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Review on Fabrication of Bamboo Composite Materials Reinforced Concrete

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Abstract: *In most developing countries, steel as a reinforcing material in construction is increasing day by day. But depending on cost and availability, it is therefore necessary to replace the steel with some other suitable materials. There's a situation where production isn't found to be sufficient to meet steel demand. Hence, having an alternative that is worth compared to steel is essential. Bamboo is one of the alternate materials used as a steel replacement in the construction of small structures and low-cost housing, particularly in countries like India. Bamboo is found in abundance, they are durable, and they can satisfy the demand as a reinforcing material and become a perfect substitute for steels. Compared with other materials including steel, the tensile resistance property which is the main requirement of reinforcing material is considered appreciable for bamboo. This property is given out from its origin through the bamboo structure. When in natural habitat, the hollow tubular structure has a high resistance to wind forces. Working on bamboo's weak points and bringing up bamboo innovation as a replacement for structural steel would be a great alternative. The goal of this present work to carry out a literature survey to determine the feasibility of bamboo reinforcement for a concrete structure. The mechanical properties and behaviour of steel-reinforced concrete have been extensively studied and well documented, there is no detailed data explaining reinforced concrete from bamboo exists. Therefore, the aim of this study is to provide a preliminary contribution toward the collection of literature to know the state of art characteristics such as mechanical properties and behaviours of bamboo reinforced concrete, with a view to solving specific problems of low-cost housing.*

Keywords*: Steel, Alternative Reinforcing Material, Bamboo, Construction, Structure, Feasibility*

I. Introduction

The concrete is widely used in most countries as the foundation for infrastructure. Concrete is used largely because it is inexpensive, readily accessible and possesses sufficient building properties such as the ability to bear high compressive charges. Concrete use is however limited, as it has low tensile strength. For this reason, it is reinforced, and one of the more popular reinforcing bars (rebar) is steel. Cost of concrete production is currently on the increase due to the recent recession in the world economy. Conventional constructions substances have become expensive .Many alternative materials are therefore being proposed for concrete manufacture. The alternative reinforcement material other than steel can be carbon fiber, aramid, glass, synthetic and bamboo. Among these bamboo is cheap and high resistance and is an alternative solution.

II. Literature Review

2.1 Overview

In the current world scenario with a rise in population numbers, there is a need for innovation in any field. Resources are being used at a faster rate so finding the alternative solution is very important [1]. Bamboo is one of the oldest constructing substances utilized by humans. Bamboo is good as a building material due to its high resistance and lower cost [1]. Steel production emitting carbon dioxide gas causes an environmental impact. Besides these, it also produces pollutants from wastewater, hazardous waste and solid wastes which pose a threat to the environment. Furthermore, steel costs have risen significantly over the years with increased demand. Bamboo is relatively cheaper than conventional concrete, and can therefore be used effectively by low-income groups. Bamboo is one of the alternative materials used in the construction of small structures as a steel replacement. Abhishek Dixit [2] has done a comparative study on reinforced concrete bamboo beams with different frictional properties. Bamboo strengthened concrete beams have executed the frictional properties by way of rolling the bamboo reinforcements with sand, G.I wire, and coir. It is concluded from the experimental work that bamboo provides a high tensile strength of 250 N / mm2 or higher which actually depends on the cultivation area, species type and cross-sectional area. Improved bamboo reinforced concrete beam flexural performance was observed with an increase in the number of days of curing period and an increase in bamboo rebar size. It is also recommended to use steel stirrups, as it enhances the beams flexural and shear capacity.

Culm bamboo or stem has been turned into a broad variety of items, varying from domestic household goods to industrial applications. The bamboo Culm shows the general part and is explained next section of the paper.

According to [3], as functionally gradient/composite material of bamboo shells that are in the direction parallel to the fibers are higher in strength as compared to perpendicular to the direction of fibers. It is a sustainable building material that has strength to specific weight ratio of more than six times that comparable to steel. To improve the bond strength between bamboo and concrete, the bamboo was utilized with three-factor impermeability treatments. Firstly, the adhesion properties of the material added to bamboo and concrete, secondly, the water-repellent nature of the chosen material, and lastly, the topography of bamboo and concrete interface. Findings from the investigations indicate that bamboo can satisfactorily substitute steel.

CO_2 emissions of bamboo to the atmosphere are 50 times less than in the case of steel and cement. Further, during its growth period, bamboo also consumes 1 ton (approx.) of carbon dioxide [4]. Bamboo is the fastest-growing, natural renewable resource and eco-friendly building materials. It has been shown that the use of bamboo laminated with glue is promising for general construction. This has a long and well-established tradition in both tropical and subtropical regions as a construction material.

Zhao Weifeng et al. [5] introduced some of the existing bamboo reinforced concrete elements studies and application technology in construction structures, such as bamboo reinforced concrete columns, beams, slabs and walls. Results of the experiments indicate that the ultimate load applied is increased by up to 400 per cent compared to the concrete beams without bamboo reinforcement simply supported for the bamboo reinforced lightweight concrete beam. The construction of the concrete cross-section of rectangular reinforced bamboo columns for bamboo reinforced columns should be conservative 2.25 times the concrete thickness of rectangular reinforced steel columns. When designs for steel-reinforced slabs are available, no change in thickness is required if reinforced with bamboo rather than steel. The use of bamboo mesh panels as walls allows the framework structural, shock absorbent and ecologically friendly. The results studies show that bamboo can substitute steel satisfactorily and structural elements of bamboo reinforced concrete could be used in many building constructions.

Due to its thin walls with separately and individually distributed nodes and high tensile strength, better flexibility, lightweight, easy design, and toughness and strength of bamboo make it suitable for building/construction material. Due to the excellent bamboo properties, this is a good alternative for steel, concrete and masonry. Bamboo is more able to withstand tension than compression. Several varieties of bamboo have been shown to have overall tensile strength comparable to that of mild steel at yield level.

Bamboo fibers run axially and have a higher tensile strength than steel but it is not possible to build connections using bamboos that can transfer this tensile strength. Bigger tubes have less compressive strength than slimmer ones. Bamboo's shrinkage properties are not as good as wood, bamboo shrinks more than wood. Appropriate steps should also be taken to avoid the loss of water from bamboo when used in building. Due to the presence of silicate acid, it has very good fire-resistance. Due to its high strength and resilience, bamboo scaffolding is used larger in scale. [1] It can be used as bamboo trusses, bamboo roofs skeleton, bamboo walling/ceiling, bamboo doors and windows, bamboo flooring, reed boards, scaffolding, bamboo doors and windows. Bamboo reinforced concrete construction is shown in Fig. 1

Figure 1: Bamboo reinforced concrete construction

2.2 Basic characteristics of bamboo

The anatomy of the culm [6, 7] can be divided into nodes and internodes. The internodes are essentially hole tubes, with cells orientated axially. To the interior of the node a diaphragm is formed, and from the exterior, the culm-sheath and branches form, as visible in Fig 2. The culm which is a cylindrical shell is the main stem of the bamboo and is made up of jointed segments called nodes. These nodes are solid and have solid plates that give the bamboo the strength to resist buckling. The region between the nodes is called an internode. The internodes are usually hollow and gives the bamboo the flexibility to withstand wind stress [7, 8] discussed the mechanical properties of bamboo, specifically pertaining to bamboo in concrete. This study showed that the ultimate load of a concrete beam reinforced with bamboo increased 400 % compared to unreinforced concrete. Bamboo culms (Figure 2) are a cylindrical shell separated by strong transverse diaphragms at nodes and have some interesting properties such as high strength in the parallel direction of fibers running longitudinally along the culm length and low strength in the perpendicular direction of the fibers.

