Migration Letters

Volume: 21, No: S2 (2024), pp. 833-850

ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)

www.migrationletters.com

Critical Review Of Bamboo As A Structural Material For Civil Engineering Construction

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ABSTRACT

This research evaluates bamboo's potential as a building material for civil engineering with a focus on its usage as reinforcement in RCC structures in harsh and corrosive conditions. When weighing benefits and drawbacks, bamboo's durability, resistance to corrosion, and accessibility locally stand out as important positives. Issues with mechanical variability, toughness, and code integration exist. Structural safety concerns draw attention to bamboo's remarkable strength-to-weight ratio and flexibility, but they also highlight the need for standardized standards. The emphasis of the conclusion is on cooperative research initiatives to create safety standards. This review fills in gaps in the literature and aids in making well-informed choices on the use of bamboo in contemporary building techniques.

Key Words : *earthquake-resilient, environment friendly, Engineered connections, bamboo-based construction materials, strength and weight ratio*

1. Introduction

The development industry is undergoing an extraordinary shift towards sustainable and ecologically cognizant practices. As conventional development materials face scrutiny for their biological effect and asset exhaustion, there is a growing interest in exploring elective materials that line up with these evolving standards. One such material that has gained consideration is bamboo. Bamboo, frequently alluded to as **"green steel"**, has gotten the attention of structural engineers and modellers because of its surprising combination of solidarity, adaptability, and quick inexhaustibility. Its innate capacity to flourish in different environments and its capability to be developed locally make it a clever answer for development[1] in both created and developing districts. This basic survey expects to evaluate the practicality of bamboo as an underlying material for structural engineering development. The centre stretches out to examine bamboo's true capacity as reinforcement in **reinforced concrete (RCC) structures**, especially in limited-scope developments arranged in cruel and destructive conditions. The research looks to give an exhaustive understanding of the job bamboo could play in shaping the eventual fate of sustainable development by delving into the benefits, limits, and security contemplations of this innovative application.

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2. Advantages of bamboo

This study investigates bamboo's potential as well as its possible uses and benefits in the building sector. Significant concerns have been voiced about the proper management of the remaining energy supplies and environmental deterioration as a result of the present energy crisis, which has been made worse by unrestrained industrial development. As a result, there is a constant, intense search for materials and production techniques that are both non-polluting and need less energy for industrial purposes. As a resource with several uses and a high strength-to-weight ratio, bamboo stands out as a desirable choice for building. Moreover, it is a lightweight and ecologically beneficial option because of how simple it is to manipulate using common equipment. It can be used in buildings, bridges, and in every structural work. It is cheap and affordable and available all over the world mainly in rural areas. It is one kind of grass and grows very fast, generally, it grows 30cm to 1m in a day (Su et al. 2021).

Figure 2.1: Benefits and uses for bamboo in contemporary design

(Source: Constrofacilitator, 2022)

Compared to other hardwood plants, bamboo absorbs more carbon dioxide and discharges 35% more oxygen into the environment. Several contemporary bamboo display structures have utilised engineered bamboo components effectively. The comparatively low rigidity of designed bamboo flexural elements as compared to reinforced concrete or steel buildings can cause significant deflection and is a major factor in limiting the span of contemporary bamboo structures. Though many people have no awareness of this material, many renowned buildings are constructed using bamboo. Anti-polluted societies are highly impressed with making construction using this eco-friendly material. It is a long-time source for the biomass industry and self-renewing products and lifetime sources. Depending on the processing technology used, raw bamboo can be transformed into several sorts of bamboo goods.

3. Disadvantages of bamboo

There are so many disadvantages to using bamboo in civil engineering constructions. These are described below:

3.1 Attracted by fungi

Bamboo is not always good for construction because sometimes it is damaged by fungus attacks. It can be damaged by our environmental causes such as water and air. Fungus infection damages its stability and destroys its strength, which is the main reason to preserve this material. Many problems have come when bamboo is

used to build up a well-designed setup and that has to be overcome by specialists and experts.

3.2 Non-Sustainability

The duration of sustainability of bamboo is approximately 5 years which is the most awful because high-cost buildings have to be restricted after 5 years. It is not possible to reconstruct that building further as well and it is a waste of money. Nowadays it's frequently observed that high roads and bridges are destroyed at any time which takes lots of life and accidents are occurring every day (Aniegbuna and Okolie, 2021).

3.3 The problem of preservation

Bamboo is not easily transportable at times due to its bearing vehicles. It can be transported from one country to another easily. Using bamboo not all types of design and codes are possible properly, it is not preferable for years, and steel and irons can be preserved for a long time. But to fulfil the market demand it is highly necessary to preserve these materials used in construction fields.

3.4 Quality issue

High-quality bamboo is not produced taking seriousness and low-quality bamboo is not good. Bamboo production is not profitable which is why people are not eager to produce bamboo. Users have to be dependent on the ecosystem because it cannot be supplied by industry. Bamboo is not sustainable and cannot hold the heavyweight, so it is risky. Until now, it has not beaten its comparative market everywhere. Many fraud engineers work with low-quality bamboo just for their profit and take it into the danger zone. Its area is limited which means as a construction material bamboo is only used in small projects, not any high projects.

4. Joints and connections of bamboo

Due to its durability, flexibility, and strength, bamboo has been utilized for ages as a structural material in many regions of the world. For employing bamboo as a structural member, correct joints and connections must be made to maintain structural integrity (Li et al. 2019). It is a kind of grass renowned for its extraordinary toughness, adaptability, and quick growth. Because of its availability and renewability, bamboo is a desirable construction material. The three basic types of bamboo joints are modern simply bolted joints, traditional methods, and engineered connections. The methods and procedures for attaching bamboo structural members vary depending on the type.

