IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 11 Issue 12, December 2024
ISSN (Online) 2348 – 7968 | Impact Factor – 6.72
www.ijiset.com

Review on Durability and Strength properties and performance of treated-Bamboo Reinforced Concrete

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Abstract

Now a days, steel and concrete are the most widely used construction materials in the world. The concrete has high compressive strength; however, it has low tensile strength. Therefore, steel is used to reinforce the concrete. Steel has a very high tensile strength as compared to concrete; but there are certain problems associated with it. Some of these problems are high production cost, large energy consumption during its production; it is a non-renewable resource and large amount of carbon emission during its production. The urge to overcome these problems without the tensile capacity of reinforced concrete being compromised, has prompted numerous scientists and engineers to seek out locally sourced materials as replacement for conventional steel reinforcement. Specifically, bamboo is one of the most suitable materials that may be used as reinforcing bar in concrete. The steel making process exhibit high impact in the categories of human health and climate change as the workers involved in the factories are exposed to pollution and huge amount of pollution and waste are produced yearly in these factories. This review paper, which is highly sustainability related construction yielding work, assessed the suitability of bamboo as reinforcement in concrete with different treatment mechanisms from Indian and Ethiopian Standards.

Key words: bamboo, bonding, durability, steel, sustainability

INTRODUCTION

Different researchers were and are working on the bamboo material to gain an insight on its durability, strength, and similar properties. Several researchers were and are trying to find-out ways in which it can be used as a construction material and capable of replacing, to some extent, conventional materials like steel, concrete, etc.

Another point of consideration is high steel reinforcement demand, which leads to increase in its price. This leads to research on different materials which can be used as a steel replacement in the industry (**Nurharniza et al., (2022)).**

Different research articles on bamboo material have been considered on its behaviour through various tests and similarly looking at preservation methods for better utilization of its durability and mechanical performance. Several studies showed that: bamboo's flattening behaviour or preservation methods or its behaviour under oil treatment or as a replacement to conventional steel reinforcement in RCC beam, etc.

Through the consideration of different papers, we are trying to look on durability properties of bamboo. Each paper investigates different aspects of the same material and seems to be not related with each other. The methods used in the tests are simple and low-cost and tries to find out ways to improve its durability and other properties **(Parkkeeree et al., (2015)).**

To improve ductility of bamboo, we can follow standard codes, like **Indian standard, IS 9096:2006** or similar **Ethiopian standard, ES 6417:2021** to have a look on different types of preservatives (chemical) that are used for treating bamboo used for construction purpose including posts, scaffolding, house buildings, purlins, etc. The choice of preservatives and method of treatment depend up on the use to which the treated material is put. Some of the preservatives are-

- Copper-chrome (used for bamboo posts, poles, fencing, etc.)
- Acid copper-chromate composition (for posts, poles, scaffolding, ladders, etc.)
- Copper-chrome-boron composition (for rafters, trusses, ladder, etc.)
- Borax acid-borax (for walls, trusses, etc.)
- Copper-zinc-Naphtenate/Abieates (for ceiling, door, purlins, etc.)

Giving attention about bamboo material, apart from having good tensile strength and high renewability, it has few weaknesses or disadvantages also. Bamboo has high sensitivity to water and moisture which can cause swellings and shrinkages, which decreases its bonding strength. It can also be attacked by fungi and other biological factors (Bui et al., (2017)).

Bamboo Specimen and Tests

Author	Title	Bamboo Specimen and Test	Test specimen for different test	Type Of Test and Response	Results and Conclusion
Nindyawati and Baiq Sri Umniati	Bond Strength of Bamboo Reinforcement in Light Weight Concrete	Brown Colour Apus Bamboo (3-year-old) used. MAWAR Paint used (for waterproofing) Cement: Sand (2:3) Sand: - Malang Sand	Light Weight Concrete Cylinder (150mm dia; 300 mm height) Light Weight Concrete Cylinder (75 mm dia; 150 mm height) Formula used for Bond Strength calculation $u = \frac{P}{\pi * d * l}$	Concrete Compressive Strength Test: - Avg. Comp. strength = 12.7 N/mm^2 Wt. of concrete = 66N Unit wt of Concrete = 1240 N/m^3 Tensile Testing of Bamboo: - Node Failure Avg. max stress = 139MPa Strain = 0.0084 E= 16454 MPa Pull-out Tests: Bond length = 300 mm P = 318 Kg U = 0.41 Mpa	Bond Failure is observed in pull-out test and bond strength obtained is 28% of the bond beam reinforcement (1.49 MPa) To account for the true bond, the direct tension pull-out bond test should be adapted to measure real bond strength reinforcement in beams.

