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Assessing The Viability Of Bamboo As A Reinforcing Material In Self-Compacting Concrete Structures

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In recent years, steel prices have soared. For developing countries, steel is difficult to obtain because of expensive prices, and for the construction industry, usage of steel is currently limited heavily. The production of steel has high consumption of fossil fuels; therefore, the steel discharge in the construction of structures has been presented, showing the possibility of drastic reduction by research institutes. Meanwhile, for developing countries, it is important to make the development of buildings construction; low cost, no requirement of sophisticated technologies and reliable construction methods. Recently, in the attention in response to global warming issues and sustainable society, the manufacturing using natural materials has become actively. Bamboo, low cost, fast growing, and broad distribution of growth, is expected to contribute significantly to earthquake-resistant construction and seismic retrofit technology in developing countries. Now a days, all the buildings and structural components are mainly depends on usage of RCC. The steel present in the RCC is responsible for taking the tensile stress that is developed in the structure. Environmental Pollution that occurring due to the manufacturing process of steel and an eager effect to find out the alternative material in building construction tends to move our attention towards Bamboo, a cheap and mostly available material. Bamboo is a kind of giant grass and an orthotropic material. Bamboo was used as a construction material in early days. The main target of the study is to reimburse the conventional materials like steel by naturally available bamboo sticks. Bamboo proves to provide good reinforcement as it holds very good tension and compressive strength. The flexural strength of the beam having bamboo reinforcement shows greater strength which helps is to improve the usage of bamboo.

I. INTRODUCTION

For many, bamboo is a useful resource. It is easily accessible due to its enormous species diversity and capacity to flourish in many different climates. Bamboo is an affordable material since it is aesthetically beautiful and cheap to grow [1]. For living things, the bamboo grass is essential. Many different creatures call the bamboo forest home, and for others, it serves as their only food supply. Regarding humans, a million of them reside in bamboo homes, which serve as their main source of income for many. Because bamboo is used by so many people

for their home structures, the building sector benefits greatly from this [2, 3, 4]. Bamboo is a cheap material that may be used to build homes for people all around the world. Due to the numerous bamboo houses that have been built successfully, businesses and researchers can now investigate the use of bamboo in more advanced forms of building, such as bamboo reinforced concrete [5, 6]. Bamboo also has the ability to stimulate creative thinking in the building industry by introducing novel materials that may be less detrimental to the environment [7, 8]. Bamboo is a great renewable resource that grows quickly on its own with little assistance. Bamboo can save a significant amount of money and energy when used in place of steel in building. Steel requires energy and resources for manufacturing, transportation, installation, and disposal [9]. Furthermore, during its basic manufacture, steel has an environmental carbon effect that is approximately 85 times greater than that of bamboo. Bamboo's capacity to store up to 12 tonnes of CO_2 per hectare is one of its advantages. Simply by being on the soil and growing bamboo, it contributes to the fight against the decrease of CO_2 in the environment. It also releases 35% more oxygen than other comparable locations with tree growth [10].
Bamboo is a building material that is mostly used for scaffolding and many other construction-related activities [11]. However, it is also employed as reinforcing for concrete structures in select parts of various countries. The bamboo reinforced concrete is constructed using the same mix proportions and designs as the steel reinforcement [12]. Here, bamboo is being utilized in place of steel as a building material. Bamboo is a naturally occurring material that has been primarily utilized for various uses. Bamboo has been used for building for centuries, but using bamboo as reinforcement for bamboo reinforced concrete is a recent development for civil engineers working in the field of construction. Due to its natural availability, environmental sustainability, renewable nature, and biodegradability, bamboo is a material that uses less energy. Because of these qualities, bamboo has been utilized for generations as a building material. Bamboo has a higher tensile strength than steel and can endure compression better than concrete when used in bamboo-reinforced concrete. By weight, bamboo is six times more robust than steel. The outer layer of the bamboo has an impermeable barrier that keeps moisture and water from degrading the material [13].

1.1 Selection of Bamboo for Bamboo Reinforced Concrete

When reinforcing a structure, a material should possess all the key characteristics required for the element to remain structurally intact under load. When it comes to steel, the material is produced in the appropriate amount and subjected to rigorous testing to ensure that its strength is up to par. Bamboo should be properly tested before being utilized as reinforcement because it comes in many kinds. Each species possesses unique qualities, such as thickness, texture, and strength. Knowing the precise species that can be utilized as reinforcement is therefore crucial [14, 15, 16].

The following criteria can be used to choose bamboo for bamboo reinforced concrete:
• **Species:** Use the appropriate species of bamboo for reinforcing. Bamboo comes in over 1500 different species. It needs to be examined for qualities, strength, texture, and other tests that determine whether or not it meets the specifications for a reinforcing material [17].