4.1 Modern simply bolted joints

Mechanical fasteners like bamboo nails, screws, and bolts have been included in modern bamboo construction techniques to make strong and dependable connections between bamboo culms. The split bamboo pins, often referred to as bamboo nails, are placed into pre-drilled holes and fastened with wedges or plugs. This method offers a simple and efficient approach to combining bamboo components.

(a) Bamboo Nails: Bamboo nails are frequently used in modern techniques these types of joints are also known as **"split bamboo pins"** or **"dendrocalamus giganteus nails"**. The holes for these nails are drilled into the bamboo culms and they are then fastened with plugs or wedges. They offer reliable connectivity and are comparatively simple to use.

(b) Screws and Bolts: Bamboo-specific screws and bolts are utilized to make strong and long-lasting connections. For bigger or more complicated structures, these fasteners are especially useful.

(c) Fishplate joint: A metal fishplate or connector is used to unite two bamboo culms in a fishplate joint. Usually, the culms are divided placed in slots on the fishplate and fastened together with bolts. This approach is used to contribute strength and stability.

4.2 Traditional methods

Traditional or vernacular construction techniques have been used for many years in areas where bamboo is abundant. These approaches rely on tried-and-true procedures that take advantage of bamboo's inherent flexibility and strength. Bamboo culms are typically lashed together using natural fibers like ropes or vines.

(a) Lashing: Lashing is the practice of binding bamboo culms together with ropes, vines, or other natural fibres. Lashing is a common step in traditional bamboo building. To form strong linkages, these lashings are tightly twisted around the culms. For basic buildings like fences and small shelters, lashing is a quick and efficient solution.

(b) Dowels: Bamboo dowels are sometimes utilized in traditional methods to fortify joints. To make a connection, holes are drilled into the bamboo culms and dowels made of wood or bamboo are inserted. This technique is frequently used to increase stability in important structural regions.

4.3 Engineered connections

Engineered connections for bamboo are typically exclusive systems created by businesses or groups with expertise in bamboo building. These systems are made to offer accurate connections that are trustworthy for a range of structural applications.

(a) Metal Connectors: Designed specifically for bamboo, metal connectors are frequently used in engineered connections (Hong et al. 2019). These connectors, which enable accurate and secure joining of bamboo members include brackets, clamps, and other gear. These are frequently employed in industrial or sizable building projects.

(b) Welding: bamboo members are connected in a specific way using welding techniques for some specific scenarios such as in industrial projects, artistic projects, and applications under high stress. High degrees of strength and dependability are provided by welded joints, particularly in industrial applications.

4.4 Code of practice available in India and abroad

A code of practice for bamboo building that promotes safe and sustainable practices has been developed both in India and overseas as a result of bamboo’s recognition as a valuable structural material. These rules offer detailed guidance and standards to maximize bamboo’s structural potential while assuring structural safety and environmental responsibility. The use of bamboo as a structural material in building and engineering projects is covered in detail in India's codes of practice for bamboo construction (Schroeder et al. 2019). These thorough rules and standards offer necessary instructions and suggestions. Regulatory organizations and institutions created and upheld these guidelines to guarantee that bamboo structures adhere to environmental and structural safety standards. These organizations go over a number of bamboo construction-related topics, such as bamboo grading, treatment procedures, structural design ideas, connecting methods, and maintenance procedures. Codes of conduct for bamboo building are produced internationally by groups like the **“International Bamboo and Rattan Organization (INBAR)”** and numerous national standards agencies. These guidelines emphasize

sustainable harvesting, handling, and cutting-edge technical procedures in order to harmonies bamboo construction practices around the world. International bamboo construction professionals benefit from INBAR's technical resources, which promote cooperation and knowledge sharing.