The number of fibers in the cross section of a bamboo shell varies with both the height and thickness. Around the edge, fiber distribution is more uniform than at the top or middle. This is because the bamboo at the top of the culm is subject to high wind-induced bending tension. It has been observed that density increases from the bottom of the culm towards the top [9], and that density increases from the inside towards the outside of the culm wall at the internodes [10]. Similarly, the ratio of fiber to matrix material increases from the inside to the outside of the wall, and from the bottom of the culm to the top [11]. The increase in density from the bottom to the top of the culm is accompanied by an increase in compressive strength and an increase in tensile strength [9, 11] observed that the moisture content from the bottom to the top of the culm decreased. Increase in strength and stiffness has been associated with the thickening of the cell walls of fiber and parenchyma [12] which occurs with age. Limaye [13] also observed that the modulus of elasticity varied with age. In this study, the age range adopted is quite limited. For green bamboo, the variation to the elasticity module is quite significant, but for dry bamboo it is relatively small.

Amada [11] observed that diameter and wall thickness decreased along the culm in almost a linear manner. They also observed that the modulus of the elastic section varied proportionally to the moment of bending caused by the wind along the length of culm.

Bamboo is a naturally occurring functionally graded substance (FGM) with its most important property being that its ratio of strength to specific weight is six times greater than steel. It is a composite with a hierarchical structure. Bamboo’s strength is greater than most products made from timber. Bamboo's compressive strength was much stronger than its tensile strength, and the fibers had a high strength, but the fibers had a weak transverse resistance. Ghavami, K. [3] [14]. Amada [11] concluded that bamboo has developed into highly effective composite materials or 'smart structures.' For example, the reduction of both the diameter and the thickness of the wall along the culm also closely correspond to the reduction of the bending moment along the culm. As a result, the bamboo is exposed to wind forces with almost constant high surface stress over its length. Another interesting result is the almost constant gyration radius throughout the culm, which ensures that the culms’ buckling capacity doesn't vary significantly over the culm’s height. Furthermore, the proportion of the area occupied by the vascular bundles and the term that the writers call volume fraction of the [vascular] bundle sheath decreases with height to account for the lack of stability incurred by the reduction of diameter and thickness of the surface. The distribution of the vascular bundles across the thickness of the wall reflects the bending stresses caused by wind, i.e. the more stressed perimeter contains a higher concentration of vascular tissue sheaths and hence fiber.

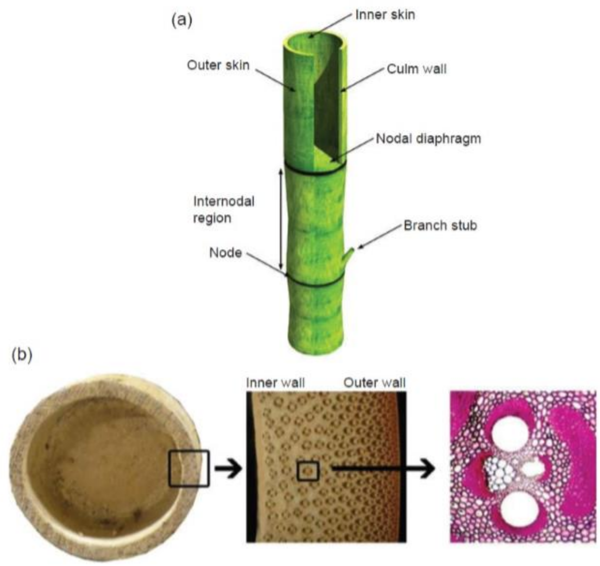

Figure 2: (a) Culm Bamboo Segment with Node, Inter-nodal region and Nodal diaphragm [6]
(b) Section of culm [7]

2.3 Bamboo as a construction material and its, mechanical properties

RCC with Steel structure is used in load-bearing structures. However, the major concern is its high cost and non-renewability of steel [16]. So, a low cost and sustainable material like bamboo are considered, which apparently possesses some physical features of steel. Bamboo is a natural perennial grass-like composite and is one of the fastest-growing woody plants in the world [17]. It belongs to the Bambusoideae family of grasses and consists of cellulose fibers embedded in a matrix of lignin. It is widely used as scaffolds and wall proportioning, because of its high strength to weight ratio. Many promising studies had been carried out which showcased various utility of bamboo for construction. In the parallel strand bamboo (PSB) study, bonded adhesively under high pressure, Huang et al. [18], discovered that PSB was a high strength and transversely isotropic biocomposite. Also, an overview of the use of bamboo fiber was made by Abdul Khalil et al. [19], and it was concluded that natural fibers such as bamboo can be used as biocomposites and integrated into cement concrete.

Karthik et al. [20] attempted various researches focusing on the use of alternative materials for construction. Bamboo strips were used as reinforcement in concrete made from additional cemented materials and partial replacement of synthetic sand (m-sand) for river sand. Cement was partially replaced by 25% of a combination of admixtures such as fly ash and Ground Granulated Blast Furnace Slag (GGBS). Concrete samples such as cubes, cylinders, and beams were developed and tested at stipulated times in line with standard requirements. The bamboo was performed with SEM and FTIR, and its tensile strength was also calculated. The results of the micro scale and tensile strength tests revealed that bamboo is a strong and ductile material. The study showed that the compressive and split tensile strengths are strengthened by a mixture of fly ash, GGBS and m-sand used as substitute concrete materials. Under flexural loading, the performance of bamboo reinforced concrete (BRC) made from alternative materials (fly ash, GGBS, and m-sand) was significantly poor compared to conventional BRC. Furthermore, BRC made from conventional materials produced more flexural resistance than the SRC, with a difference of 6.5 percent increase in strength.

C B Yong et al. [21] have been chosen bamboo to replace steel as reinforcement as one of the alternative material for reinforcement of concrete. The Semantan Bamboo (Gigantochloa Scortechinii) splint with a size of 20 mm x 10 mm (Thickness) was used as the main reinforcement. Three samples of two- way concrete slabs were prepared with a dimension of 1200 mm x 1200 mm x 100 mm. One sample will be constructed without reinforcement, while the remaining two samples will be reinforced with 1.5%, 2.5%, 3.5% and 4.5% of bamboo. All the samples will undergo concentrated punch loads and control slab without reinforcement. The results show that the maximum punching shears that the slabs can sustain more 60 kN. The slabs fail by the cracking of concrete at the bottom of the slab under the concentrated load. It is concluded that the Semantan bamboo able to replace the steel reinforcement bars but the slabs would be installed or constructed at a particular position especially those that hold lightweight. Chetan Bhatiwal et al. [22] presented a review on bamboo reinforcement in the beam and highlighted the advantage and disadvantage.

Adekunle P et al. [23] assessed bamboo (Bambusa vulgaris) reinforced concrete parts, rattan (Calamuc deerratus) and twisted steel flexural performance and deformation. The yield strength (YS), ultimate tensile strength (UTS) and the elongation of 50 specimens of the three materials were determined using a universal testing machine. Around the age of 28 days, three beams with concrete strength 20 N / mm2 were strengthened separately with the same amount with bamboo, rattan, and steel bars, while the stirrups were essentially mild steel bars. In order to test the flexural behavior the beams were subjected to center-point flexural loading according to BS 1881. The YS of bamboo and rattan bars were respectively 13 % and 45 % of that of steel, while their UTS was in the same order of 16 percent and 62 % of that of steel. Bamboo, rattan and steel elongation levels 7.42%, 10% and 14.7% respectively. The natural rebar were below the BS 4449 minimum norm of 12 %. The bamboo and steel RC beam load-deflection plots were quadratic, while the rattan RC beams were curvilinear in trend. The flexural rigidity of bamboo RC beams (BB) and rattan RC beams (RB) was 32 % and 13.5 % of steel RC beams (SB) stiffness. The remaining flexural power after the first crack was 41% for BB and SB, while RB was 25%. In comparison, the moment capacities of BB and RB corresponded to 51 % and 21 % of the steel RC beam capacity, respectively. The failure mode for bamboo and steel RC beams was shear, demonstrated by diagonal cracks due to the adopted short-span specimen and comparatively higher tensile strength than the RC beams that collapsed due to flexure (vertical crack). The difference between the flexural capacities of the natural rebar and that of steel can be attributed not only to the tensile strength but also to the weak bonding at the interface of the concrete plates. It can be inferred that the bamboo bars are ideal rebar for non-load bearing and lightweight flexural RC systems, whereas rattan requires more pre-strengthening preparation for improved interfacial bonding and load-carrying ability.

