soaked in water for at least 24 hours. The bamboo sticks were then beaten into strips so that the fibers could be extracted from them. After that, the fibers underwent treatment by spending 24 hours submerged in a 2% solution of sodium hydroxide. Furthermore, the bamboo fiber's capacity to absorb water is diminished by soaking it in NaOH. Fig. 5 depicts the methods used to prepare and remove bamboo fiber

Figure 5 Removal of bamboo fiber

Frequently, alkali treatment is used to alter the composition of fibers. To create new kinds of amorphous system structures, sodium hydroxide (NaOH), a common alkali, is employed to dissolve the hydroxyl (OH) groups and the densely packed crystalline component. Additionally, it gets rid of the hemicelluloses, lignin, waxes, and oils that increase the fiber's surface abrasiveness. Additionally, the alkali treatment increases the fiber's surface area, which improves fiber adhesion and interlocking with blends, leading to improved composite strength characteristics.

As seen in Fig. 6, the cement containing 0.5% untreated bamboo fibers exhibits a collection of different strands. This should be due to the fibers' strong hydrogen connections with one another, which prevent individual fiber dispersion. Surface and bulk flaws would emerge from unevenly dispersed fibers. The stress level at these faults would lower the fracture strength of the mortar sample, hastening the crack transmission. The study discovered that the treatments improved the fiber's chemical properties, enabling the fiber to adhere to the matrix's hydrophobic features more effectively.

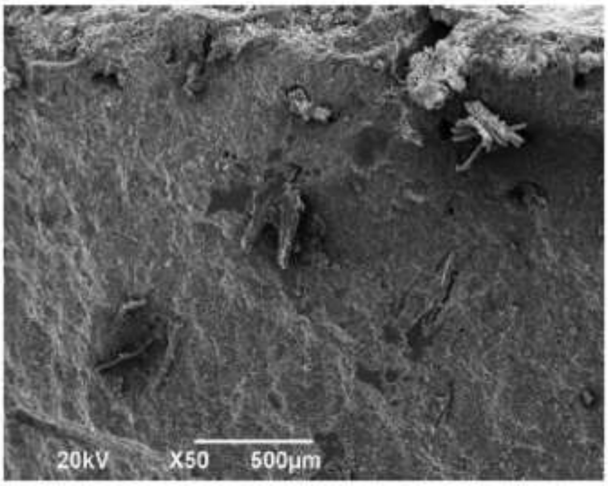

Figure 6 Untreated bamboo containing 0.5% cement

As you can see in Figure 7a, the bamboo fibers are spread out evenly and finely through the cement. By spreading treated bamboo fibers out evenly, you could improve the mechanical properties of the fiber-reinforced cement and stop cracks from growing. Figure 7b shows that the broken areas of the cement are made of bamboo fibers that have been treated with alkali. The treated bamboo fibers are tightly wrapped in the cement matrix, spread out evenly throughout the cement matrix without visible phase boundaries, and clumped together on the fracture surface. This shows that the cement base and the bamboo fibers that have been treated with alkali stick together better. It was found that the alkali-treated fiber had lost various functional groups, including cellulose, hemicellulose, and lignin, in studies comparing treated and untreated bamboo fibers. Heat treatment modifies properties, resulting in an improvement in dimensional stability, strength, and durability. In recent years, saturated steam heat treatment has drawn increasing amounts of attention due to claims that it is more economical and environmentally friendlier than traditional methods. Additionally, it has been shown that a light-saturated steam heat treatment successfully improves the mechanical and physical properties of bamboo-based materials.

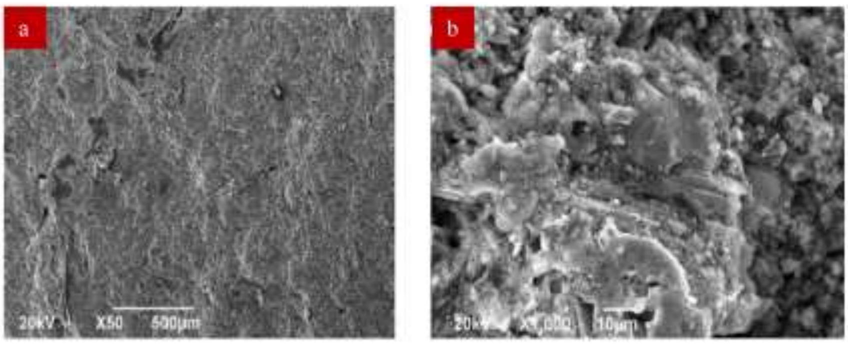

Figure 7 Bamboo fibers on cement

Additionally, the heat treatment increases the crystallinity of the cellulose in the fibers, increasing their stiffness and tensile power. The process also removes the fiber's natural sugars and starches, making it less susceptible to attacks from insects and fungi.