• **Age and Colour:** The bamboo that is chosen for reinforcement should be clearly brown in colour, indicating that it is at least three years old.
• **Diameter:** Although there is no precise diameter for choosing bamboo for reinforcement, research suggests that the chosen bamboo should have long, thick culms.
• **Harvesting:** When utilizing bamboo as reinforcement, it is best to avoid cutting it during the summer and spring.

1.2 Strength of Bamboo Towards Bonding

When it comes to steel reinforcement, the bar has ribs on it to establish a high bonding with the concrete. In order to form a bond with concrete, bamboo must possess some sort of adhesion. For the bamboo to bind perfectly, its surface should be rough. Untreated bamboo can cause voids in the concrete or cause cracks to emerge as a byproduct of the void creation, which can weaken the bonding strength. Additionally, as the bamboo pulls the asphalt out, it may swell and weaken the bond. Bamboo may be properly treated to effectively address these issues.

- **Durability of Bamboo**

Bamboo reinforcement is not as durable as steel reinforcement because it is a natural product and is therefore more susceptible to environmental factors and insects [18]. For this reason, bamboo curing is used as a treatment to prevent issues of this nature.
The main draw for insects is the starch and humidity that are extracted during the curing process. Only when the right bamboo is selected, as indicated in the bamboo selection procedure, can the benefits of curing be realized.
When the bamboo is dry, it is when it should be treated. Several techniques can be used to cure bamboo, including:

- Curing on spot
- Smoke curing
- Immersion process
- Heating process

Bamboo is preserved by treating it to ensure that its durability is maintained and that its chemical composition is unaffected. When it comes to bamboo reinforced concrete, durability is the main issue [19].
It is discovered that bamboo has high chemical and physical qualities and low humidity levels. Bamboos would not develop mould due to the low humidity concentration.

1.3 Traditional Methods For Treating Bamboo

Bamboo, despite being a strong renewable resource, is susceptible to pests like the powder-post beetle, which can weaken its structure. To prolong the life of bamboo in construction, it's crucial to deter these insects. For centuries, people in Southeast Asia and South America have used simple, organic methods to enhance bamboo's durability. While these techniques are not suited for permanent structures, they are effective for creating inexpensive, semi-permanent bamboo constructions. We discuss the four conventional ways for treating bamboo in this paper, which include:

1.3.1 Time Of Harvest

Bamboo harvesting traditionally occurs when starch content is at its lowest. While midday is ideal for harvesting due to high starch levels, the best time is actually before sunrise, between 10:00 AM and 6:00 PM, when most starch resides in the roots. Lunar phases also play a role; starch content peaks during the waning gibbous to third-quarter moon, particularly six to eight days after a full moon, making this the optimal time for gathering bamboo for construction.

1.3.2 Water-Leaching

One of the most basic traditional methods for conserving bamboo is this one. The idea is to immerse the bamboo for four to eight months in pure, flowing water. The carbohydrates and sugars that are soluble in water found in the bamboo will gradually wash away. Insects will find the pole less appealing as food as a result.

1.3.3 Fermentation

The aim behind this procedure is to compost the bamboo for a few months (three to four months) inside mud and tree leaves. The compost's microbes and harmful bacteria turn the starches and sugars into acid, which reduces the possibility of insect predation. Though clever, this strategy is erratic it does not guarantee that the bamboo will not be more infested with insects in the future.

1.3.4 Smoking And Heating

Smoking bamboo poles extracts the sugars from the pole and lowers the moisture level of recently harvested bamboo. Moreover, the tissues of the bamboo absorb the chemical components included in smoke, which helps shield them from insects. Maintaining uniformity in heat and smoke quality during the bamboo preservation process is the primary issue with this method, as it ensures that every pole receives equal treatment. Large-scale material burning for the purpose of producing smoke presents additional environmental difficulties.

1.3.5 Saltwater And Seawater

Smoking bamboo poles extracts sugars and reduces moisture, while also allowing the bamboo to absorb protective chemicals from the smoke against insects. However, ensuring consistent heat and smoke quality during this process is challenging, and large-scale burning raises environmental concerns. Additionally, using seawater, which contains corrosive chlorine, can lead to humidity absorption and corrosion of steel bolts in joinery, causing future structural issues. While traditional bamboo preservation methods are generally eco-friendly, they often lack reliability and practicality in modern construction.