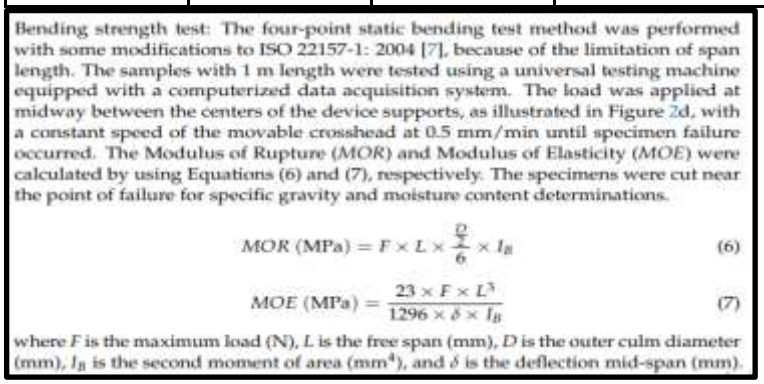
5. Systematic literature review

Table 5.1: Systematic Literature Review

Author's Name	Article Title	Analysis	Findings and Result	Literature Gap
"Kitti Chaowana, Supanit Wisadsatorn, and Pannipa Chaowana"	"Bamboo as a Sustainable Building Material - Culm Characteristics and Properties"	Systematically Reviewed a wide range of literature sources on bamboo's use in construction. Analysed environmental benefits, challenges in standardization, material properties, and potential applications.	Highlighted bamboo's renewable nature, low embodied energy, and versatility in Construction. Addressed challenges related to standardization, variability, and durability. Called for further research in design codes, structural analysis, and long-term Performance.	Emphasized the need for more research in design codes, structural analysis methods, and long-term performance monitoring to fully leverage bamboo's potential in sustainable construction.
"Osmi, S.K.C., Ngadenin, A., Nor, N.M., Husen, H., Yahya, M.A. and Daud, N.M."	"Bonding Strength of Bamboo Reinforcement in Concrete – A Systematic Literature Review (SLR)"	Systematically gathered and evaluated studies on bamboo-reinforced concrete (BRC). Analysed mechanical and structural performance of BRC, including tensile strength, crack	Highlighted benefits of BRC in terms of flexural strength and Crack resistance. Addressed concerns about durability, bond strength, and code compatibility. Summarized effects of bamboo species and treatment methods on BRC properties.	Addressed the need for more research on durability, bond strength, and code compatibility of BRC.

		control, and fibre arrangement.		
Aider, M.F.V., Sevilla, M.E.P., Valerio, D.N.R. and Ongpeng, J.M.C.	Bamboo as Sustainable Building Materials: A Systematic Review of Properties, Treatment Methods, and Standards	Systematically reviewed research on structural performance and reliability of bamboo-based Structures. Analysed case studies of traditional and modern bamboo structures under various loading conditions.	Emphasized the advantages of bamboo's flexibility and resilience in structural applications. Addressed concerns about standardized design guidelines and mechanical variability, and long-term durability. Called for collaborative efforts to establish safety standards.	Highlighted the lack of standardized design guidelines and the need for collaborative efforts to establish safety standards for bamboo-based structures.
"Yuxiang Huang, Yaohui Ji & Wenji Yu"	"Development of bamboo scrimber: a literature review"	Performed a thorough analysis of works focusing on the engineering qualities of bamboo and its properties and potential applications in construction. Analysed mechanical, physical, and	Highlighted bamboo's attractive mechanical properties, such as Its high strength-to-weight ratio. Explored bamboo's applications in roofing, scaffolding, and other construction elements. Identified	Addressed the need for standardized testing procedures and design guidelines specific to bamboo-based construction.

		durability properties of bamboo. Examined its use in various structural and non-structural applications.	challenges related to design standards and treatment methods.	
"Boumas, M., Belaadi, A. and Bourchak, M."	"Assessing the potentials of Bamboo and sheep wool fibre as sustainable construction materials: A review"	Research on bamboo and plastic bond behaviour that has been thoroughly concrete in reinforced concrete structures. Analysed factors influencing bond strength and mechanisms of load transfer.	Discussed the positive influence of bamboo on bond strength in concrete. Explored the effects of factors such as surface treatment, diameter, and embedment length. Identified challenges in ensuring consistent bond behaviour due to bamboo's natural variability.	Highlighted the need for standardized testing methods and guidelines for designing bamboo-reinforced concrete structures.



Bending strength test: The four-point static bending test method was performed with some modifications to ISO 22157-1: 2004 [7], because of the limitation of span length. The samples with 1 m length were tested using a universal testing machine equipped with a computerized data acquisition system. The load was applied at midway between the centers of the device supports, as illustrated in Figure 2d, with a constant speed of the movable crosshead at 0.5 mm/min until specimen failure occurred. The Modulus of Rupture (*MOR*) and Modulus of Elasticity (*MOE*) were calculated by using Equations (6) and (7), respectively. The specimens were cut near the point of failure for specific gravity and moisture content determinations.

$$MOR\ (\text{MPa}) = F \times L \times \frac{\frac{D}{2}}{6} \times I_B \quad (6)$$

$$MOE\ (\text{MPa}) = \frac{23 \times F \times L^3}{1296 \times \delta \times I_B} \quad (7)$$

where F is the maximum load (N), L is the free span (mm), D is the outer culm diameter (mm), I_B is the second moment of area (mm^4), and δ is the deflection mid-span (mm).

Figure 5.1: Bending Strength Test
(Source: Chaowana et al. 2021)

The above figure shows the calculation of Chaowana et al. (2021). MOR means Modulus of Rapture and MOE means Modulus of Elasticity.

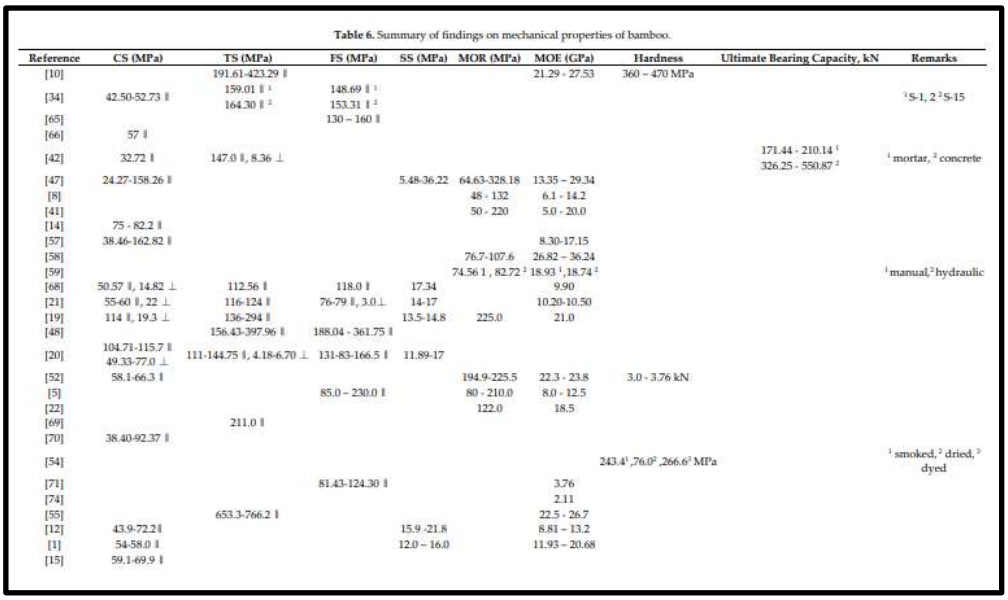


Table 6. Summary of findings on mechanical properties of bamboo.