Table-1[Adekunle P, 23]: Tensile parameters of, Bamboo, Steel bars and others like Rattan

	YS (MPa)	UTS (MPa)	UTS / YS	% el
Rattan	58.46	85.33	1.46	10
Bamboo	201.14	335.23	1.67	7.42
Steel	442.73	540.13	1.22	14.7

The results summarized in Table 1 that all the three reinforcing bar Rattan, Bamboo and steel met the minimum specification stress ratio of 1.08 by BS 4449 [24] and bamboo showing the highest value of 1.67. Bamboo does not meet minimum ductility requirement of 12%.

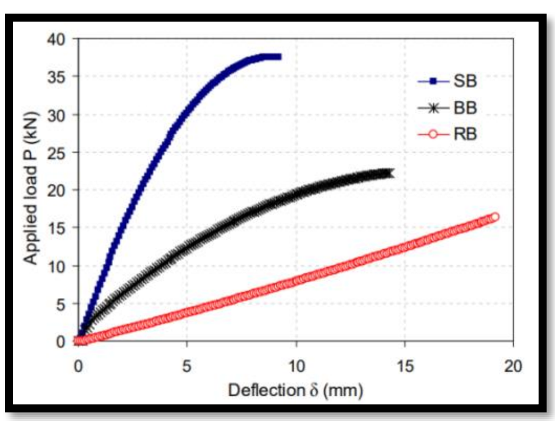

Figure 3: A typical load deflection curve of steel reinforced concrete beam (SB), bamboo reinforced concrete beam (BB) and rattan reinforced concrete beam (RB) [Adekunle P, 23]

Fig 3 explains that the load-carrying capacity of bamboo is more resilient than steel but less tough than steel. Further, the flexural stiffness of bamboo is only 1.97 N/mm as compared to steel of 6.15 N/mm.

Ari Wibowo [25] conducted an investigation to replace steel reinforcement with bamboo bars and using recycled materials such as Styrofoam lamination filler with an aim to make concrete element structure lighter and economical. Flexural strength test results showed that the flexural strength of specimens decreased by 15% but with the weight advantage of 20% as compared to normal RCC slab with identical dimensions. It gives a good insight into bamboo performance a practical design context since the nominal flexural capacity of RC slab with minimum reinforcement are usually much higher than the required moment.

Alireza Javadian et.al. [26] assessed the dependence of bamboo mechanical properties on culm physical properties such as diameter, wall thickness, height, moisture content Correlations between mechanical properties such as tensile strength [27] rupture module and flexure elasticity modulus [28] and tension [27] and culm physical properties. The results show specific density [29] is directly correlated with all these mechanical properties of bamboo whereas the moisture content values [30] are correlated only with the value of a modulus of rupture. While the culms' wall thickness magnitude is associated with all the mechanical properties tested, the diameter of the culm was only associated with the rupture modulus and flexure elasticity modulus. Therefore, measurements of the culm geometry and basic density of raw bamboo have the potential for rapid, non-destructive evaluations of bamboo quality, particularly in nurseries and forests where access to test facilities is limited. The second purpose of this analysis is to determine whether these experiments qualify for an evaluation of the bamboo's mechanical ability for the manufacture of high-performance polymer-reinforced bamboo fiber composites. The use of these formulae is demonstrated by a case analysis of reinforced concrete bamboo composite reinforcement. Pull-out tests and beam tests using this composite validate successfully the utility of this sustainable construction strategy.

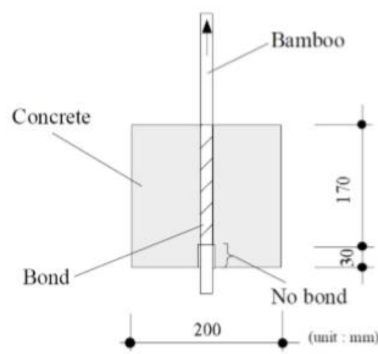

Figure 4: Typical Pullout test for Bamboo [8]

Figure 5: A typical bamboo reinforcement & failure of a bamboo concrete beam [Alireza Javadian, 26]

Fig 5 shows typical bamboo reinforcement for beam and failure mode of bamboo reinforcement beam in shear mode i.e. 45 degree plane [Alireza Javadian, 26].

Figure 6: A typical bamboo tensile test specimen [Alireza Javadian, 26]

Usage of bamboo as concrete reinforcement material was first studied by the U.S. Naval Civil Engineering Laboratories, California and issued a 1966 study to support building workers in the design and development of reinforced concrete structural components. It suggests some design charts and the method of working stress. ISO-22156 for structural design of bamboo and ISO-22157 for evaluation of bamboo's physical and mechanical properties have been written. Indian regulations have issued numerous codes on bamboo, only a few as structural materials for bamboo. Dinesh Bhonde et.al. [31] examined bamboo as reinforcement in the laboratory's concrete slab, and reported the findings. Anurag Nayak et al. [32] compared the cost-effective strengthening of bamboo-reinforced steel. The designs are done in this paper on the basis of shear and bending. Bamboo reinforcement technique is a smart choice for low-cost economic structure rather than conventional steel reinforcement. Bamboo reinforcement technique is used to reinforce both the main and the distribution, as was achieved earlier with steel reinforcement. From the results, it is clear that this bamboo reinforcing technique is absolutely cheaper than the steel reinforcing technique, particularly for single stories. P. Sharma et al. [33] discussed how bamboo can be used as the material for construction. It is used as a woody material as well as food for a wide variety of everyday purposes. It has been the backbone of much of the rural life of the world and will remain so as the population grows. The properties in our country as a top-quality building material and the increased availability of bamboo enable the extensive use of bamboo in the construction sector. Its highly valued utilization not only promotes economic development but also saves forest resources as a wood substitute for protecting our ecological environment. M. A. Mansur et al. [34] an experimental research on cement mortar was performed, reinforced with a bamboo mesh woven in a similar fashion to ferrocement.The study's principal parameter was the bamboo volume fraction and its surface treatment. It presents and discusses the results of the tests conducted in direct tension, flexure and effect. Test results show that the inclusion of bamboo mesh imparts considerable ductility and toughness to the mortar, and significantly increases its strengths in tensile, flexural and impact. Use of certain waterproof coating has been found to be effective in overcoming bamboo’s high water absorption and improving its comparatively poor bond strength. A small amount of casting pressure applied greatly increases the composite operation. Masakazu Terai et al. [35] presented the viability of using bamboo and non-steel as a building material for concrete parts. To investigate fracture behaviour and mechanical properties of reinforced concrete in bamboo reinforced concrete members, 9 pull-out and 4 slab specimens were constructed and the pull-out and 3-point bending tests were performed. From results conclusions made is pull-out test behaviour with bamboo is nearly the same as the plain steel bar; however, bond strength with bamboo was higher than that with a plain steel bar. When fresh concrete is poured, the bamboo will be moistened by its water for reinforced concrete slabs in bamboo; then the concrete will harden and lose water so the bamboo will dry out again. This drying process will break any bond between the bamboo and concrete altogether. Dhanendra Kumar et.al. [36] reviewed the research work on bamboo reinforced concrete with an emphasis on the different causes that hinder the construction of reinforced concrete bamboo as a tool to make the dreams of ordinary people come true for their home. On the basis of the study, it is concluded that positive attributes of bamboo such as a lightweight build, increased durability and resilience due to its thin walls with discreetly spaced nodes and great strength make it a better material for building. In this age of sustainable development, there is a wide scope and a growing need to understand bamboo which could be an environmentally friendly and comfortable steel alternative. Sharif Ullah Khan et al. [37] investigated the feasibility of reinforced bamboo concrete, and whether it can replace reinforced steel concrete for future construction. Under four-point loading, two slabs reinforced with two bamboo culms and three bamboo culms were tested to investigate the flexural strength or bending strength. Slab 2 reinforced with three bamboo culm showed strength which is a third larger than slab1 with two bamboo culm. Also, deflection of slab 2 also showed twice the deflection of slab1. Waterproofing agent should be used because this will reduce water absorption, and use of sand/adhesive to improve the bond strength between bamboo and concrete should be done.