5. STRENGTH PROPERTIES

5.1 Compressive strength

Bamboo fibers may increase the compressive strength of concrete, according to one study. The compressive strength of concrete is at its highest when the proportion of bamboo fibers is 0.26% because bamboo fiber lengths remain constant. The concrete compressive capacity decreases with bamboo fiber length as the quantity of bamboo fibers is constant. According to one study, bamboo fibers greatly slow down the growth of cracks, increasing compressive strength. Through the interlocking phenomenon, the fiber surface pretreatment also enhanced the bond between the bamboo and the paste. Bamboo fibers are used to represent the compressive strength of concrete. Bamboo fibers may increase the compressive strength of concrete, according to one study. The compressive strength of concrete is at its highest when the proportion of bamboo fibers is 0.26% because bamboo fiber lengths remain constant. The concrete compressive capacity decreases with bamboo fiber length as the quantity of bamboo fibers is constant. According to one study, bamboo fibers greatly slow down the growth of cracks, increasing compressive strength. Through the interlocking phenomenon, the fiber surface pretreatment also enhanced the bond between the bamboo and the paste. The study discovered that at 1.0% fiber concentration, the compressive strength started to decline. Due to the high fiber content, the concrete may have developed pores, which may have affected the matrix's compactness and aggregate packing. The presence of honeycombs creates the perfect conditions for the emergence and expansion of micro cracks, which causes the sample to degrade prematurely. The fibers, however, acted as crack arrestors in samples with less than 0.75 percent fiber, delaying the progression of any cracks and raising the final strengths.

5.2. Tensile strength

Adding bamboo fibers to concrete increases its compressive and tensile strengths by 22 and 17%, respectively, according to the study. The bridging role of the fiber, which stops cracks in the hardened mix from propagating, is responsible for this improvement. The improved tensile strength of the samples was caused by the alkali treatment, which removed contaminants and reduced the amount of lignin and cellulose in the fiber surface morphology of the bamboo. The rougher surface improved the fiber-matrix adhesion, which led to an improvement in tensile strength. The lack of bamboo fibers in the cement, which could have diminished strength, has been significantly reduced as a result of the surface pretreatment. Because of this, the bamboo fibers could perform as effectively as possible in minimizing fractures in the mortar specimens. Similar to this, it was discovered that the length of the fiber had a significant influence on the tensile strength of concrete.

5.3. Flexural strength

A examined the concrete's ability to bend at different bamboo fiber mix percentages, including 0%, 0.50%, 1%, 1.50%, 2.00%, and 2.50%. When fiber additions are done at a rate of 0.5, 1.0, 1.5, and 2%, the concrete's flexural capacity improves when compared to conventional concrete, but it decreases at a rate of 2.5% when compared to other fiber ratios. Similar to this, the split tensile strength of concrete reinforced with bamboo fibers has increased when compared to unreinforced concrete, but it has decreased when bamboo fiber reinforcement is employed at a ratio of 2.5% as contrasted to other fiber ratios. According to a study, the addition of fiber (up to 2%) increased the concrete's ability to flex. When the fiber is added at rates of 0.5%, 1.0%, 1.5%, and 2.0%, respectively, the concrete's flexural strength increases by 0.2%, 1.3%, 1.85%, and 3.3%. After a 2.5% addition of fiber, the concrete's flexural strength started to deteriorate and fell by 0.43%. This is a result of the fibers' higher cohesion and collective resistance to splitting forces than the maximum values seen in the control samples.

Additionally, the fibers extreme aspect ratio increased their lateral surface area in relation to the paste, which increased the strength that was seen after their introduction. Additionally, the rupture mechanism changes from fiber breaking to fiber extraction from the blend due to the fiber's greater tensile capability. This implies that the process is governed by the strength of the bonds holding the fibers and cement together.

According to the study, the inclusion of bamboo fibers also had a substantial effect by halting the propagation of these fractures. The ductility property bamboo fibers offered led to an increase in the samples' flexural strength when compared to the control samples. By connecting around these fractures and offering some post-cracking ductility, the fibers were added to the mortar to boost strength, control mortar breaking, and alter how the substance behaves after the blend has broken. The improved bond between the bamboo fibers and the blend may be the result of paste precipitation into the fibril-exposed surface and the fiber voids.

Later, an interfacial connection was made between the calcium-based, hydrated cement formation and the bamboo cellulose chain. As a result, the crack propagation mechanism and fracture resistance of the composite samples were both dramatically improved.

5.4. Failure pattern

The control mixture exhibited linear elastic behavior until reaching the maximum stress, at which point it experienced rapid failure, resulting in the total separation of the specimens into two distinct pieces. In contrast, the bamboo fiber combinations exhibited enhanced post-crack behavior, resulting in a strain-softening response characterized by the occurrence of a single crack in the central region of the prismatic sections. This impact is seen in Fig. 8 visual representation of the specimens subjected to bending tests. These photos specifically pertain to samples containing 300-mm fibers. One can see the fibers spanning the formed fissure, which became much more noticeable as the fiber concentration rose from 4 to 8%.