1.4 Codes and Standards

Although the basic definitions of codes and standards are frequently unclear and used interchangeably, it is wise to consider the important distinctions between them for the purposes of this study. "A standard tells you how to do something, and a code tells you what to do." The foundation of standardization is the cooperative participation of all parties involved in building, who support and encourage the standardization process. According to a review of the literature, bamboo construction needs to be internationally standardized and codified in order for designers and policymakers to recognize it as a sustainable structural and building material [20].

1.4.1 Existing Standards for Bamboo Structural Element Design

Standards are essential for establishing quality and safety requirements in materials and construction, guiding manufacturers and designers. They help engineers meet technical criteria, enhance consumer confidence, and reduce production costs through mass manufacturing. Standardized testing procedures assess design values like strength and stiffness, providing a common reference for users. By analyzing this data, the design community can improve material properties and promote wider acceptance of innovative and traditional construction methods.

International Organization for Standardization (ISO)

Essential design guidelines for whole-culm construction were released in 2004 by the International Organization for Standards (ISO) (ISO 22156). In September 2018, ISO 19624: 2018, which outlined the grading methods for mechanically and visually classifying bamboo poles for structural purposes, was approved as an additional standard.

1.4.2 BS ISO/NP 23478: Bamboo Structures

Test Procedures for is Determining Mechanical and Physical Properties of Glued Laminated Bamboo. The circular hollow section design of bamboo culms and their range of diameters make them suitable for only a limited number of structural applications. [21]. Engineered Bamboo Products (EBPs) are a standard developed by ISO/NP 23478 to expand the use of bamboo by mitigating its limited range of structural applications. By modularizing the product, EBPs can be designed to be more resilient to fire and more durable than bamboo culms.

Table 1: Standards for bamboo structural design [20]

Year	Code name
1994	13958: Specification for bamboo mat board for general purposes
1976	8242: Method of test for split bamboo
1973	IS:6874: Method of test for round bamboo
1979	9096: Code of practice for preservation of bamboo for structural purposes
2005	The National Building Code of India—developed a Code of Practice for Bamboo Design-Section 3Timber and Bamboo: 3B

1.5 Mechanical Properties Of Bamboo Material

1.5.1 Elasticity

It has been found that as bamboo culms age, their elasticity increases. The specific modulus of elasticity is 16,268 for a 1-year culm, 14,346 for a 3-year culm, and 17,414 for a 5-year culm. This demonstrates how age improves bamboo culm flexibility. Specific gravity and bamboo culm elasticity are directly correlated. The removal of the bamboo's outer covering lowers its specific gravity, which in turn reduces its flexibility [22]. When steam-exploded bamboo filaments are inserted into a polylactic acid matrix, the maximum elasticity is seen. Between the longitudinal and transverse directions, the modulus of elasticity significantly decreases. In the cell walls, the longitudinal modulus of elasticity is 16.1 GPa, whereas the transverse modulus is 5.91 GPa. The flexibility of bamboo fibres increases with filler loading. Density, drilling resistance, modulus of elasticity, and modulus of rupture all rise with increases in the dynamic modulus of elasticity [23, 24, 25].

1.5.2 Flexural Strength

Flexural strength of up to 90 MPa is demonstrated by bamboo fibre reinforced mortar laminates with reformed bamboo plate acting as the bottom tensile layer and a fiber-reinforced mortar sheet acting as the top compressive layer [26]. In composites, flexure strength increases noticeably at 50% volume percentage of extracted bamboo fibres. The predicted flexural strength of epoxy resins reinforced with bamboo fibres is 230.09 MN m^{-2}. The maleicanhydride-treated bamboo polyester composite exhibits a 50% increase in flexural strength. The flexural strength of autoclaved bamboo fibre reinforced cement composites is more than 18 MPa [27].

1.5.3 Moisture Absorption

Bamboo fibres are shown to absorb moisture at a rate of 13%, higher than that of cotton, lyocell, viscose rayon, modal, and soybean fibres. Moisture is stored in bamboo fibre, which often diffuses into boundary areas and reduces the shear strength. Bamboo epoxy composites have a moisture absorption percentage of 41%; after benzoylation, this percentage drops to 16%. After nine days in the water, bamboo fibres absorb moisture, which causes the interfacial shear strength (IFSS) to drop by at least 40%. [28]. Bamboo has extremely high moisture content; its outermost layers have 155% moisture and its green bamboo contains 100% moisture.

1.5.4 Specific Gravity

Bamboo's anatomical structure determines its specific gravity, which ranges from 0.4 to 0.8. Compared to 3- or 5-year-old bamboo culms, the specific gravity of 1-year-old bamboo is extremely low [29]. The outer layer of bamboo is found to have a specific gravity value that is double that of the inner layer [30].