Reference	CS (MPa)	TS (MPa)	FS (MPa)	SS (MPa)	MOR (MPa)	MOE (GPa)	Hardness	Ultimate Bearing Capacity, kN	Remarks
[10]		191.61-423.29 ∥				21.29 - 27.53	360 – 470 MPa		
[34]	42.50-52.73 ∥	159.01 ∥ [1] 164.30 ∥ [2]	148.69 ∥ [1] 153.31 ∥ [2]						[1]S-1, 2 [2]S-15
[65]			130 – 160 ∥						
[66]	57 ∥								
[42]	32.72 ∥	147.0 ∥, 8.36 ⊥						171.44 - 210.14 [1] 326.25 - 550.87 [2]	[1] mortar, [2] concrete
[47]	24.27-158.26 ∥			5.48-36.22	64.63-328.18	13.35 – 29.34			
[8]					48 - 132	6.1 - 14.2			
[41]					50 - 220	5.0 - 20.0			
[14]	75 - 82.2 ∥								
[57]	38.46-162.82 ∥					8.30-17.15			
[58]					76.7-107.6	26.82 – 36.24			
[59]					74.56 1 , 82.72 [2]	18.93 [1],18.74 [2]			[1] manual,[2] hydraulic
[68]	50.57 ∥, 14.82 ⊥	112.56 ∥	118.0 ∥	17.34		9.90			
[21]	55-60 ∥, 22 ⊥	116-124 ∥	76-79 ∥, 3.0⊥	14-17		10.20-10.50			
[19]	114 ∥, 19.3 ⊥	136-294 ∥		13.5-14.8	225.0	21.0			
[48]		156.43-397.96 ∥	188.04 - 361.75 ∥						
[20]	104.71-115.7 ∥ 49.33-77.0 ⊥	111-144.75 ∥, 4.18-6.70 ⊥	131-83-166.5 ∥	11.89-17					
[52]	58.1-66.3 ∥				194.9-225.5	22.3 - 23.8	3.0 - 3.76 kN		
[5]			85.0 – 230.0 ∥		80 - 210.0	8.0 - 12.5			
[22]					122.0	18.5			
[69]		211.0 ∥							
[70]	38.40-92.37 ∥								
[54]							243.4[1] ,76.0[2] ,266.6[3] MPa		[1] smoked, [2] dried, [3] dyed
[71]			81.43-124.30 ∥			3.76			
[74]						2.11			
[55]		653.3-766.2 ∥				22.5 - 26.7			
[12]	43.9-72.2∥			15.9 -21.8		8.81 – 13.2			
[1]	54-58.0 ∥			12.0 – 16.0		11.93 – 20.68			
[15]	59.1-69.9 ∥								

Figure 5.2: Findings on Mechanical Properties of Bamboo

(Source: Adier et al. 2023)

The above research has been done by Adier et al. (2023) that shows the **"MOR, MOE"**, correspondence with Hardness and Ultimate Bearing Capacity.

6. General uses

Bamboo is the world's one of the finest plants. In today's world bamboo is used to make different interiors, to make houses, to make footbridges, and for many other purposes. Bamboo easily adapts to various weather conditions (Kumar and Mandal, 2022). Bamboo's lastingness is better than many materials that are used to make the above things. The main uses of bamboo are given here

- Bamboo can capture 60-70 tons of carbon per hectare area. So, it is an environment-friendly material. This can be one of the main reasons for using bamboo.
- Bamboo is one of the fastest-growing plants. So, bamboo is easily available for use in various fields.
- Bamboo can be used as a construction material to save other raw materials like iron and steel.
- Many houses and footbridges are constructed with bamboo in the village site.
- Bamboo can be used as a biomass source for an industry for a long time period and also can be used in the textile industry.
- Bamboo is anti-bacterial and anti-fungal. So, for making a home interior, furniture bamboo is widely used.
- Bamboo can absorb 96% of UV rays and as well as it can absorb water. So, the wall of the house can be made of bamboo.
- Any kind of people use bamboo to build their houses and shops because it is cost-effective.
- People use bamboo to make truck bodies, railway carriages, etc. in the transportation industry.

- People of hill areas use bamboo to make their houses because bamboo is very much capable of shock absorption which is happened because of earthquakes.
- In making new-generation products bamboo is used instead of other woods.
- Bamboo's leaf is widely to produce medicine.
- Bamboo fibre is used to make towels, and clothes because this fibre is anti-bacterial and smoother than cotton.
- Bamboo is also used to make paper, sunglasses cycle, and many daily usage things.