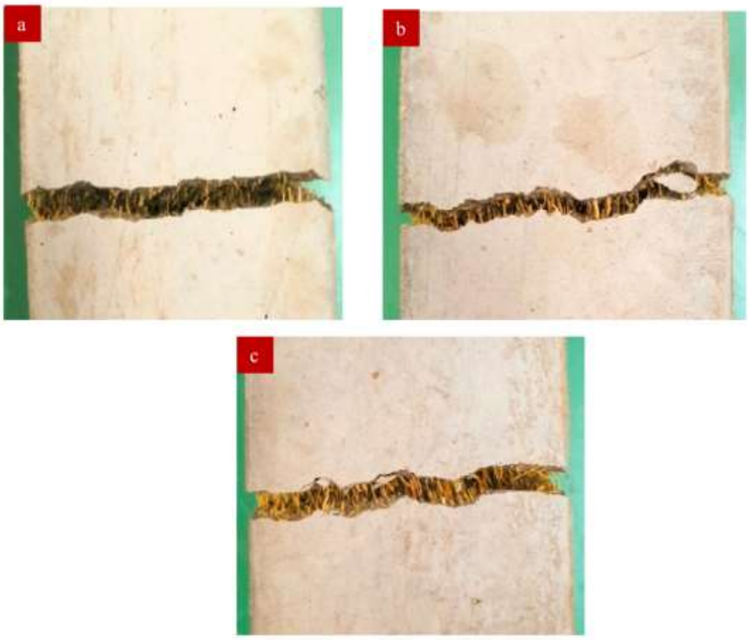

Figure 8 Failure pattern (a) 4% (b) 6% (c) 8% bamboo fibers

Concrete reinforced with fibers has superior tensile strength compared to conventional concrete due to the incorporation of fibers, which enhance elasticity by delaying the onset of tension ruptures or preventing the formation of fractures. The impact of fibers is characterized by fracture-blocking rather than fracture-restraint. The incorporation of fiber in traditional concrete has been found to have a greater impact on the tensile capacity rather than the compressive capacity. This is primarily attributed to the ability of fibers to prevent cracking by means of a bridging effect. Multiple studies have provided evidence that fibers contribute to the improvement of tensile capability in post-cracking behavior. Based on scholarly study, the enhancement of concrete strength can be achieved through the uniform dispersion of fibers throughout the material, hence preventing agglomeration. The bulk of the studies exhibited enhancements in the compressive strength of concrete with decreased fiber quantities. In contrast, the scattered fibers present in the concrete serve to delay the propagation of cracks during testing by means of bridging, thus enhancing the structural integrity of the concrete.

5.5. Load deflection curve

Based on the findings presented in Figure 9, it can be observed that the samples lacking bamboo fibers exhibit a brittle behavior during static rupture. This is evident from the load-deflection curve of the reference sample, which remains relatively linear until reaching its maximum position. At this point, a violent crack formation takes place, leading to a rapid decrease in applied force. However, the load-deflection curve of the composites filled with bamboo fibers demonstrates an initial period of linear behavior followed by a subsequent nonlinear response. Additionally, the decline in load subsequent to reaching the maximum load is characterized by a slow rate, indicating that the static rupture of the specimens containing bamboo has ductile properties. Based on empirical investigations, the incorporation of fibers into concrete has demonstrated a notable enhancement in the material's overall deflection and ductility characteristics. Furthermore, it can be shown that there is a direct correlation between the proportion of bamboo fibers and the deflection exhibited by the sample in the load-deflection curves. The deflection values at the failure of the specimens increase by approximately 3.5, 10.5, 19.0, and 22.0 times when the bamboo fiber percentages are 4, 8, 12, and 16%, respectively, compared to the reference sample that does not contain any bamboo fibers.

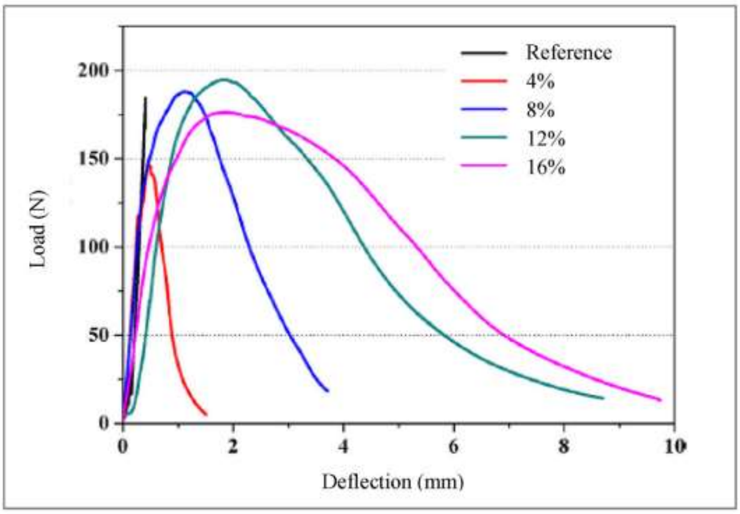

Figure 9 Load deflection curve

According to the conclusions of the study, bamboo demonstrated a strength of 82% and a ductility of 93%, which sets it apart from steel-reinforced slabs. Consequently, bamboo has the potential to function as a substitute for steel in concrete reinforcement. However, further investigation is required to ascertain the possibility of enhancing its mechanical qualities. Based on the findings of the study, it was observed that bamboo fiber groups, consisting of fibers measuring 300 mm and 500 mm, exhibited similar trends. It can be observed that the interfacial adhesion between alkali-treated bamboo and cement is significantly enhanced. As a result, the cement matrix exhibits the capability to effectively transfer a specific magnitude of the external load to the bamboo material. The stress propagation within the treated bamboo can lead to the brittle failure of oil well cement, resulting in a decrease in both its strength and elastic modulus, hence enhancing its deformation capabilities. The pullout behavior of treated bamboo fiber along the fracture crack and its ability to maintain post-continuity are influenced by the higher strain observed in the stress-strain curves, in comparison to pure cement. Furthermore, it is worth noting that there is a notable increase in the surface area beneath the stress-strain curves, suggesting that the application of alkali-treated bamboo fibers has the potential to enhance the strength of oil well cement and prolong the initiation of fracture failure. The enhancement of energy dissipation resulting from crack deflection, fiber debonding, fiber joining, fiber pull-out, and fiber rupture is associated with the toughening mechanism exhibited by oil well cement, which can be attributed to the inherent resistance of natural fibers to fracture.