1.5.5 Tensile Strength

Bamboo fibres have been found to have a tensile strength of 56.8 MPa, which is greater than that of aluminium alloy. Tensile strength and elastic modulus of bamboo fibre reinforced polypropylene composites and bamboo glass fibre reinforced polypropylene hybrid composites decrease in the presence of wate. [31]. It has been demonstrated that when maleated polyethylene is used in the fabrication process, the tensile strength of high density bamboo fibres increases [32, 33]. Compared to isolated fibre bundles, bamboo fibre derived from bamboo fibre blocks has a higher tensile strength. This result from the way bamboo's constituent parts interact, allowing parenchyma cells to transfer loads [34, 35, 36, 37].

1.5.6 Thermal Resistance

The fibres made of bamboo are incredibly heat resistant. Fibres reinforced with epoxy resins have a higher heat resistance. When reinforced with biodegradable PBS, the chemically altered water bamboo fibres improve the composite's heat resistance. Heat-treated cotton/bamboo fibre composites show that an increase in bamboo concentration results in a decrease in thermal conductivity and an increase in resistance. Thermogravimetric research shows that as the percentage of bamboo in the composite grows, so does the thermal stability of polypropylene bamboo/glass fibre reinforced hybrid composites.

1.5.7 Durability of bamboo

Bamboo, like lumber, is prone to environmental damage, insect infestations, and mold, with its durability influenced by species, age, and treatment methods. Effective curing and drying processes reduce starch and moisture content, enhancing resistance to pests and improving mechanical properties. Preservative treatments are essential for bamboo's longevity, and various application methods exist, from simple immersion to complex vacuum techniques. Unlike steel structures, which often corrode, treated bamboo reinforcement has shown durability over 15 years, with only minor strength loss [37,38]. Additionally, using chemical admixtures and low-alkali cement can further increase the durability of bamboo-reinforced concrete.

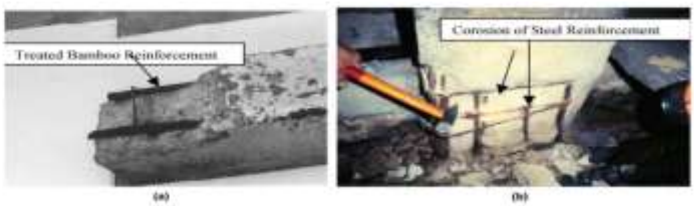

Figure 1: Durability of bamboo and steel reinforcement in concrete elements [39]

Figure 2:

1.6 Grading Of Bamboo

Strength or capacity grading could be used for bamboo culm structural grading. The best predictor of load carrying capacity is linear mass, although density is an excellent indicator of compressive strength. When designing with bamboo, the capacity approach is preferable to the strength method.

1.7 Bonding With Concrete

Systems of bamboo-composite reinforcement were constructed to reinforce concrete beams up to 1,300 mm in length. The length of the beams was selected based on the accessibility of testing facilities and the 100 kN loading capacity of the Universal Testing Machine (UTM). The concrete beams in this investigation were reinforced using two different forms of reinforcement: longitudinal and transverse (shear) reinforcement. Transverse reinforcements were used to give enough shear strength transverse to the longitudinal reinforcements, which were positioned parallel to the beam's long axis to offer the necessary tensile and flexural capacity [40, 41]. The distribution of this attractive species is in northeastern India. Bamboo serves as the primary building material, and chimneys with a diameter of twenty-seven to twenty-five are utilised [42]. Similar to sisum and other martial arts, it is considered the most beneficial. Concrete beams reinforced with the recently developed bamboo composite reinforcement are designed and proportioned based on a number of variables[43]. This work examines the relationship between the bamboo composite reinforcement and the concrete matrix, as well as the impact of water penetration and the alkaline environment of the concrete on the mechanical characteristics of the bamboo composite reinforcement [44].

1) Ambusa Striata: This is a newly developed bamboo that is 8 to 10 metres tall and has a diameter of around 8 cm. The plan frame suggests using yellow hue for these types of bamboo often grow up to 250 metres above mean sea level over all of India. It is typically used for toys and internal materials for young children.

2) Bambusa Tulda: This bamboo grows erratically between 400 and 600 metres above sea level and is native to eastern India. The plains and slopes of northern India are also home to its cultivation. It's among the most practical bamboos. Because of its robust culms, it is used for roofing, scaffolding, and construction. It is also used for general purposes, particularly for mats and baskets, and is frequently used to make paper pulp.

The largest bamboo, Dendrocalamus giganteus, is grown primarily in the northeastern region of our nation but is sometimes occasionally found elsewhere. native to Burma, or Myanmar. Its diameter is 20–30 cm, and its height is 24-35 m. It is utilised for construction, as well as for flower vases, water buckets, crates, and boat masts. The tender shoot is of sufficient quality to be eaten. In terms of papermaking, it is superior to D. strictus.