Bamboo has an ultimate tensile strength of 138 N / mm2. This is almost half of the mild steel's total tensile strength. Bamboo can be used as rebar for concrete for lightweight structures under certain conditions and a strict preparation. Murni Dewi et al. [38] presented the latest research on reinforced concrete from bamboo at Brawijaya University Indonesia. Forms of structures studied in the last year are installing reinforcement pegs, using a lightweight brick to minimize the weight of the beams, and using the lightweight aggregate for the reinforced bamboo concrete frame. The use of pegs around the beam allows for reinforcing of the tensile load-bearing capacity. Strengthening the extra pegs will add effective stress from 45 MPa to 90 MPa. Using pegs like hooks on the steel reinforcement on reinforcement will be an opportunity to create a rigid beam-column connection. The use of lightweight materials is very useful for prefabricated buildings and earthquake-resistant buildings. Construction and industrial waste use are beneficial in the light of environmental friendliness. Harish Sakaray et al. [39] investigated tensile stress, compressive stress, elasticity module, water absorption capacity, shear stress and bonding stress of bamboo. It can be inferred from tests that bamboo's compressive strength is almost the same as bamboo's tensile strength and this action is identical to steel. Due to the smoothness of the bamboo structures, bonding stress of bamboo with concrete is very weak relative to HYSD steel plates. Bamboo water absorption is very high, and it is recommended a waterproofing agent. Since bamboo is environmentally friendly material, steel usage limits will reduce carbon dioxide emissions. Use of bamboo reinforced concrete may be recommended in the green building concept. Javadian, Alireza et al. [40] investigated the possibility of replacing steel components in reinforced concrete structures with high-performance bamboo fiber composite materials. The technology as such should be considered low-tech with injected high-tech knowledge and components for upgrading and installation in developing regions. With their increasingly growing urbanization rates, these areas overlap with the bamboo's global natural habitat, making bamboo an accessible, locally available natural resource for the potential construction industry. In summary, the newly designed and tested composite bamboo reinforcement has demonstrated effective load-bearing capability and bonding throughout our tests, showing its advantage compared to many other alternative reinforcing materials. Abdul Ahad et al. [41] discussed how bamboo is used in buildings with organic form. The relationship between shape, structure, design and joint system is described in several case studies The use of bamboo as a building material in the organically shaped building has proved vastly potential because it can be accommodated by the nature and properties of bamboo. Organically shaped building generally develops using active structure system or semi shaped active system, though non-shaped active structure system, i.e. trusses, can also be used. There are many methods for curving or bending the bamboo into an ideal form, such as hot bending method and cold bending method. Besides knowing the nature and properties of bamboo, knowledge of the structure system and method of bending, knowledge about the joinery mechanism is also needed. Omkar Gaikwad et al. [42] reviewed on bamboo reinforced concrete and evaluate its structural and environmental efficiency as an alternative to reinforced steel concrete. To demonstrate bamboo reinforced concrete design and as a model for testing the same life cycle, a three-bay portal prototype structure that would not be uncommon in regions of the world where concrete enhanced with bamboo could be considered. From this study of literature, it can be concluded that bamboo is eco-friendly and economic material as a natural material. S.V. Rayadu et al. [43] investigated bamboo reinforcement in the beam. Tests were carried out on 28 beams of size 750 mm length and 150 mm x150 mm under two-point load tests to study the effect of replacing steel reinforcement by bamboo. From the experiment, it can be concluded that bamboo shows reasonable tensile strength, which suggests that it can be used in low-cost housing projects as reinforcement in the RCC structure. It cannot be used as shear reinforcement in RCC structures since bamboo is weak in shear. If complete steel reinforcement is replaced with bamboo, it only gives a strength of 26 %. . Bamboo is weak in the node section, major bamboo failure occurs at the node section. The tensile strength of the middle bamboo-portion is always greater than that of the top and bottom portions. Bamboo does not exhibit ductile behaviour like steel. Therefore it can be used in both steel compression members and RCC structure. Bamboo elasticity module is very lower than steel module. RCC beam performs more elastically than bamboo beam when flexural measurements are conducted. Vertical cracks are created in the middle third area of the beam as beams fail. This form of failure is proof of pure moment life without any shear. The mode of failure for bamboo and RCC beam was shear, demonstrated by diagonal cracks due to the adopted short-span specimen. Jigar K. Sevalia et al. [44] presented a feasibility assessment of the use of bamboo as reinforcement in concrete components. The findings based on the experimental analysis are stress tests with revealed elastic behavior conducted on bamboo strips. Both single and double-reinforced beams have demonstrated elastic behaviour while performing flexural tests. The load carrying capacity increased by 29.31 % in a double-reinforced beam compared to single-reinforced beams. Vertical cracks form in the middle third area of the beam after the failure of the structure. This type of loss is proof of pure moment existence without any shear. The doubly reinforced beam elasticity module is more than two times the single-reinforced beam elasticity module. Alvin Harison1 et al. [45] carried out experimental research to determine the mechanical properties of reinforced concrete in bamboo and is presented in terms of compressive strength, split tensile strength and flexural strength. As the concrete is reinforced with bamboo, the result shows a plunging increase in compressive strength of about 10 to 15 %. This alarming emanation provided an approach to working towards making a low cost and environmentally friendly construction building using bamboo reinforcement as well as resulting in enhanced parameters of strength along with reduced construction costs. The results of the split tensile strength are nearly similar for both cases but their magnitudes are distinct and clearly discern the dominant effects of bamboo reinforcement in concrete. Flexural test findings indicate the major increase in compressive strength and flexural strength of bamboo reinforced concrete as compared to cement concrete plane. Lokendra Kaushal et al. [46] reviewed bamboo reinforced concrete beam performance in which bamboo strips were provided as possible reinforcement in concrete beams or concrete structure in place of steel. It was found that bamboo has high tensile strength and because of its low cost, it can be used as an alternative substitute material for steel reinforcement. Bamboo reinforced concrete can be used in the manufacture of table, benches and stools in public areas such as hospitals, classrooms, parks, train stations etc. to make the more eco-sustainable and for low-cost building. Bamboo constructions can be very durable and strong if they are well immunized and well-selected methods try to obtain the best quality of the material. Francis E. Brink et al. [47] provided a set of guidelines on methods and ways of using bamboo for different structural elements in the building. The study revealed that there should be no use of green and unseasoned bamboo for building. Until using it for building, the bamboo should be fully coated with water repellent paint. The combination pattern used with traditional concrete can be used for bamboo reinforced concrete. With regard to reinforced concrete from bamboo, it has been found that the designs of the concrete mix can be the same as those used for steel, with a slump as low as workability would allow. It was reinforced concrete from bamboo is a potential low-cost alternative light construction process. Abdourahim Jallow et al. [48] experimentally compared bamboo reinforced concrete beams with steel-reinforced concrete beams. The key objective is to assess the applicability of reinforced bamboo concrete beams versus reinforced steel-concrete beams in developed countries where bamboo is readily accessible relative to steel reinforcement bars. We can see from the research that reinforced steel beams are more ductile than reinforced bamboo beams. The strength of the concrete also had little effect on the behaviour that caused the beams to fail. It can be inferred that bamboo is still an option for steel to be replaced as reinforcement, but