5.6. Elastic modulus

This paper provides a description of the elastic modulus of concrete that has been reinforced with bamboo fibers. Additionally, studies have indicated that air becomes trapped during the process of mixing the adhesive surfaces, resulting in its accumulation within the space between concrete and fibers. The limited interaction between the fiber and the binder can be attributed to the presence of air gaps. The presence of a small air volume has a detrimental effect on the compressive strength of high-performance concrete. Furthermore, the inclusion of a higher quantity of fibers in the concrete mixture results in a reduction in the volume of the concrete. This decrease in volume is accompanied by a decrease in both the compressive strength and elastic modulus of the concrete, as stated in the reference. The research findings also showed a drop in the elastic modulus when fibers were included. Although the fiber-reinforced mixtures had a rise in strength, it was observed that on average there was a drop of 10%. One potential reason for the decrease in elastic modulus is the hypothesis that fibers aligned in the same direction as the load may exhibit characteristics similar to vacancies. The consolidation process could potentially be influenced by the incorporation of fibers, resulting in a reduction of the elastic modulus. Furthermore, it can be observed that mixtures with longer fibers have a reduced elastic modulus in comparison to fiber-reinforced materials with an equivalent fiber content.

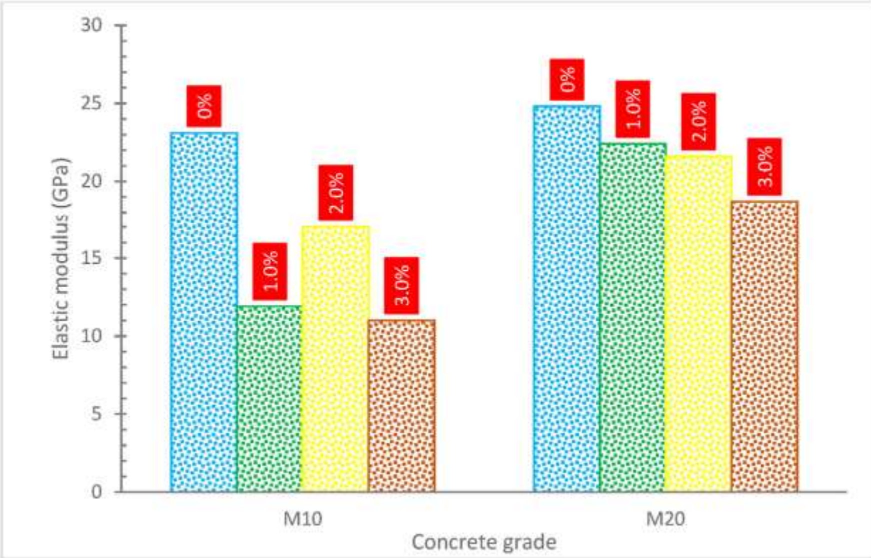

Figure 10 Elastic modulus

5.7. Toughness

The graph presented in Figure 10 demonstrates a decrease in the strength of concrete when reinforced with bamboo fibers. Moreover, the attribute of toughness is also dependent upon the dimensions of the fibers. The thicker and longer fibers found in the 500-mm batch exhibited a decrease in overall toughness when contrasted with the smaller and shorter fibers in the 300-mm batch. The phenomenon can be explained by considering the enhanced resistance to pull-out exhibited by fibers with a higher aspect ratio, as well as the increased capacity of the bridge to support loads in mixtures including a greater quantity of fibers.

In comparison to blends containing 4% bamboo fiber, the toughness values of the 300-mm fiber samples at 1 mm deformation exhibited an increase of 40.0% and 73.3% for the 6% and 8% blends, respectively. Based on the assessment of the 500-mm fiber batch, it was seen that the toughness of the mixtures containing 8-volume percent and 6% improved by 16% and 47% respectively, when compared to the blends consisting of 4%.