1.8 Bonding strength

Adhesion, or the link between them, keeps a reinforcing bar in concrete from sliding. The cement matrix's adhesive qualities, the compression friction forces that result from concrete shrinkage on the surface of the reinforcing bar, and the cement's shear resistance as a result of the surface form and roughness of the reinforcing bar are the primary factors influencing the bond between the reinforcing bar and concrete [45, 46, 47]. All three of the binding qualities are greatly impacted by the dimensional changes that bamboo experiences as a result of temperature fluctuations and moisture [48, 49, 50]. During the casting and curing of concrete, reinforcing bamboo absorbs water and expands as shown in Fig. 1(a). The swelling of bamboo pushes the concrete away, shown in Fig. 1(b). Then at the end of the curing period, the bamboo loses the moisture and shrinks back almost to its original dimensions leaving voids around itself, shown in Fig. 1(c). The differential thermal expansion of bamboo with respect to concrete may also lead to cracking of the concrete during service life. Bamboo's ability to replace steel in concrete is severely limited by its tendency to swell and shrink in the concrete [51]. The concrete-bamboo segment bond needs to be strengthened with an efficient water-repellent treatment. Different therapy modalities have been investigated, with varying degrees of success.

Three aspects influence the impermeability treatment of bamboo: the topography of the bamboo/concrete interface, the water-repellent property of the chosen substance, and the adhesive capabilities of the substance applied to bamboo and concrete. Applying a thin layer of epoxy and then fine sand to the bamboo surface is one method of effective treatment.

1.9 What is bamboo fiber?

Fibre, a long, thin, flexible material, is widely used in manufacturing and can be synthetic or natural, derived from plants, animals, or minerals. Bamboo fibre, made from bamboo cellulose, is increasingly popular for its rapid renewability and strength. Produced by crushing bamboo and using enzymes to break it down into a pulp, bamboo fibre can be spun into products like paper, insulation, and textiles. Known for its softness, breathability, and moisture-wicking properties, bamboo fibre is gaining traction in home textiles and apparel. As an eco-friendly, biodegradable alternative to synthetic fibres, it offers a low-impact, sustainable choice that is expected to become even more popular in the coming years as consumer demand for sustainable materials grows [51, 52, 53, 54, 55].

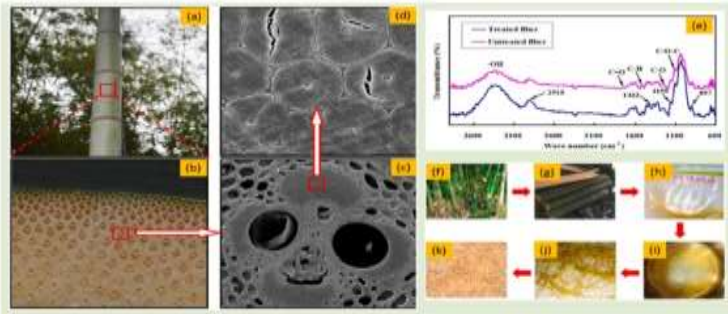

Figure 3: (a) bamboo culm, (b) cross-section of bamboo culm, (c) vascular bundle of the bamboo fiber, (d) elementary bamboo fibers, (e) FTIR spectra of bamboo fibers, (f) selection of bamboo plant for preparing bamboo fiber, (h) cutting of bamboo plants for preparing bamboo fiber, (i) separating the bamboo fibers through manual operation, (j) boiled bamboo fibers, (k) dried bamboo fibers, (l) cutting bamboo fibers according to desired dimensions. [10]

Figure 4: Bamboo fiber of diameter 1.156 mm Of aspect ratio (l/d)=40 [10]

1.10 Self-Compacting Concrete

One of the most recent innovations in the concrete sector is SCC. It was initially presented in 1980 by Japanese manufacturer Okamura [56, 57, 58]. From then on, it is the focus of numerous investigations to achieve the desired qualities of newly constructed concrete structures [59]. It became apparent that this cutting-edge technology might realise the greatest idea in the concrete industry [60]. The fundamental advantage is that even in the presence of dense reinforcement, it flows under its own weight to achieve full compaction and fill the formwork entirely [61, 62]. Because of its sophisticated construction practices, superior performance, and advantages for both safety and health, it is the greatest option for both conventional and precast concrete building [63]. SCC's most recent application is concentrated on excellent performance and consistent quality [64, 65]. The SCC's Need The concrete will compact and vibratory compaction costs will go down when self-compacting concrete is used in structural parts [66,67,68]. Self-compacting concrete produces significantly better structures [69,70,71]. SCC is frequently utilized in practice because real-world applications have demonstrated that it can decrease casting noise, improve construction efficiency, and increase concrete durability [72,73,74,75].