Vijay R. Wairagade, Ishwar P. Sonar	Bamboo Concrete Bond Strength	27 Moso Bamboo or kolkata bamboo Culms (4-year age, 40-70 mm dia) length 5.2 m.	M30 grade concrete used (IS 10262:2009) GI wire for wrapping.	Two-point loading test on UTM of 400KN capacity Bond strength of bamboo splints: - Cube size (150*150*150 mm)- 3 samples with 5 different bond arrangements. Bond strength of half bamboo culms embedded in concrete: Cube size (150*150*150 mm)- 3 samples with 4 different bond arrangements	Pull out test under UTM for 27 samples (15 splints, 12 half culm). Average bond strength between the bamboo splints and concrete is highest i.e., **0.87 MPa** (for oil paint sprinkled with sand and wrapped with wire in both direction (cross)). Strength enhanced = **193%**. Average bond strength between the half bamboo culms and concrete is again maximum i.e., **1.12 MPa** (for oil paint sprinkled with sand and wrapped with wire in both direction

					(cross)). Strength enhanced = **200%.** The average bond strength of the enhanced and treated samples is discovered to be closer to the values for the design bond strength. This research also examines the possibilities for new, affordable, and simple treatment options (oil paint).
Athiyyah Harivi Putri1 , Ova Candra Dewi1	Overview of Bamboo Preservation Methods for Construction Use in Hot Humid Climate	Bamboo in Indonesia: Characteristic, Utilization and Type of Bamboo 189 varieties of bamboo identified, only four are commonly used as construction materials.	Bamboo Preservation Methods: - Traditional or Non chemical Preservation of Bamboo, soaking of bamboo in water reduces starch as well	The woven technique links bamboo blades or tutu such that they do not escape from one other. It creates stress at the cross point, resulting in high friction without affecting the webbing's form.	The difference of preservation methods used by the two observation objects: - gravity method only requires 7-14 days at most, which is faster than the traditional

			as powder beetle's attack. Modern or Chemical Preservation of Bamboo: - chemical methods of bamboo preservation are the Butt Treatment method, the open tank method, the Boucherie method, and fumigation **Bamboo for Construction Use**: - woven techniques vertical techniques pelupuh techniques	Vertical or stacking technique is an ancient way that arranges the whole stems of bamboo vertically or horizontally. Pelupuh or splitting technique is the process of cutting bamboo segments using an axe or machete. This process starts with dividing the whole bamboo stem on one side, and then the gap is stretched. **Damage Factors of Bamboo**: - termites, dry wood powder, and bamboo destroyer fungus	preservation method. bamboo liquid used must also be prepared through a distillation process. the chemical gravity method only cleans and keeps the bamboo away from pests; it neither changes the shape of the bamboo nor adds strength to the bamboo. In terms of productivity, the chemical process is more productive because it can be completed more quickly. Bamboo should be preserved in great quantities.

					However, in terms of durability, the conventional approach yields more dependable and long-lasting bamboo. Traditional methods are thought to be more appropriate for bamboo building construction in a hot, humid climate.

METHODOLOGY

Methods used to understand bamboo's behavior was different for researchers to researchers. For example: **(Parkkeeree et al., (2015))** tried to understand the flattening behaviour of half-tubular bamboo culms immersed in hot linseed oil whereas **(Nurharniza et al., (2022))** prepared a bamboo reinforced concrete beam, in which steel is replaced with bamboo.

Methodology used by **(Parkkeeree et al., (2015))** includes construction of a pressing test rig containing two flat steel plates to apply compressive force, then immersion of specimen in hot linseed oil and using thermocouples to measure temperatures of the oil and specimen. Effects of linseed oil temperature and properties of bamboo specimens, i.e., initial moisture content, volume fraction of vascular bundles and thickness, on the flattening behaviour were examined. They introduce a parameter F, degree of flatness to understand flattening behaviour properly.

$F = \frac{(r_0 - h)}{(r_0 - d)}$ where r_0 is initial height and d is the specimen thickness.