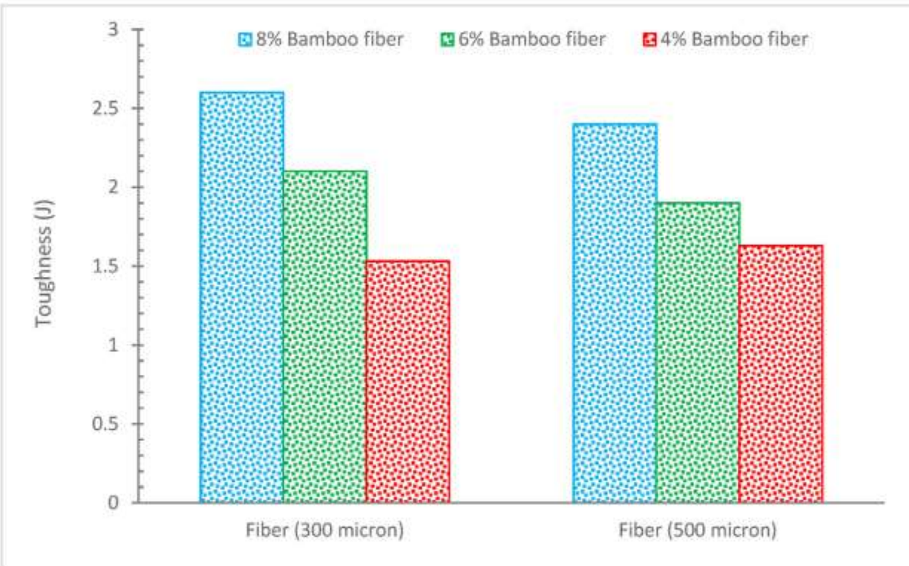

Figure 11 Toughness curve

5.8. Impact resistance

This study demonstrates the capacity of concrete reinforced with bamboo fibers to withstand elastic impacts. In research work, fiber was incorporated into concrete with the aim of enhancing its impact resistance, including attributes such as strength and energy absorption capacity. Based on the findings of a study, it has been observed that the fracture energy absorption capacity of concrete exhibits significant improvement within the range of fiber volume fractions from 0.5% to 0.75%. The figure 12 shows the elastic impact resistance of concrete reinforced with bamboo fibers

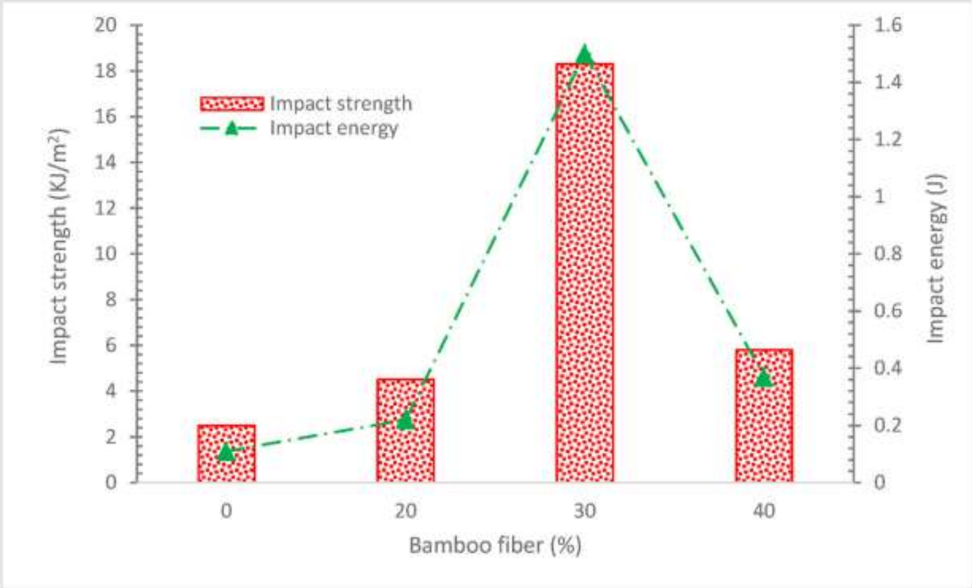

Figure 12 Impact curve

As impact energy increases, more energy is absorbed. For impacts of 5, 10, 15, 20, and 25 J, the specimens' respective absorbed energies are 3.82, 9.19, 14.35, 19.30, and 23.16 J. The equivalent absorption coefficients for impacts with energies of 5, 10, 15, 20, and 25 J are 0.76, 0.92, 0.96, 0.97, and 0.93, respectively. The absorption coefficient, on the other hand, first shows an increase and then a decline. The figure 13 provides the absorbed energy and absorption coefficient of the samples with 12% bamboo fibers.

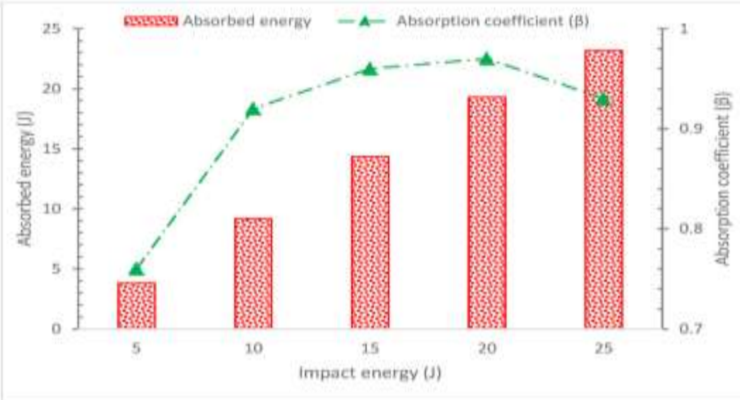

Figure 13 Absorbed energy curve

The toughness of cement may be increased by adding the proper amount of bamboo fibers, but too much bamboo fiber might cause fiber aggregation, which prevents composites from achieving their optimum flexural strength and impact resistance. According to the study, material with a 10% fiber loading has a higher impact strength than material without bamboo fibers. However, the impact strength tends to drop when the fiber content exceeds 10%. According to Fig. 14, the top surfaces of the slabs formed pits of varying diameters, and as the impact energy increases, so does the depth of the pits. When compared to the loss on the top surfaces, the damaged pattern on the slabs' bottom surfaces is roughly spherical, and the impact area is bigger. Additionally, as the impact energy increases, so do the size of the matrix fracture and the affected region. In Fig. 14, it is demonstrated that the inner specimens have matrix fractures, delamination, and a minor degree of fiber breaking at an impact energy of 5 J. The fracture path is also close to the cone's edges, whose top and bottom surfaces correspond to the damaged areas on the top and bottom surfaces of the samples, and the spalling of the slabs is mainly perpendicular to the direction of impact of the hammerhead. As impact energy rises, the impact loading is transferred to the following layer through the cement mixture and the interlocking of the fibers, causing increasingly noticeable separating and fractures. Consequently, the surface damage to the samples is less severe than the delamination region and numerous fractures.