only in situations where the structure does not have a lot of loads. Nikhil N [49] has done comparative analysis on steel reinforcement replacement with bamboo reinforcement. To assess this, the test of tensile strength is conducted on bamboo strips, with bamboo having one node in the midspan, two nodes being done at each end and without node. The bamboo reinforced beam was found to have a tensile strength of 9.25 kN (avg) for 7 days, and it was found to be 18.5 kN for 28 days, which indicates that this reinforcement can be used in some minor construction. From this comparative analysis, it may infer that nodes have no effect on the bamboo's tensile strength. Therefore bamboo construction can be used instead of plain cement concrete for improved portion longevity. In the building of rural areas, bamboo reinforcement may be used which will facilitate better strength. Sudarisman et al. [50] studied the bamboo fiber/epoxy composite tensile and flexural properties. Five different fiber volume fractions were considered, i.e. 0, 10, 20, 30 and 40 volume per cent. It was concluded from the study that tensile strength, strain to failure and modulus were found to increase with an increase in fiber content up to V_f = 29.8 per cent, followed by a slight decrease in Vf = 47.7 per cent. Most specimens failed due to longitudinal splitting and fiber breakage followed. Besides strain-to failure, flexural resistance and flexural modulus tend to increase with increased fiber content. Unlike synthetic fibers with high strength, flexural failure at the tension face was found to be initiated. Ajinkya Kaware et al. [51] have done the design and testing of the bamboo reinforced concrete column. For this 3 rectangular specimen of 230 x 150 x 750 mm3, 3 square column specimens of 150 x 150 x 750 mm3 and 230 mm diameter and 750 mm long 3 circular specimens are used for each reinforcement increment. It can be concluded from the study that the split bamboo width should not exceed 2 to 2.5 cm. Bamboo reinforced concrete failure is of a similar pattern when compressed. Fissures in the edges and cracks along the column length. It should be painted with black Japan, as it has excellent water repellent and bonding ability. Bamboo should spend at least 6 months seasoning before being used as a reinforcement. The load-displacement and stress curves in the bamboo reinforce column are typical of the steel-reinforced column. However, the use of reinforced bamboo concrete is highly recommended for regions of the world where there is minimal supply of steel and plain concrete members are widely used. Rajveer Singh Rathore et al. [52] reviewed studies on the use of bamboo as a building material. Our ancestors used bamboo as a building material in many of the structures. These studies establish bamboo as a material for sustainable construction. Using it saves construction costs, promotes environmentally friendly construction and improves strength and durability. We can conclude from this study of bamboo that the bamboo is a natural and environmentally friendly material. Although it has low steel stiffness and strength, it can be used in limited storeys as a reinforcement, and must be treated before using bamboo as a reinforcement. Ayesha Syeda et al. [53] discussed the potential of bamboo and project the potential for bamboo use in the construction sector. It is concluded from the study that bamboo is lighter by weight than a bird but stronger than steel. It absorbs carbon dioxide and releases 30% more oxygen than a tree. It grows one meter in a year and matures in nearly 3 years. Houses built with this bamboo are cool in the summer and stay warm in the winter, and more can withstand earthquakes and stand forever. The environmental and financial analysis shows bamboo can compete with construction material. Bamboo is a natural product and it will still have a degree of irregularity. Therefore it is proposed that the bamboo culm can be used in functions where the measurement specifications are not completely correct or defined, as in temporary buildings (e.g. pavilions and tents) or small civilian projects. S. Y. Kute et al. [54] presented the results of experimental studies conducted to determine the ability of bamboo to be used as concrete reinforcement and to compare the bond strength of mild steel, TMT steel and untreated bamboo with that of bamboo with various low-cost treatments to minimize water absorption, thereby improving the bond strength of bamboo in concrete. Extracted specimens with and without nodes of the well-seasoned bamboo variety dendrocalamus strictus and regulated by twenty separate treatments for water absorption, dimensional growth, and tensile strength and bonding ability in M20 concrete. Mechanical treatments such as notching, nailing, or wrapping the binding wire around the specimen indicate increased bond strength but tests differ widely. Locally known as Black Japan, the coating of bituminous paint decreases water absorption by 75% but also increases bond tension by 10%. Fine zeolite powder applied in wet condition with oil coat or bituminous paint has increased the bond stress by 50–90 % to that of untreated specimens. Pankaj R. Mali et al. [55] investigated bamboo concrete bonding behaviour through pullout testing. The bamboo strips used as concrete reinforcement are first formulated with chemical adhesivity to make the bamboo coating impermeable. Different surface coatings are studied to understand their water-repelling properties. The result of pullout research showed a rare combination of surface treatment and grooved bamboo profile. This combination of surface treatment with bamboo grooved profile increases bonding strength. A newly produced grooved bamboo stripe output is tested against the equivalent plain rectangular bamboo strip. It is also found that the strength of the bond is largely determined by the form of surface application, the size and groove spacing. Test results indicate that the suggested reinforcement of grooved bamboo has the strongest bond strength when treated compared to untreated plain bamboo reinforcement, untreated plain and untreated grooved. M. M. Rahman et al. [56] assessed bamboo's suitability as concrete reinforcement using tensile strength test and flexural strength test. 1 m bamboo sticks with different cross-sections are used in this study. For this study, single and double bamboo reinforced beams are compared to standard concrete beams. From the stress-strain curves of bamboo, it is shown that bamboo exhibits low modulus of elasticity relative to steel. So, it can't prevent concrete cracking under ultimate load. But from the bamboo-reinforced beam flexural test it was shown that using bamboo as concrete reinforcement would increase the load-carrying ability of beams of the same size. The load-bearing capacity increased approximately 2 times for single bamboo reinforced concrete beam and approximately 2.5 times for double bamboo reinforced concrete beam that of the plain concrete beam of the same dimensions. The maximum deflection of the single-reinforced beam and the double-reinforced beam is about 4.5 and 8 times that of plain concrete, respectively. Chandra Sabnani et al. [57] developed a design using bamboo materials for a healthy and sustainable house that is affordable by the urban poor. The design thus established clearly indicates the cost reduction of the superstructure in which reinforced steel concrete is replaced by reinforced bamboo concrete in key structural elements. From the study, it is concluded that the use of bamboo as concrete reinforcement establishes that bamboo can substitute steel for modest housing for the urban poor who live near bamboo growing regions. The reason why it is not a favourable proposal arises not because of the inherent limitations of the material, but because of the procedural methods required for its treatment before it is actually used as a structural material. The research so far leads to further analyzes on how to simplify its treatment and eliminate operational issues in making bamboo one of the key structural materials. Yushun Li et al. [58] studied the potential as a structural member of the lightweight bamboo steel composite slab. Six slab specimens were tested to study the composite slabs' flexural behavior, consisting of cold-formed thin-walled steel channels and bamboo plywood sheathings. Results indicated that the specimens fabricated using the stability improved connection showed a remarkable increase in stiffness, capacity and stability, compared with the other two connections. The bamboo–steel composite slabs have the potential to replace concrete or wood slabs in low buildings. Steinfield [59] depending on the species and maturity bamboo can behave differently. Like steel rods, bamboo can pose a lot of durability concerns. Bamboo may contain high nutrients to support the growth of the fungi and attacking insects. It needs to be secured against different conditions like temperature, humidity, and pests. Bamboo has high water absorption, higher resistance to fire than steel and low bonding with concrete.