II. Recent Research in Structural bamboo

Bamboo, a fast-growing and eco-friendly material, is gaining interest for structural use due to its properties similar to steel (Prof. Satish A. Pitake, Ms. Snehal Sanjay Tipale, et al., June 2022). Various tests on messy and manga bamboo, including moisture content, density, compressive, and tensile strength, show that bamboo's high tensile strength (109.9 to 118.37 MPa) makes it a strong alternative to steel for reinforcement. This study aims to develop engineered bamboo components suitable for G+1 structures or affordable housing [76].

A study by Mark Adom-Asamoah, Jack Osei, and Russell Afrifa (2018) explored the use of bamboo-reinforced self-compacting concrete (SCC) slabs to support sustainable construction. Testing showed that bamboo-reinforced SCC slabs had lower post-cracking stiffness than standard concrete but doubled in load and flexural capacity with increased bamboo reinforcement (from 1% to 3%). The researchers suggest re-evaluating safety factors for bamboo in structural applications based on these findings [77].

In many underdeveloped nations, bamboo is an inexpensive, readily available natural resource that grows quickly. In terms of weight to strength ratio, it may be better than construction steel and wood. Through composite action, a novel method has been created in this research to improve physical qualities and maintain the mechanical properties of bamboo for use in structural concrete. Wielopolski, A. A. Javadian, et al. (2016) the current study aims to use pull-out tests to examine the bonding characteristics of a recently developed bamboo-composite reinforcement in concrete. To ascertain the bonding behaviour between concrete and the recently created bamboo-composite reinforcement, different coatings are applied. The study's findings show that when bamboo composite reinforcement is left uncoated, it forms a sufficient 28 connection with the concrete substrate [78].

Concrete has high compressive strength but low tensile strength, leading to the frequent use of steel as reinforcement (Dr. Ashok Kumar Gupta et al., 2015). However, steel production is costly and environmentally harmful due to its significant greenhouse gas emissions. Engineered bamboo offers an eco-friendly alternative, as it absorbs CO_2 and releases oxygen during growth. Known for its high tensile and flexural strength and favorable strength-to-weight ratio, bamboo has historically been used as a structural material. This study investigates bamboo's mechanical and physical properties to assess its potential as reinforcement in low-cost housing structures [79].

here is a growing concern that the sustainability of our built environment is being endangered, due to the uncontrolled and massive use of non-renewable natural resources in the production of structural concrete that is used for the construction of her infrastructure. Alternative material resources are being discovered through myriads of research efforts to address this concern. One of such alternative materials is the wood waste material. This paper presents a comprehensive review of properties, structural behaviour and application potentials of concrete containing wood waste, either in form of saw dust ash (SDA) as partial replacement of cement, or saw dust as partial replacement of fine aggregates, or wood aggregates as partial replacement of coarse aggregates. The results of the review showed that,

(i) with appropriate mix design, wood waste, either in the form of saw dust ash, or wood aggregate, or saw dust; can be incorporated into the concrete mix to develop structural concrete that satisfies codes requirements, provided the replacement is not above 20%,.and (ii) concrete incorporating SDA has good durability properties against most of the process of deterioration encountered by concrete in service life. Thus, the use of saw dust waste in concrete will enhance sustainable structural and constructional practices

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practices
The overuse of non-renewable resources in structural concrete production is raising sustainability concerns. Research, such as by Christopher Bolatito Akinbile Fapohunda (2018), highlights wood waste as a viable alternative material. Wood waste can replace cement, fine aggregates, or coarse aggregates up to 20%, maintaining code compliance and enhancing durability. Using sawdust waste in concrete supports eco-friendly building practices [80].

Concrete, the most widely used building material, primarily consists of fine aggregate, commonly sourced from natural river sand in many countries. However, rising demand has led to river sand scarcity, harming ecosystems and generating quarrying dust, which contributes to environmental problems. This study investigates using bamboo and quarry dust as sustainable alternatives in M40 concrete. Bamboo was added in percentages of 0%, 5%, 10%, 15%, 20%, and 25% as a substitute for coarse aggregate, with 15% showing optimal results in durability, tensile, flexural, and compressive strength. Quarry dust, replacing fine aggregate in amounts of 0%, 15%, 20%, and 25%, further aids in managing environmental waste, providing a viable solution for eco-friendly concrete production [81].