7. Main properties of bamboo

Bamboo offers an appealing alternative in place of common building materials like steel, concrete, and masonry, Due to its substantial silicate acid content and water composition, it exhibits outstanding fire resistance qualities. Its fibres align axially and provide amazing durability even at temperatures as high as 4000°C. It is possible to build connections that can convey this enhanced tensile strength because bamboo's vascular bundle is made up of extremely elastic fibres with amazing tensile strengths that surpass those of steel. The structural potential of bamboo is further increased by the fact that its tensile strength is much beyond that of steel. Axially oriented elastic fibres with a tensile strength of 400N/mm2 are embedded inside its silicate outer layer, in stark contrast to the relatively weaker fibres present in wood, which can only withstand up to 50 N/etc in stress. Due to their lower skin area, thinner bamboo tubes have better material characteristics and are therefore better able to handle tension, shear, and bending forces. Bamboo has an increased risk of earthquakes because of its anisotropic structure, which results in cellulose fibres in the longitudinal direction of the material being strong and stiff while those in the transverse direction of the material are softer and more brittle owing to the presence of lignin. Furthermore, when bamboo loses moisture while being used as a building material, it tends to shrink more than wood (Liu et al. 2022).

Bamboo Steel more than oat lost the water the bamboos in Christ the 10% to 16% it is necessary of that takes who is the moreover water losses bail the uses as the blind material how over the precious is the very good because of the higher contest Island seat feel up to water in can harm the temperature at 10 degrees Celsius with the close the inside. Bamboo prevents wetter loos in arches when used as a building material. Due to its outstanding qualities, bamboo is of utmost significance in the fields of engineering and building. It is well regarded for its exceptional fire resistance, ability to withstand high temperatures, and water resistance even at temperatures as high as 40 degrees Celsius. The exceptional strength-to-weight ratio that bamboo possesses further makes it a great construction material. Because of its remarkable compressive strength, bamboo is commonly used in buildings, especially in areas where it is abundant. Bamboo is a key component in the construction of scaffolding and residential buildings as well as a crucial support element for concrete structures. Bamboo stands out for its quick development, which is made possible by its special rhizome-dependent system. This makes it a desirable and environmentally beneficial option for the construction sector, in line with the increased focus on eco-friendly products and procedures (Chen et al. 2019). In terms of engineering and building applications, bamboo essentially represents a flexible and environmentally responsible alternative.

The stress projected in practice for materials used in civil construction. Bamboo has been compared to the civil constant. Bamboo steel is necessary to spend 50 times more energy than bamboo (Hamada et al. 2013). The production of one-tone steel and two-tone CO2 of producing. Bamboo is relatively high and can reach tensile strength in civil engineering. The turn use of bamboo is attractive as a substitute steel when considering the tensile of steel especially. The relation between the tensile resistances of bamboo used to

be six times greater than that of bamboo steel. Bamboo steel reinforced concert is bamboo anisotropic material in the longitude materials the same those over heading in the cellulose in the longitudinal in the bamboo heading is solving and firm the cross over the crock over the course is lignin. Bamboo can be abundant and that too at a lower cost which makes it more economical than less developed wood of the poor the cost of construction for premium Quality. The properties top grade buildings of use in the field of construction extensively with bamboo material to use structural. A fast fool question arises in safety in Canada country when the value of the material the building normally uses is taken as the unit. The indicated 140N/mm bamboo steel and 10 N/mm timber. The three diagrams' formation like a hill can be seen.

After all, the is stress at failure during tests in the middle part of the hill indicating. Bamboo stress under which 5% or 2.5% of the specimens fail, the allowable stress shall be at a safe limit. For bamboo trees, these limits are indicated. On the vertical axis, we see the value chance that stress will occur wide and flat, the lowest diagram is produced using a very controlled process, and hence very rare. The shows a narrow and steep hill, indicating in the narrow range indicated small value. The case of a disaster like a hurricane in the bamboo. In steel, their stresses will come into the area of failure not in timber and bamboo. The point when utilized to structure carbon in the put away is not only the climate but also the bamboo.

Bamboo can supplant a number of mate’s fossil fuel products like steel and cement, diminishing the strain of f backwoods wood assets. The sure bamboo items can have a low even regrettable carbon impression across their lifecycle. The upside of industrialization cannot be high creation effectiveness. The steer less applied practically speaking all around the world significant wellspring in bamboo. Over the gas bamboo the warm and electrical energy age.

8. Bamboo as a building material

Bamboo has more than 1200 species found across the world and it can work for replacing steel in concrete because of its high probability of standing firmly on the ground. Bamboo is used in reinforcing the material in concrete and bamboo splits in the configuration even this is also used in full-scale building. Seasoned bamboo has a higher tensile strength than unseasoned bamboo. Bamboo is often used in buildings as reinforcement building and columns. The behaviour of reinforced concrete beams can be used for reinforced bamboo beams. Bamboo is most used in building materials as a support for concrete usually for those locations where bamboo is found in abundance (Deresa et al. 2021). Chemical treatments were also made on bamboo composite strength to find sufficient bond strength. Sand particles are used to make the bond strength increase to more than 3.50MPa. The flexibility of the wall can be increased due to the addition of bamboo mesh to the walls.