2.4 Applications of bamboo

Applications of Bamboo is multifold such as building construction, housing, bamboo furniture, ply-boo (plywood out of bamboo), temporary suspension bridges, scaffolding in high rise buildings, bamboo fishing rods, blunt weapon in defense, recreation. etc. It can also be used for soil stabilization, rehabilitation of degraded lands, medicine, handicrafts, biomass, fuel, food (the shoots), water transportation facilities, paper and pulp. Bamboo is also used in household utilities, such as containers, chopsticks, woven mats, fishing poles, cricket boxes and chairs. Culms are used as load-bearing elements in construction, such as roofs for housing, trusses, bridges and towers. It's mechanical and physical properties qualify it as a suitable alternative material for use in the building, construction, automobile, aerospace, art and design, food and beverage, textile and garment, and pulp and paper industries. [60]

2.5 Comparison of properties bamboo and steel

Concrete mix design is a very important factor for strength evaluation. So before comparing the various properties the concrete mix is explained briefly as follows.

2.5.1 Concrete mix proportions for bamboo reinforced concrete

The same mix designs that would normally be used with reinforced concrete made from steel can be used. The concrete slump should be as low as it would allow for workability. The excess of water causes bamboo to swell. High early-resistance cement is preferred to reduce cracking due to bamboo swelling when seasoned bamboo cannot be waterproofed. The water-cement ratio plays an important part in reinforced concrete strength and durability. As discussed earlier, bamboo is a natural building cloth has the assets of absorbing water. Water absorbance causes bamboo swelling. Therefore, the proportion of concrete mix for bamboo reinforced concrete must have the lowest possible water-cement ratio. It is also necessary to take into account the use of concrete with high early strength cement to reduce cracking due to bamboo swelling. The design of the concrete mix can be as per the structural power requirement as per the structural design. Since the use of reinforcement does not have an impact on the demand for compressive power of concrete, bamboo reinforced concrete.
Procedure for Concrete Mix Design of Concrete: [61]

Indian Standard method (IS: 10262 - 2009) is used for Concrete mix design.

1. Determining the Target Strength for Mix Proportioning
   F'ck = fck + 1.65 x S
   Where, 1.65 is tolerance factor (1 in 20)
   F'ck = Target average compressive strength at 28 days
   Fck = Characteristic compressive strength at 28 days
   S = Assumed standard deviation in N/mm2 (as per table -1 of IS 10262- 2009)
2. Selection of Water-Cement Ratio
   From table 5 of IS 456:2000, maximum water-cement ratio is chosen
3. Selection of Water Content
   Maximum water content for nominal maximum size of aggregate is taken from table 2 of IS 456:2000
4. Calculation Of Cement Content
   Cement Content = Water content/Water-cement ratio
5. Proportion of volume of Coarse Aggregate and Fine Aggregate Content
   Volume of coarse aggregate per unit volume of total aggregate for different zones of fine aggregate from IS 456:2000
6. Estimation of concrete mix proportion calculations

The mix calculations consistent with unit quantity of concrete shall be as follows:

- **a)** Volume of concrete
- **b)** Volume of cement = (Mass of Cement) / (Sp. Gravity of Cement) ×1000
- **c)** Volume of water = (Mass of Water) / (Sp. Gravity of Water) ×1000
- **d)** Total Volume of Aggregates = a - (b+c)
- **e)** Mass of coarse aggregates = d × Volume of Coarse Aggregate × Specific Gravity of Coarse Aggregate ×1000
- **f)** Mass of fine aggregates = d × Volume of Fine Aggregate × Specific Gravity of Coarse Aggregate × 1000

➢ **The average tensile modulus of bamboo is on the order 20 GPa, resulting in a modular ratio E_{Steel}/E_{Bamboo} = 10 [62]**

Literature	**Tensile modulus**	**Remarks**
Alireza Javadian et al.(2019) [26]	Varies from about 18 to 28 GPa	The modulus of elasticity in tension of bamboo varies with different classes of bamboo with varying culm diameters and wall thicknesses

Harish Sakaray et al.(2012) [39]	15 GPa	This study examines the bamboo type of Moso. Coating waterproof done as a treatment.
P. G. Dixon et al.(2014) [63]	Varies from about 5 to 25 GPa	The modulus of elasticity in tension of bamboo varies with micro structural variations and extrapolated solid cell wall properties of bamboo
Seite (2002) [64]	19 GPa	Bamboo species "guadia angustifolia" taken for study.
Anil shastry et al.(2017) [65]	45.4 GPa	Static bending test on bamboo splints was performed to evaluate elasticity modulus.
Vengala J et al.(2010) [66]	Varies from about 20GPa to 40 GPa	The modulus of elasticity in tension of bamboo varies with axial tensile properties
SP 7: Group 2 (2005) [67]	7.762	Provides information about various physical and mechanical properties of bamboo available in India
Zhang J et al.(2012) [68]	37 GPa	Properties of recombinant bamboo were studied.
Shah et al.(2016) [69]	Varies from about 17 GPa to 39 GPa	The modulus of elasticity in tension of bamboo varies with extraction procedures
Hong Chen et al.(2015) [70]	Varies from about 23.6 - 24.5 GPa	The modulus of elasticity in tension of bamboo varies with different

- **Tensile strength**

Literature	Tensile strength	Remarks
Abhishek Dixit (2019) [2]	250 MPa	Tensile strength depends on the area of cultivation, type of species and cross-sectional area.
Ghavami K(2005) [3]	370 MPa	Surface chemical treatments such as negrolin, sanded negrolin, sanded negrolin, and sikadur 32 gel wire.
Ghavami, K. (1995) [14]	Varies from about 140 - 120 MPa	Bambusa vulgaris species is taken. Surface chemical treatments done using negrolin
Adewuyi et al. (2015) [23]	Rattan- 58.46 MPa Bamboo-201.14 MPa Steel -442.73 MPa	Concrete elements reinforced with bamboo, rattan and the twisted steel rebar taken for testing
Alireza Javadian et al.(2019) [26]	Varies from about 193-340 MPa	Mechanical properties of bamboo sections often diminish with the culms’ wall thickness increasing.

Terai M et al (2012) [35]	118.2 MPa	Bamboo used in this is Japanese timber bamboo for investigation. Synthetic Resin Synthetic Rubber Coating was done.
Harish Sakaray et al.(2012) [39]	125 MPa	This study examines the bamboo type of Moso. Waterproof covering used as treatment.
Anil shastry et al.(2017) [65]	203 MPa	Bamboo possesses enough tensile strength to be used as tensile reinforcement
Zhang J et al.(2012) [68]	248.15 MPa	Tensile properties of recombinant bamboo were studied.
Musbau Ajibade Salau et al (2012)[71]	70 MPa	In this work, strips of coated seasoned bamboo were used in concrete column as reinforcement.
Sethiya et al. (2014) [76]	114 MPa	Moso Bamboo has been used for the test.
Kavitha S et al.(2018) [81]	73.95 -116.7 MPa	Bamboo Specimen tensile test result varies with diameter, area and load taken.
Ashok Kumar Gupt et al.(2015)[83]	282 MPa	To determine the ultimate tensile strength of bamboo, the tension test was performed on bamboo splints.

- **Compressive strength**

Literature	Compressive strength	Remarks
Ghavami, K. (1995) [14]	Varies from about 12 - 53 MPa	Bambusa vulgaris species is taken. The values of the test of dependent on the type of bamboo
Harish Sakaray et al.(2012) [39]	108MPa	This study examines the bamboo type of Moso. Waterproof covering used as treatment
Ajinkya Kaware et al.(2013) [51]	Varies from about 47.9 - 69.9 MPa.	Bamboo weak at the node, maximum failure at the bamboo node.
Anil shastry et al.(2017) [65]	97.48MPa and 83.28MPa	Culms with and without nodes taken for study
SP 7: Group 2 (2005) [67]	42 MPa	Provides information about the different physical and mechanical properties of bamboo in India
Zhang J et al.(2012) [68]	129 MPa	There was analysis of the compressive properties of recombinant bamboo.