III. Material Used

Below are the materials that have been used in this study:

3.1 Selection and Preparation Of Bamboo

The brown variety of bamboo with longer, larger culms has been chosen for the sample selection. As seen in Figure 2, bamboo culms have cylindrical shells that are separated by solid transversal diaphragms at nodes [82]. Because the top part of the culms of bamboo is subjected to the most bend stress from wind, the strength distribution there is more uniform than it is at the top or centre. The following standards for choosing bamboo culm to be used as reinforcement in concrete structures have been measured in this study based on earlier research:

i. Bamboo that is at least four years old and displays a brown tint is chosen.
ii. The culm's largest diameter that is reachable is chosen [83].
iii. The green bamboo culm as a whole is not being utilized.
iv. Prevent cutting the bamboo in the spring or early summer as its moisture content and fibre content rise, making the bamboo weaker.

Three-year-old bamboo plants that were clearly coloured were chosen for this study. One-meter samples with four or five nodes each were taken from the plant's base [84].

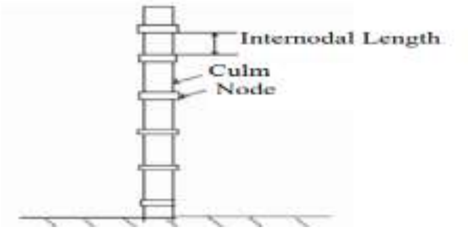

Figure 5: Whole bamboo culm [84]

When it comes to building projects, bamboo sticks are typically more common than entire culms. Before utilizing, the chopped bamboo plant needs to be given three to four weeks to dry and season. Bamboo was allowed to cure for 30 days before being divided into the appropriate dimensions for the sample preparation. With a hand knife and some mechanical tools, the bamboo culms can be split or chopped. The dimensions of 10 mm x 20 mm x 700 mm were utilized in this study to prepare the beam reinforcement sample. As a natural material whose qualities cannot be strictly regulated, the sample's thickness varies along its length. The testing parameters for the tensile test were 10 mm x 300 mm in diameter and length. Figure displays the concrete reinforcing sample specimen.

Figure 6: Samples of bamboo used in concrete reinforcement [4]

3.1.1. Water-proof material -

According to a prior study, when bamboos were utilized as reinforcement in concrete, their characteristics revealed excessive water absorption and low bonding strength between the surface of the bamboos and the concrete. Tackle coat has been used to reduce bamboo swelling and strengthen the bond in order to avoid this issue [85]. One day prior to the bamboos being employed as reinforcement in the beam sample, the coating was applied.

3.1.2. Steel bar

The purpose of this study was to compare the performance of bamboo reinforcement with normal reinforcement used in concrete using high yield steel deformed (HYSD) steel [86, 87].

3.1.3. Concrete

Ordinary Portland cement [88, 89], sand for fine aggregate and stone chips for coarse aggregate with a maximum size of 20 mm was utilized to make the concrete that was to be used in the beams. In this investigation, the concrete mix percentage (cement, fine aggregate and coarse aggregate) was 1:2:4, with a 0.5 water-to-cement ratio [90].

3.2 Experimental Investigation

3.2.1 Mechanical properties of bamboo

To determine bamboo's distinctive strength, mechanical characteristics are crucial. Every characteristic value was taken into account when calculating the design. If all mechanical property values were substituted in the reinforcement calculation, bamboo reinforced concrete could be designed using the equation and design process based on the earlier study. In this study, a few tests, including the tensile, compressive, and pull-out tests, were used to determine the mechanical properties.

3.2.2 Tensile test of bamboo stick

A 300 mm-long bamboo sample was chosen for the tensile test. Tensile tests were performed on a specimen with many samples that lacked nodes throughout their length. Galvanized wire was used to wrap the end of the specimen in an attempt to prevent failure at the grip during the tension test of the bamboo reinforcement. To solve the gripping issue between the bamboo surface and the machine, galvanized wires with a diameter of 2 mm were spirally wound around both ends of the specimens. Proper gripping is an important component of the tensile test and is necessary to obtain an accurate result.

3.2.3 Compressive strength test of bamboo

A distinct sort of sample specimen was chosen, and 150 mm hollow culms of bamboo were manufactured for the compressive strength test. Figure illustrates how one sample specimen with nodes and the other without nodes were created. Every sample's dimensions were taken before it was put into the UTM apparatus. The compressive strength was ascertained from the ultimate load graph [91].