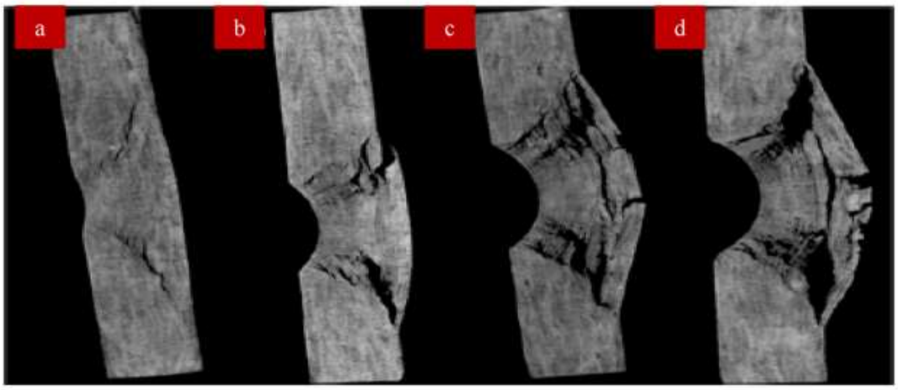

Figure 14 Varying diameter of pits as the impact energy increases

6. BAMBOO AS A BUILDING MATERIAL

6.1. Bamboo in bridges

Xiao et al. (2008) conducted research in the field of modern bridge construction and afterward published a report on their findings. The construction of this bridge involved the utilisation of Glubam, a material produced through the finger-jointing process of sheets. Following this, two layers of epoxy glue were placed onto the surface of the bridge. Subsequently, the bridge was subjected to pressure hardening for a duration of 24 hours at a temperature of 150 degrees Celsius within the IBTCS Laboratory at Hunan University. A total of six specimens were subjected to testing, each possessing planar dimensions measuring 2440*1220*28 mm.

Figure 15 Bamboo bridge

6.2. ZCB Bamboo pavilion

The 'ZCB Bamboo Pavilion' is a temporary public event space capable of seating 200 people, completed in October 2015 in Kowloon Bay, Hong Kong, where it was used for 8 months before being recycled. It is a bending-active grid shell structure that spans 37 meters, is four stories high, and is wrapped in a lightweight translucent glass-fiber reinforced polymer membrane. Its design development works through immediate and specific problem solutions on-the-go until sufficient confidence is built up to initiate final construction.

Figure 16 ZCB Bamboo Pavilion' during a night-time even

6.3. Bamboo frame

In their study, Elizabeth and Datta (2013) examined the seismic performance of two-story bamboo structures in comparison to reinforced concrete (RC) frame buildings. The bamboo utilised in this project possesses a lightweight and flexible nature, enabling it to endure a weight of 7.5 tons. Additionally, its density ranges from 500 to 800 kg/m3, as observed in Brazil. A model of a bamboo structure was constructed using a bamboo grid measuring 70mm by 100mm, with a thickness of 15mm. The density of the structured bamboo is measured to be 7.3575 kilonewtons per cubic meter (kN/m^3). Its modulus of elasticity is determined to be 20 giga newtons per square meter (GN/m^2). The Poisson ratio of the bamboo is found to be 0.3, while the damping ratio is calculated to be 0.0152. The connection between the two column and beam elements of the bamboo construction was established by inserting a steel rod into a hole in the bamboo, followed by the application of grouting to secure the connection. To study the response of bamboo and reinforced concrete (RC) structures to seismic activity, we utilised input data from the EI-Centro earthquake and the Kobe earthquake. The results of the study demonstrate a clear correlation between the use of bamboo as a building material and a lower frequency of seismic activity. This finding provides evidence supporting the efficacy of bamboo as an earthquake-resistant construction material.

6.4. Bamboo in building wall

In a study conducted by Chakrabortty (2017), an investigation was carried out on the structural response of bamboo prefabricated reinforced walls subjected to various loading conditions. Two different methods were employed to design six wall panels, each measuring 2440 x 305 x 50 mm. In the initial approach, the proportion of OPC (Ordinary Portland Cement) to sand was 1:2, whereas in the subsequent approach, the cement was substituted with fly ash. In order to eliminate the lime water content, the bamboo mat reinforcement underwent a treatment involving the application of lime water, followed by a period of sun drying lasting around 24 hours. It was observed that the panels exhibited enhanced strength when fly ash was used, as compared to panels without fly ash, when subjected to a maximum load of 5kN.

Bamboo is extensively used for the construction of walls and partitions. Posts and beams are the main elements normally constructed with bamboo to provide the structural framework for walls. They are positioned in a way to be able to withstand the forces of nature. An infill is used between framing elements to add strength and stability to the walls.