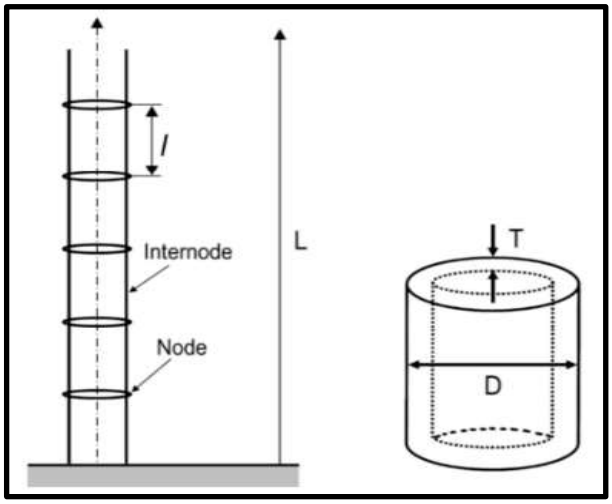


Figure 7.1: Simulation picture of the bamboo culm characteristics

(Source: Kitti Chaowana et al. 2021)

The bond development tool checks the reinforcing bars and affects the section stiffness and crack controls. The bond behaviour is affected by reinforced bar spacing, transverse reinforcement concrete and steel properties, the surface area of reinforcement bars and position of casting, and production of spice length. Some countries' houses were developed with plastered bamboo houses and used wooden skeletons and bamboo mats on the outer layer. The bamboo mats were covered in plaster so that the bamboo wooden frame could be seen from the outside as well as from the inside. Bamboo is used in constructing cheaper houses in developing countries. Various bamboo-based construction materials were created like coated bamboo and bamboo-reinforced concrete. These structures are very comparable in quality and can be checked and calculated in the manner of wood construction for they have better tensile strength and termite-resistant quality than untreated bamboo.

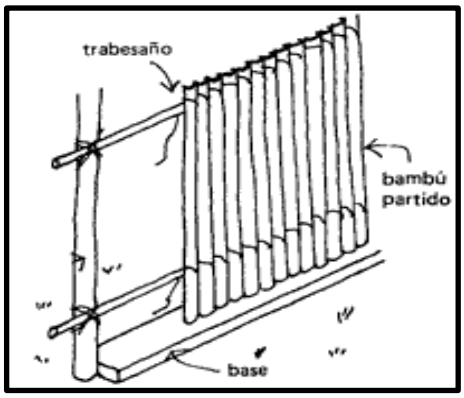


Figure 7.2: Bamboo as a Building Material

(Source: Azfreemk, 2022)

Bamboo has a distinctive rootstalk-dependent system and it is one of the fastest-growing plants in the world it can grow more than three times the of other plant species. Researchers are extremely flexible and mostly renewable with multiple usages. Housing is the primary usage of bamboo mainly where other resources are low and people are in large quantities to live in. The region of Southeast Asia and some parts of South America were largely produced where the climate is suitable for its cultivation. Bamboo is often used in bridges as a suspension and to hold tensile strength to hold them together and in buildings in other parts of the country. The case of timber frame is done by bamboo structural frame procedure is utilized by the bamboo constructions. The bamboo walls, floors, and walls are always

interconnected with each other to provide high tensile strength and flexibility. The enterprises and rural transformation get boosted by the usage of bamboo which is why it plays a vital role in the environment. Bamboo is so reusable that it can be reused for reforestation and gives protection to the soil and it is also used for interpolating with the other crops. The crops then gain fertility and provide fresh nutrients to the soil and permanently fruitfulness the whole vegetation.

Bamboo can be used as a suitable wooden material that works exceptionally in manufacturing and construction usage. Forest resources can be increased with the use of bamboo and production emissions from building bricks and cement can be controlled. Bamboo as a building material has provided a positive effect on people who have recently lost their houses due to a natural disaster. Bamboo houses are built easily and speedily and they are resilient to earthquakes and support neighbourhoods that just lost their houses and recover from those disasters. Bamboo not only prevents greenhouse gases to the atmosphere but also their roots provide strength to the ground in all general directions to stabilize the ground by making the ground solid which were destroyed by earthquake and landslides. Bamboo building material with which people created earthquake-resilient buildings. Bamboo has a higher density yet is lighter than timber due to its hollow nature is a perfect material whose resistance is strong and not yet heavy enough to withstand strong pressure-imparted acceleration from earthquake-prone grounds.

Bamboo tensile strength varies with its different species with the tensile can get up to an average of 50% to 80% and sometimes even more. The dampness of bamboo depends on the height, seasoning time, and position. This is a very vital time for the deciding factor of the bamboo whether it gets enough seasoning or not. The top portion of the bamboo is hydrated compared to the medium and base portions during its seasoning stages. The bamboo temperature and moistness variance are inclined to affect the cement matrix binding characteristics.

9. Why did bamboo rise to prominence as an RCC material of choice in harsh, corrosive environments?

RCC stands for Reinforcement Cement Concrete in Construction. Reinforcement concrete is known as a composite material. This type of material is made from cement and steel reinforcement. In recent times the price of steel has been increasing. That's why people use bamboo as reinforcement RCC structure because this is more cost-effective than steel reinforcement. Bamboo has more tensile strength than steel. The developing countries, that don’t have many funds use bamboo for RCC structure (Mohan et al. 2022).

In a very corrosive environment, where earthquakes, floods, or other natural disasters happen steel reinforcement is not a good option for construction because steel has less tensile strength than bamboo. As well as Bamboo has a more comprehensive strength and more flexural strength. Bamboo has more durability. That is why engineers prefer bamboo as reinforcement for RCC structures for small construction. Bamboo reinforcement is used to make footing, roofs, columns, beams, and slabs of houses. Bamboo is lighter in weight than steel. So, in harsh corrosive areas, bamboo reinforcement is used as reinforcement for RCC structures for construction.