Figure 7: Bamboo samples in compressive strength test [84]

3.2.4 Pull-out test

The UTM machine has been used to conduct a pull-out test to determine the strength of the bond between the concrete and bamboo surface. Three distinct types of samples, including steel, coated and uncoated bamboo, have been put to the test. 150 mm is the length of bonding in concrete that was used for the test. Figure 7 displays the schematic diagram. The bond stress formula (units are in N/mm^2) is used to calculate the bond stress based on the ultimate load

$$Z_{bd} = \frac{P}{\pi d \, L_b}$$

Where:
Zbd = bond stress
P = ultimate load at failure
d = diameter of specimen
Lb = lengths of bonding

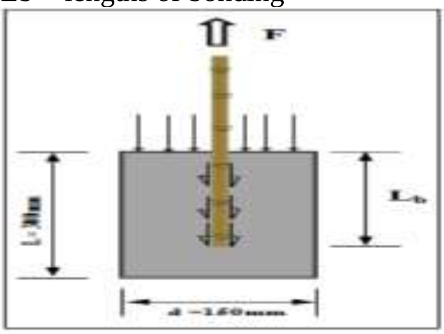

Figure 8: Schematic diagram of specimen [39]

3.2.5 Beam specimen

The EUROCODE 2 standard, "Design of Concrete Structures: Part 1: General Rules and Rules for Building," has been cited in this study to design concrete utilizing steel and bamboo reinforcement. A 25 kN/m load—which includes both a constant and a variable load have been assumed for the concrete sample. The mechanical characteristics of the bamboo reinforcement have been altered to account for the material's safety factor and the characteristic strength of the bamboo (fyk). [79, 82] Based on the tensile test, the typical strength of bamboo (fyk) is 168.31 N/mm2. In reference, the bamboo material's safety factor is 1.5 or 2. The safety 2.0 factor has been applied in this investigation. The concrete beam sample was reinforced with bamboo measuring 10 mm by 20 mm, while the steel bar reinforcement had a diameter of 12 mm. Three different types of beams were developed in this study: steel reinforcement (SR), bamboo reinforcement (BR6), which had six pieces of bamboo reinforced, and bamboo reinforcement (BR2), which had two pieces of bamboo reinforced. The figure displays the beam's dimensions. To ascertain whether bamboo-reinforced concrete reinforcement is feasible, the specimen beams have been built for single support. The flexural test is being used to determine the beams' strength [92, 93, 94, 95].

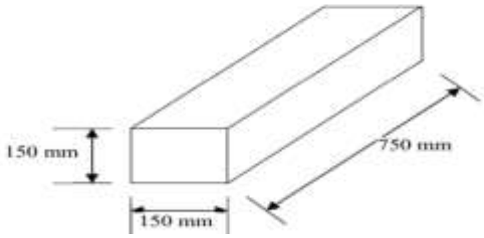

Figure 9: Dimensions of sample beam [94]

Bamboo shouldn't be positioned any closer than 40 mm from the concrete's surface. The minimum size of coarse aggregate cannot be less than the appropriate distance between bamboo strips. This is crucial to ensure that the concrete will not form a honeycomb during the casting process [96]. Prior to casting, the bamboo strips were securely wound around galvanized wire. The positioning of bamboo prior to concrete casting was depicted in Figure 9.

Figure 10: Bamboo placement [97, 98]

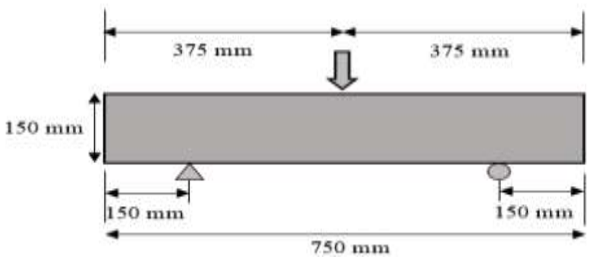

Figure 11: Test setup for flexural test of the beam [99]

IV. CONCLUSION

Bamboo is suggested as a possible concrete reinforcement in this study. The flexural test of the bamboo-reinforced beam revealed that adding bamboo to the concrete reinforcement can boost the beam's ability to support more weight. The results of the tensile test indicate that bamboos behave similarly to steel in that they possess the elastic feature [100]. Reducing the use of steel can lower carbon dioxide emissions because bamboo is an environmentally beneficial material. Bamboo-reinforced concrete may be a recommended material for green buildings.

Bamboo fibres can be used as novel fibres in SCC to increase the strength, ductility, and post-cracking load-carrying ability of concrete [101]. The strength variation between the self-compacting concrete specimens is with bamboo fibre and the control group. It was discovered that the fresh state's workability decreased as the fibre content increased and that the aspect ratio increased as well. By adding bamboo fibres, the concrete gains maximum strength after 28 days and becomes extremely resistant to flexure; as a result, adding fibre content raises the flexural strength.

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