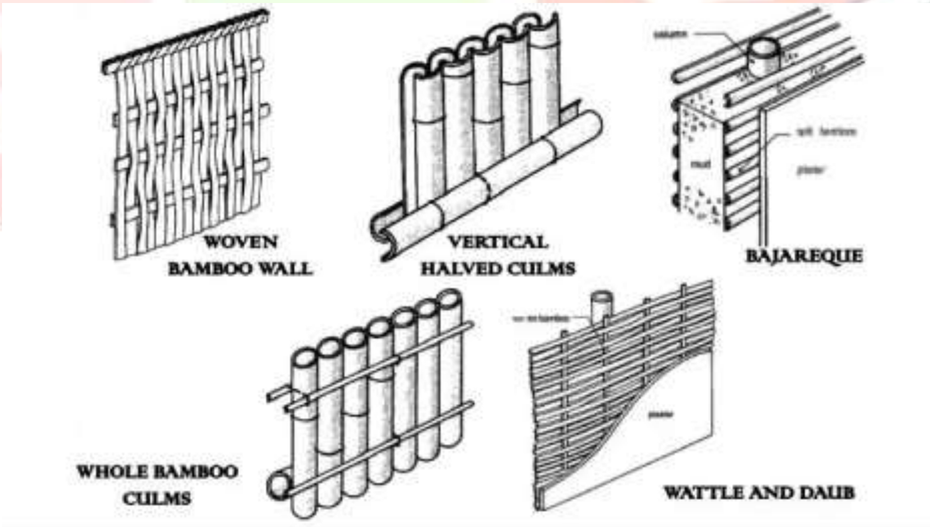

Figure 17 Bamboo walls

6.5. Fiber-reinforced bamboo concrete

Huang et al., (2012) conducted a study to examine the compressive strength, tensile strength, and bending strength of Carbon Fiber Polymer Reinforced Bamboo (CFPRB). In this experiment, a three-year-old Zhu-type bamboo specimen that had been air-dried for around three months was utilized. To determine the tensile strength of bamboo, a test specimen of bamboo was prepared by cutting it into the shape of an I-section, with a length of 280 mm. The mean tensile strength of six specimens was determined to be 179.6 MPa. Bamboo strips with a maximum width of 20 mm were utilized for the assessment of compressive strength. The mean compressive strength of carbon fiber-reinforced polymer (CFRP) specimens is 53.01 MPa when reinforced, and 42.41 MPa when not reinforced. The bending test was conducted on each specimen, which had a length of 900 mm and had bamboo joints. The discrepancy in the exterior diameter between the top and bottom sections of the bamboo does not exceed 10 mm. The length of the span for supporting the specimen is 450 mm, and the loading speed is 1 kN/m^2. The average bending strength of carbon fiber-reinforced polymer bars (CFPRB) is found to be 90.7 MPa when reinforced, and 59.8 MPa when not reinforced**.**

6.6. Scaffolding with bamboo as a building material

Due to the advantageous properties of bearing heavy loads bamboo is considered as one of the highly-endorsed materials for scaffolding even for tall structures. For the construction of scaffolding, cane extensions are obtained by lashing cane ends using several ropes. The ties are positioned in such a way that forces acting vertically downward lodge the nodes in the lashing. This technique has immense significance since the joints can be re-aligned in the right degree.

Figure 18 Bamboo scaffolding

6.7. Organic-shaped building with bamboo

Organic architecture term comprises a literal relation between a building and its environment, a building should integrate itself with its site. While the organic shape term may have a slightly different meaning than the organic architecture term. An organic form can be described as a form that has been generated or created inspired by natural forms in nature. Organically inspired structural systems typically exhibit interesting aesthetic qualities that are not necessarily intuitive.

Figure 19 Green School,Bali, Indonesia

Bamboo as a building material is not constantly used in organic-shaped buildings. The reference shape of bamboo buildings mostly comes from wooden buildings which is generally constructed using simple frame structures. Therefore, the builders tend to construct bamboo into a frame structure. , the evolution of building shape and form of the building with has become more dynamic, moving and flowing. The strength and internal properties of bamboo are studied. Bamboo is pushed to the limit to find what bamboo can do in a building, what shape and form can be developed using bamboo, and what suitable system is needed to design a unique bamboo building.

Green School is a school building build using bamboo as the main structure materials. Initiated by John Hardy, the school complex building finally won the Aga Kahn Award in 2010. The school building is located in Bali, Indonesia, designed in 2006 and completed in 2007. It is considered as the originator of bamboo revival in Indonesia. Even though bamboo is a common building material in Indonesia, as mentioned before, due to the idea of bamboo as cheap and “poor man timber”, bamboo potential and charm in creating unique buildings become submerged. Thus when a bamboo building is awarded by an international organization and the design is being discussed by experts, people become aware to bamboo