In recent times global warming has been a major issue for the environment. Making of one ton of steel two ton of CO2 is produced. On the other hand, bamboo is capable of absorbing CO2. So, bamboo reinforcement is an eco-friendly material. So, bamboo can be used as a reinforcement for the RCC structure for small kinds of structures Steel concrete may be a reason for water leakage. But bamboo can absorb water better than steel in concrete. Also, bamboo can absorb water faster than other materials. That is another reason to use bamboo as reinforcement for RCC for small constructions. Carbon corrosion

concrete corrosion may happen in steel reinforcement but in bamboo reinforcement, there is no chance of any kind of corrosion. That is a reason bamboo reinforcement is used for RCC structures in major disaster areas. But bamboo has some limitations like contraction and expansion which is caused by climate changes and absorption of water. So, bamboo as a reinforcement also has a drawback (Dauletbek et al. 2021).

There are also some limitations to the use of bamboo as a reinforcement for RCC structures for small construction. Bamboo reinforcement must not be stated as less than 1.5 inches from the face of the surface, which is made of concrete. The ties between the bamboo should be made with greenery stripes. Bamboo reinforcement must be spaced evenly and placed at the right angle with respect to the main reinforcement.

10. Structural safety

The integration of bamboo as a structural material in civil engineering construction introduces both intriguing possibilities and pressing safety considerations. The safety of any construction material is paramount, as it directly affects the well-being of occupants and the long-term stability of structures. When evaluating bamboo's suitability for load-bearing applications, several factors must be carefully weighed. Bamboo has drawn interest for its potential as a structural material in civil engineering projects due to its special qualities and environmental advantages. When thinking about using bamboo for building, however, guaranteeing structural safety is a crucial factor. Although bamboo has many benefits, its drawbacks and weaknesses need to be carefully considered in order to build sturdy buildings.

10.1 High Strength-to-Weight Ratio

The strength-to-weight ratio of Bamboo is remarkable. This ratio of strength and weight of bamboo gives great competition to many traditional construction materials. This attribute offers the potential for efficient and lightweight designs, reducing the overall load on foundations and structural elements.

10.2 Natural Diversity and Grading

Bamboo has significant natural diversity in terms of its mechanical attributes, such as strength and stiffness. This variety results from elements including species, age, growing circumstances, and harvesting methods. It might be difficult to predict bamboo's precise behaviour in various structural applications because of inconsistent mechanical characteristics. Bamboo must be appropriately graded and tested to make sure that its qualities fulfill the needs of the intended usage in order to be safe. To classify bamboo according to its stiffness and strength, it is essential to create trustworthy grading methods. This enables engineers to make knowledgeable design decisions.

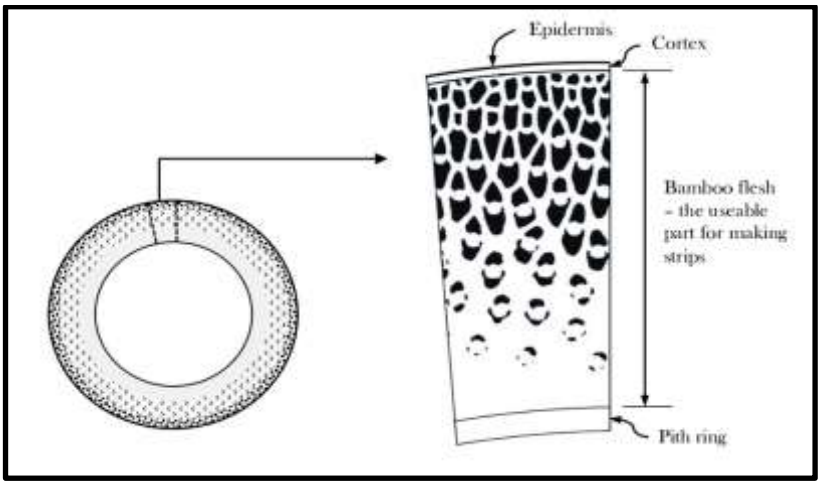


Figure 9.1: Cross-section Of bamboo

(Source: Dauletbek et al. 2021)

10.3 Longevity and Preservation

Bamboo's sensitivity to biological deterioration, including assaults by fungi, insects, and other organisms, can erode its structural integrity over time. Bamboo may decay quickly in areas with high humidity and frequent rain. In order to increase its endurance, proper preservation measures are crucial. Chemical treatments can offer defines against biological threats, but the choice of preservatives must strike a balance between the demand for lifespan and considerations for the environment and human health. Additionally, to guarantee the long-term security of bamboo constructions, innovations in preservation techniques are required.

10.4 Joinery and Connection Methods

The strength of the joints and connections between the parts has a significant impact on a structure's safety. Traditional timber building techniques are less suitable for bamboo because of its hollow structure and cylindrical form. Because of variations in material stiffness and characteristics, joining bamboo components can be challenging. For example, ordinary metal fasteners and connections may not be acceptable. For bamboo buildings to be secure and stable, specialized connecting methods must be created. These methods must also take into account weight transmission systems.

10.5 Tradition and Heritage

Throughout history, several civilizations have used bamboo's structural strength to create timeless traditional buildings. These case studies highlight bamboo's potential as a dependable building material when used in thoughtful designs.

10.6 Fire Resistance

One of the main issues with any construction material is how it reacts to fire. Because bamboo is naturally flammable, using it as a building material raises concerns about how fire-resistant it is. To reduce this risk, it is crucial to create efficient fire-retardant treatments that may be used on bamboo without affecting its mechanical qualities. Additionally, fire safety precautions like compartmentalization and proper egress plans must be taken into account in structure designs.