E.T. Akinlabi et al.(2017) [60]	113.54 and 98.10	Results are taken for specimen with node and without node
Musbau Ajibade Salau et al (2012)[71]	26.18 MPa	In this work, strips of coated seasoned bamboo in concrete column have been used as reinforcement.
M.Usha Rani et al.(2017) [75]	47.6 and 57.8 MPa (7days and 28 days)	Test performed on reinforced concrete beams that replaced all rebar, including the main rebar and stirrups, with bamboo
Sethiya et al. (2014) [76]	56.5 – 87.7 MPa	Moso Bamboo was used for research. Bamboo samples collected well seasoned and well finished before testing.
Suresh Barmavath et al.(2017) [82]	17.3 – 47 MPa	It uses the Dendrocalamus strictus. Test results vary with no days.
Ashok Kumar Gupt et al.(2015)[83]	90.72 MPa	Compression test was performed on hollow bamboo culms.

- **Bond strength**

The slippage of the reinforcement is prevented by the bonding between the concrete and the reinforcement material. The elements responsible for producing bond strength are the adhesive houses of the cement matrix, the compression friction forces acting on the floor of the reinforcement bars due to the shrinkage of the concrete and the shear resistance of the concrete due to the shape of the floor as well as the roughness of the reinforcement bar [2].

The bond strength of bamboo with M20 concrete was equivalent to that of steel by taking out a pull out test on cubes, with steel bars and bamboo splits as reinforcement according to IS guidelines: 2770 (Part – 1) – 1967. 6 cubes of side, 150mm were cast, 3 cubes were provided with a 16mm diameter bar each and 3 cubes with a bamboo splint each of size 20mm x 10mm as cross section and projecting outward by 510mm from face of the cube. Pull out test was conducted in UTM, by fixing reinforcement to top grip of the machine and passing rod or splint through the middle portion of the machine. Method adapted for fixing bamboo splint to UTM top jaw was same as the setup used for tensile testing of splints. Test setup and specimen for the test are shown in fig 4 & 7.

Bond strength = $\frac{P}{\pi dl}$ for steel bars

Bond strength = $\frac{P}{2[bl+wl]}$ for bamboo splints

Where, P = Maximum applied load at slip in N
d = Diameter of steel bar
l= Embedded length of reinforcement
b = Width of bamboo splint
w = Wall thickness of bamboo splints

Reinforcement slip was measured using machine-mounted scale. Bond strength of bamboo and steel was calculated on the basis of the ultimate load the cubes had taken. Ultimate load was considered to be the load at which the concrete failed. [65]

Figure 7: Specimen for reinforcement pull-out test [2]

Literature	Bond strength	Remarks
Abhishek Dixit (2019) [2]	Varies from about 5.9- 9.7 MPa	BRC beams with higher bonding shear stress depends on curing time
Ghavami K(2005) [3]	Negrolin –0.52 MPa Negrolin with sand-0.73 MPa Negrolin with sand and wire - 0.97MPa Sikadur 32 gel -2.75 MPa	Surface chemical treatments like negrolin, negrolin with sand, negrolin with sand and wire, sikadur 32 gel.
Ghavami, K. (1995) [15]	Treated bamboo -0.97MPa Untreated bamboo -0.52 MPa	Two types of bamboo, treated and untreated, were considered by bond test.
Agarwal et al.(2014) [17]	0.13 MPa	Treating bamboo splints with commercial epoxy-based adhesives.
Harish Sakaray et al.(2012) [39]	Varies from about 0.98-1.95 MPa	This study investigates the bamboo type of Moso. Waterproof coating made as a treatment.
Alireza Javadian et al.(2019) [26]	Varies from about 2.42 to 3.65 MPa	The bond capacities ranging from direct pull-out tests were reported to be around 80 % of the comparable strength of the steel reinforcement bond
Anil shastry et al.(2017) [65]	1.7MPa	Concrete bonding with steel was very strong
Terai M et al (2012) [35]	Fully treated bamboo with synthetic resin and rubber - 1.2 – 1.35 MPa Partially treated with synthetic resin and rubber or untreated bamboo - 0.6-0.85 MPa	Bamboo used the Japanese Timber bamboo in this investigation.
Nindyawati et al.(2017) [78]	0.41 MPa	Waterproofing paint sprinkled with sand as a surface finish
Mulyati et al.(2016) [79]	Varies from about 0.62 -2.22 MPa	Varnish and winding wire done as a surface treatment

- **Flexural strength**

Flexural or bending characterizes the behaviour of a material subjected to an external load implemented perpendicularly to a longitudinal axis of the material as shown in fig 8. Flexural test design determines the material's potential to withstand load deformation. Two types are available which are the 3-point and the 3-point bending test.

- 3-point bending test: It produces peak stress at the material mid-point and reduces stress elsewhere.
- 4-point bending test: It produces peak stresses along the extended area of the material, thereby exposing the material to a larger length.

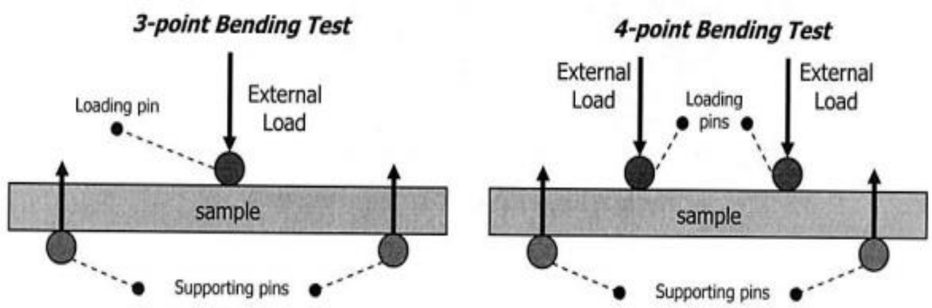

Figure 8: Schematic of flexure tests (3-point and 4-point bending test)

- **Three-point bending flexural test** [75]

The three-point flexural bending test provides values for the modulus of elasticity in bending , flexural stress , flexural strain and the flexural stress–strain response of the material. The principal advantage of a three-point flexural test is the ease of preparation and testing of the specimen. However, there are also some drawbacks to this method: the results of the test method are sensitive to specimen and the loading geometry and strain rate.

Testing Method:-
The test procedure for performing the test typically requires a specified test fixture on a universal test machine. The sample shall be mounted on two supporting pins with a set distance apart.

1. Calculation of the flexural stress σ_f

$$\sigma_f = \frac{3FL}{2bd^2} \text{ for a rectangular cross section}$$

$$\sigma_f = \frac{FL}{\pi R^3} \text{ for a circular cross section}$$

2. Calculation of the flexural strain $\in_f$

$$\varepsilon_f = \frac{6Dd}{L^2}$$

3. Calculation of flexural modulus E_f

$$E_f = \frac{L^3 m}{4bd^3}$$

Where ,
σ_f = Stress in outer fibers at midpoint, (MPa)
ε_f = Strain in the outer surface, (mm/mm)
E_f = flexural Modulus of elasticity,(MPa)
F = load at a given point on the load deflection curve, (N)
L = Support span, (mm)

b = Width of test beam, (mm)
d = Depth or thickness of tested beam, (mm)
D = maximum deflection of the center of the beam, (mm)
M = The gradient of the initial straight-line portion of the load deflection curve, (N/mm)
R= The radius of the beam, (mm)

- **Four-point flexural test [76]**

The flexural four-point test provides values for the bending elasticity module, flexural stress, flexural stress, and the material's flexural stress-strain response. This test is very similar to the three-point flexural bending test. The main difference is that, with the addition of a fourth bearing, the portion of the beam between the two loading points is placed under the maximum stress, as opposed to only the material under the central bearing in the case of three bending points.