Figure 19 A bamboo architecture

7. ADVANTAGES AND DISADVANTAGES OF BAMBOO

Advantages of bamboo	**Disadvantages of bamboo**
Sustainable and eco-friendly	Availability and cost vary in certain regions
Affordable compared to traditional building materials.	Can be prone to pest attack
High strength-to-weight ratio	May not be as fire resistant as other building materials
Versatile and adaptable to various building designs	Can be subjected to dimensional changes due to moisture
Aesthetically pleasing	May not have standardization in quality and size
Efficient use of resources	Can be difficult to find skilled labor to work with bamboo
Lightweight and easy to transport	May require special storage and handling to prevent damage
Biodegradable and low carbon footprint	May not have local codes and regulations for use as a building material

The various advantages of bamboo are as mentioned below:

1. Tensile strength: Bamboo has higher tensile strength than steel because its fibers run axially.
2. Fire Resistance: The capability of bamboo to resist fire is very high and it. This is due to the presence of high values of silicate acid and water.
3. Elasticity: Bamboo is widely preferred in earthquake-prone regions due to its elastic features.
4. Weight of bamboo: Bamboos due to its low weight is easily displaced or installed making it much easier for transportation and construction.
5. Unlike other building materials like cement and asbestos, bamboo poses no danger to health.
6. They are cost-effective and easy to use.
7. They are especially in great demand in earthquake-prone areas.

Bamboos come with their own set of drawbacks such as:

1. They require preservation
2. Shrinkage: Bamboo shrinks much greater than any other type of timber especially when it loses water.
3. Durability: Bamboo should be sufficiently treated against insect or fungus attacks before being utilized for building purposes.
4. Jointing: Despite the prevalence of various techniques of jointing, the structural reliability of bamboo is questionable

CONCLUSION

Bamboo is recognized as a fast-growing species of large grass and is regarded as an economic and appropriate material in certain northern regions of India. When utilized as a reinforcing material in concrete, it enhances the strength, durability, and flexibility of the material. The experimental and analytical studies conducted by the experts indicate that bamboo exhibits a low modulus of elasticity. The material's inability to resist cracking under extreme loads is a limitation. In contrast, the load-carrying capacity is enhanced due to the flexural strength exhibited by the material. The addition of bamboo fibers in concrete resulted in a reduction in fluidity, similar to other types of fibers. This can be attributed to the presence of more surfaces created by the bamboo fibers, which need a greater amount of paste for lubrication purposes. Moreover, the hygroscopic nature of bamboo fiber allows for increased water absorption and reduced availability of free water for lubrication.

The inclusion of bamboo fibers in concrete did not significantly improve its compressive capacity and elastic modulus. Nevertheless, a significant enhancement was noted in terms of the tensile and flexural capability. Moreover, it can be shown from the load-deflection curve that the incorporation of bamboo fibers resulted in enhanced ductility, as evidenced by the increased capacity for deflection before to collapse. Additionally, the observation of crack patterns indicates that the inclusion of bamboo fibers in concrete enhances its performance through a bridging effect.

The incorporation of bamboo fibers resulted in enhancements in both impact strength and impact energy. Fibers enhance flexibility by mitigating or postponing the occurrence of tension fractures, hence leading to heightened strength. The application of treatment on bamboo fibers results in an increase in fiber roughness, hence enhancing adhesion qualities. Consequently, the treated bamboo fibers exhibit improved performance compared to untreated fibers. Among the several treatment procedures, namely glycerol, aluminates ester, and silane, it is shown that bamboo fibers treated with glycerol exhibit superior performance in terms of resistance to shrinkage. On the whole, bamboo is suggested as the best, economical, and environment-friendly alternative material for steel in masonry structures.

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REFERENCES

[1] Ahmad, J., Zhou, Z. and Deifalla, A.F., 2023. Structural properties of concrete reinforced with bamboo fibers: a review. *Journal of Materials Research and Technology*

[2] Abdalla, J.A., Thomas, B.S. and Hawileh, R.A., 2022. Use of hemp, kenaf and bamboo natural fiber in cement-based concrete. *Materials Today: Proceedings*, *65*, pp.2070-2072

[3] Elizabeth, S. and Datta, A.K., 2020. Retraction Note: On the seismic performance of bamboo structure. *Bulletin of Earthquake Engineering*

[4] Lima, H.C., Willrich, F.L., Barbosa, N.P., Rosa, M.A. and Cunha, B.S., 2008. Durability analysis of bamboo as concrete reinforcement. *Materials and Structures*, *41*, pp.981-989.

[5] Kathiravan, N.S., Manojkumar, R., Jayakumar, P., Kumaraguru, J. and Jayanthi, V., 2021. State of art of review on bamboo reinforced concrete. *Materials Today: Proceedings*, *45*, pp.1063-1066.

[6] Puri, V. and Chakrabortty, P., 2017, October. Behavior of sustainable prefabricated bamboo reinforced wall panels under concentrated load. In *International Conference on Sustainable Infrastructure 2017* (pp. 116-125).

[7] Schneider, N., Pang, W. and Gu, M., 2014, August. Application of bamboo for flexural and shear reinforcement in concrete beams. In *Structures Congress 2014* (pp. 1025-1035).

[8] Wei, H., Deng, S., Hu, B., Chen, Z., Wang, B., Huang, J. and Yu, G., 2012. Granular bamboo-derived activated carbon for high CO2 adsorption: the dominant role of narrow micropores. *ChemSusChem*, *5*(12), pp.2354-2360

[9] Xiao, Y., Inoue, M. and Paudel, S.K. eds., 2008. *Modern Bamboo Structures: Proceedings of the First International Conference*. CRC