10.7 Dynamic Loads and Vibrations

Bamboo has a relatively low rigidity when compared to conventional building materials like steel and concrete, which can cause higher deflections and vibrations. Vibrations caused by wind, seismic activity, and other outside influences may jeopardize the structural integrity of bamboo-based structures if they are not controlled. Engineers must use dynamic analysis and design approaches to guarantee that bamboo constructions can safely bear such loads.

10.8 Long-Term Behaviour and Monitoring

Compared to conventional materials, bamboo's long-term behaviour, particularly how it reacts to loads, environmental factors, and aging, is less well understood. It's essential to keep an eye on bamboo buildings throughout time to evaluate their strength, efficiency, and safety. Research should concentrate on comprehending how bamboo evolves throughout the course of its service life and how these changes affect structural integrity.

10.9 Rules and Standards

Rules and standards must be developed to ensure the safe use of bamboo in buildings. These regulations must cover bamboo structure-specific design principles, material requirements, building techniques, and inspection procedures. Engineers and architects have clear instructions to follow when utilizing bamboo in building projects thanks to properly created norms and standards, assuring compliance and safety. Bamboo has enormous potential for use in civil engineering construction as a sustainable and environmentally friendly material. The use of it as a structural material necessitates a thorough study of its characteristics, constraints, and security issues. Engineers and scientists must work together to find solutions to the problems posed by bamboo's inherent diversity, durability, connections, fire resistance, dynamic loads, and long-term behaviour to assure structural safety. Bamboo has to be used as a practical and secure solution for creating a sustainable and resilient future by accomplishing this.

11. Secondary data analysis

Secondary data refers to those data that are collected from primary sources. The data that has been collected from the primary sources are then analysed and then the measures are taken accordingly. The water absorption capacity of bamboo is 50% higher by weight which means there is no swelling in bamboo. The collected data also shows that the strength and weight ratio of bamboo is way much better than any of the traditional materials. As per Kantharuban and Krishnaiah (2022), the tensile strength of bamboo is 3 - 4 times that of steel per unit weight.

The species of D. giganteus's fibre length value of the first node is 19.16, the 3rd node is 18.04, the 5th is 19.16, and 7th is 19.0 and the average is 18.84. The fibre length of the species D.asper, 1st node is 19.28, 3rd node is 19.60, 5th node is 21.16, 7th node is 20.10 and the average is 20.03 The fibre length of the species G.robusta, 1st node is 19.66, 3rd node is 15,5th node is 19.66, 7th is 18.16 and the average is 18.12 The fibre length of the species B.vulgaris var striata, 1st node is 19.92, 2nd node is 20.24, 5th node is 18.2, 7th node is 17.2 and the average is 18.92. It produces 35% more oxygen in the atmosphere and less than 40% cost.

Table 11.1: Bamboo species

(Source: Self-created)

Bamboo Species	Fiber Length	Fiber Length	Fiber Length	Fiber Length	Average Fiber

	(cm) - 1st Node	**(cm) - 3rd Node**	**(cm) - 5th Node**	**(cm) - 7th Node**	**Length (cm)**
D. giganteus	19.16	18.04	19.16	19.0	18.84
D. asper	19.28	19.60	21.16	20.10	20.03
G. robusta	19.66	15.0	19.66	18.16	18.12
B. vulgaris	19.92	20.24	18.20	17.20	18.92
Bambusa bamboo	18.50	17.80	19.00	18.30	18.40
Bambusa balcooa	20.00	18.70	20.50	19.80	19.75
Bambusa nutans	17.80	18.20	18.40	17.60	18.05

The above table shows the structural details of t the bamboo species. It includes the fibre lengths of the bamboo species across each node.

12. Conclusion

Bamboo is most efficient for building houses and preventing carbon emissions from factories, it provides oxygen by taking carbon dioxide in the process of photosynthesis. It can provide oxygen of more than 30% than the other species of trees and it provides strength more than a rock but light as a bird. It can grow more than 1 meter and after a period of 3 years, it is fully matured. Harsh weather conditions do not affect the houses because bamboo can also perform as a coolant inside the house during summer and a great insulator during winter. The tensile of the bamboo can withstand earthquakes and tend to stay strong forever. Bamboo can take part in all aspects whether the environment is harsh or financially disabled. It can help people to withstand great pressure and provides much cheaper building materials.

Bamboo materials are much cheaper and therefore the chances of misshapen are very low. Bamboo clumps should be used for purposes where the making of the building-making resources are limited and the measurements are not ideal or fixed for temporary buildings or some little civil projects. It can also be used for finishing materials and with more research and development bamboo can be hard and more tensile than perfect steel and used as building structural material in small engineering civil projects. Natural resources like bamboo fibre materials provide viable modern architectural necessities and insulting materials and energy efficient and provide insulation materials for making the buildings. The surface chemical treatments can increase the sufficient bamboo bond strength efficiency and decrease the rate of water absorption and shrinkage of the bamboo. This guidance sometimes is not very effective depending on the quality of the bamboo sometimes standard testing for the fibre density variation of the bamboo. This variation affects the bamboo bond strength determination.

Acknowledgments

The completion of this critical review has been made possible through the invaluable contributions of numerous individuals and organizations. Gratitude is extended to the mentors, advisors, and experts who provided their guidance and expertise, shaping the direction of this work. Recognition is also due to the authors and researchers whose studies served as the cornerstone for this review. The support and engagement of colleagues and peers in insightful discussions are greatly acknowledged. Appreciation is extended to friends and family for their unwavering encouragement. Their collective efforts have played a vital role in enriching this review and facilitating its realization.

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