This distinction is of prime interest when researching brittle structures, where the number and extent of defects subjected to maximum stress is closely linked to the initiation of flexural strength and cracking. There are no shear forces in the four-point bending flexural test in the area between the two loading pins as compared with the three-point bending flexural test[1]. Therefore, the four-point bending test is particularly suitable for brittle materials which can very well withstand shear stresses.

Testing Method :-
The test method typically involves a specified test fixture on a universal test machine. Details on the preparation, conditioning and conduct of the test will affect the test results. The sample is positioned a fixed distance apart on two supporting pins, and two loading pins placed around the middle at an equal distance. These two loadings are lowered at a constant rate from above until the sample failure.

1. Calculation of the flexural stress σ_f

$\sigma_f = \frac{3FL}{4bd^2}$ for four point bending test where the loading span is 1/2 of the support span (rectangular cross section)

$\sigma_f = \frac{FL}{bd^2}$ for four point bending test where the loading span is 1/3 of the support span (rectangular cross section)

$\sigma_f = \frac{3FL}{2bd^2}$ for three point bending test (rectangular cross section)

Where ,
σ_f = Stress in outer fibers at midpoint, (MPa)
F = load at a given point on the load deflection curve, (N)
L = Support span, (mm)
b = Width of test beam, (mm)
d = Depth or thickness of tested beam, (mm)

A flexural test produces compression stress on the concave side, and tensile stress on the material's convex side. That creates a shear area along the midline. Thus the span (distance between the two supporting pins) to depth (height of the sample) ratio must be managed to mitigate shear stresses in order to avoid the primary failure of the material from the shear stresses but rather from the tensile or compression stresses

Literature	Flexure strength	Remarks
Sudarismanet al.(2014) [50]	3.19 MPa	Composites of bamboo / epoxy fiber are used. By degumming process bamboo fiber was obtained from local bamboo.

Anil shastry et al.(2017) [65]	5.74 MPa	Results depends on reinforced concrete beams & plain concrete beams
Durgesh kumar gupta et al.(2018) [61]	Varies from about 4.18-4.6 MPa	Addition of bamboo fiber to concrete increases its strength continuously
Adewuyi et al. (2015) [23]	6.22MPa	Concrete components reinforced with bamboo, rattan and the rebar of twisted steel taken for examination.
Khan (2014) [77]	Bamboo reinforced beam with 1) triangular cross section –4.65 MPa 2) circular cross section-6.48 MPa 3) square cross section-7.64 MPa 4) steel reinforced beam with circular cross section-15.46 MPa	Different types of bamboo stick cross section such as circular, square, and triangular were used as reinforcement.
Amit Singh et al.(2016) [80]	1) 150 x 150 x 700 mm Plain cement concrete beams – 3.82 MPa Bamboo reinforced concrete beams – 5.93 MPa Treated bamboo reinforced beam – 6.57 MPa	Results depend on different types of concrete beams and size.
	2) 150 x 200 x 700 mm Plain cement concrete beams - 4.18 MPa Bamboo reinforced concrete beams – 6.27 MPa Treated bamboo reinforced beam – 6.86 MPa	
Kavitha S et al.(2018) [81]	Varies from about 6.61 -11.31 MPa	Bamboo specimen 's flexural test results vary with the load taken and no of days.
Suresh Barmavath et al.(2017) [82]	Varies from about 8.59 -10.39 MPa	Test done for single bamboo RCC beam and double bamboo RCC beam

III. Conclusion

From the study we can conclude that there are some advantages and disadvantages for using bamboo as a reinforcement. Some of advantages and disadvantages are as follows:

- Bamboo has been utilized as a building material for many years since the ancient days. Owing to its high strength-to-weight ratio, ease of use and quality, bamboo is a versatile material.
- Bamboo's property is the reason it was chosen as the reinforcing material for beams and columns. It is a sure inevitability that the structural member reinforced with bamboo would lose its strength to a considerable extent, therefore a mechanism by which steel and bamboo can be used together so that the strength of the member and hence the structure is not weakened by the seeing of a reduction in self-weight and making the structure economic.
- Using bamboo strips as column reinforcement should not be intended to impart compressive strength, but rather to induce elasticity in the concrete section, which in turn leads to sudden failure. Second, the bamboo strips lack concrete grips and deteriorate with age.
- The density of is low so bamboo is light in weight.

- For lightly loaded structures and low rise constructions, therefore, the reinforced concrete column of bamboo is recommended.
- Bamboo exhibits a ductile nature like in steel. Therefore it can be used both as steel compression members and as R.C.C. structure.
- Proper workmanship and supervision of skill helps to get the strength of desire. Concrete compaction should be adequate or honeycombed structure should be created elsewhere.
- Steel formwork should be used to achieve the required strength and good quality. The strength of bamboo is greater than the steel itself.
- Bamboo lowers construction costs and also increases the strength of the buildings Bamboo can crack and deflect more than steel reinforcement.
- They are especially in great demand in areas prone to earthquakes due to its elastic features.
- Bamboo has a great shock absorbing capacity.
- Due to hollow structure, it is highly flexible.
- Like other construction materials such as cement and asbestos, bamboo poses no health threat.
- Bamboo is also an easily accessible material because it can grow in tropical and subtropical zones. Some species of bamboo can develop up to 1 m in a day. It is recommended that more work be carried out on bamboo strip reinforced concrete construction, focusing on determining the optimal percentage of reinforcement.
- The comparison of environmental and financial aspects shows that bamboo can compete with building material. Bamboo is a natural commodity and it has a degree of irregularity at all times. It is therefore advised that the bamboo culm need to be used in features wherein the specifications of the measurement are not completely accurate or set, as in temporary homes or small civil projects.
- Usage of bamboo reinforced concrete can be suggested in the green building definition. In addition, bamboo may play a function as a non-supporting or finishing fiber.
- A lot of new techniques are being developed which can make bamboo the best building material in the future. In low-cost constructions , it has a wide scope.
- Bamboos are a sustainable alternative material available in most areas, particularly in a rural area. Bamboos are easy to find and handle because they are light in comparison with steel.
- Bamboo which is one of the fastest growing plants and is a great potential for economic growth. It grows naturally, and easily available, in many parts of the world.
- One of the bamboo's benefits is that the strength is greater than timber but is calculated to be half the steel's tensile strength. However, it solved the problem of corroding.
- Bamboo is a major sustainable building material because it is defined as a natural resource that is organic, biodegradable and energy efficient.
- Orthotropic materials of bamboo shells bamboo that are in the direction parallel to the fibers are higher in strength as compared to perpendicular to the direction of fibers.
- It has been discovered that bamboo can prevent pollution by absorbing large amounts of nitrogen from wastewater and reducing the amount of carbon dioxide in the air
- Bamboo is able to resist more tension than compression. Because of the high silicate acid content the fire resistance is very strong.
- Bamboo is more likely to attack insects than other trees and grasses, due to its high nutrient content. Bamboo's water content by weight is between 50%-60%..
- Due to the significant deflection following their failure, it may not be ideal in water retaining structures.
- The negative attributes of bamboo is its tendency to absorb water. Bamboo has a strong capacity to absorb water and can reduce mechanical properties and cause structural failure. There is a need to control the water abortion of bamboo. So usage of proper seasoning method to reduce the water absorption has to done. Seasoning of bamboo done by using bituminous paint, epoxy, and coal tar.
- Less durable than steel. Therefore it cannot be used in permanent structure.
- Bamboo 's structural reliability is questionable, despite the prevalence of various jointing techniques.
- Bamboo durability heavily depends on the preservation treatment method. This method of preservation involves smoking, heating, drying, coating and chemical treatment.

- Bamboo has low bond stress with concrete. There need to use epoxy to bond with concrete Epoxy should be applied in a thin coat using a brush, the thickness of the bamboo lubricant should be added and the bond tension should be reduced.
- Bamboo's strength depends on the age of bamboo. Strength goes decreases as the increase in age.

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