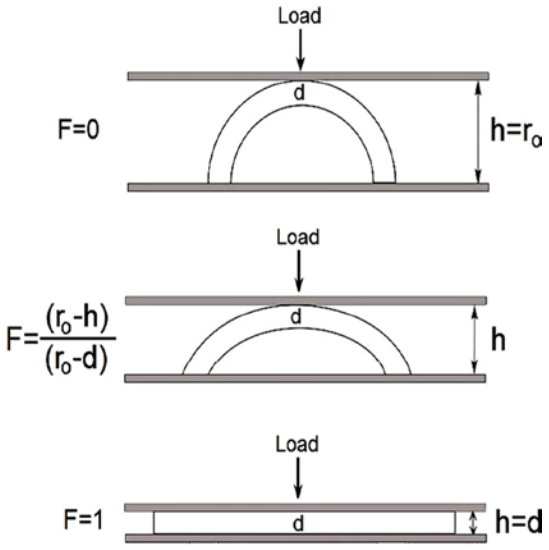


Figure 1: Schematic diagram of the definition of the degree of flatness, F **(Parkeeree et al. (2014))**

(Dewi et al., (2020)) studied bamboo preservation methods used by two industries in Indonesia. Both the industries treat various species of bamboo (for ex., *Petung bamboo* (***Dendrocalamus asper***) and *Apus bamboo* (***Gigantochloa apus***), making them better options for study. The basis for the analysis includes five parameters-

1. Preservation medium (pond, river),
2. Preservation duration,
3. Signs of the preservation being done,
4. Types of bamboo and
5. Durability of the bamboo after preservation.

In this study, the authors did not conduct their own preservation methods and only observations were done.

Researches were conducted by (**Bui et al., (2017))** and (**Nurharniza et al., (2022)),** in which they have conducted different tests on bamboo like uniaxial compression tests, three-points bending tests, tensile test, etc. **(Bui et al., (2017))** concludes that some treatment methods could increase both the durability and the compressive strength.

(Nurharniza et al., (2022)) used mix design method to design the beam and the concrete and uses bamboo sticks and slats as longitudinal bar and shear reinforcement respectively.

Figure 2: Details of bamboo reinforcement **(Nurharniza et al., (2022)).**

They had prepared two types of beams- normal RCC beam and bamboo reinforced concrete beam (Bamboo reinforced concrete is built using the same design, proportioning, and processes as steel-reinforced concrete. Only the steel reinforcement is changed for bamboo reinforcement), and compared various test (uniaxial compression test, flexural test, tensile test on bamboo sticks and steel bar) results with each other.

The study by **(Bui et al., (2017))** explores the oil-heated treatment. They keep varying conditions and tried to investigate bamboo's behaviour under different treatment processes. Firstly, for heating they tried two ways- oven heating or hot oil immersion. Then heating time was varied keeping method of heating as constant. Similarly, they have tested different oils (sunflower oil and linseed oil) for heating and also for cooling. They had eleven different sets, each set had subsets where each subset had five specimens. Thus, large number of sample points are considered to ensure accuracy in the results. After the treatment, specimens were weighed and then acted upon by different mechanical tests. Apart from uniaxial compression tests and three-points bending tests, they had also conducted water immersion test, tests under high humidity and accelerated aging test.

Table 1:Different methods of treatment and cooling. (Bui, et al., (2017))

Set	Subset	Treatment Method	Treatment Duration	Cooling Medium	Cooling Duration
1	1a	Flax oil, 100 °C	1 h	Flax oil, 20 °C	24 h
	1b		2 h		
	1c		3 h		
2	2a		1 h		1 h
	2b		2 h		
	2c		3 h		
3	3a		1 h		12 h
	3b		2 h		
	3c		3 h		
4	4		2 h		72 h
5	5a	180 °C in oven	1 h		24 h
	5b		2 h		
	5c		3 h		
6	6a	100 °C in oven	1 h		24 h
	6b		2 h		
	6c		3 h		
7	7a	Sunflower oil, 100 °C	1 h	Sunflower oil, 20 °C	24 h
	7b		2 h		
	7c		3 h		
8	8a	180 °C in oven	1 h		24 h
	8b		2 h		
9	9a	100 °C in oven	1 h		24 h
	9b		2 h		
	9c		3 h		
10	10a	Sunflower oil, 180 °C	1 h		24 h
	10b		2 h		
	10c		3 h		

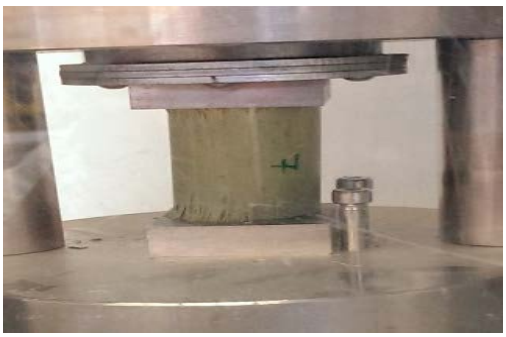


Figure 3: A bamboo specimen during the uniaxial compression test.

Figure 4: Three-point bending test on a bamboo specimen.

1. **Concrete Compressive Strength Testing**

The specimens measured height of 300mm and diameter of 150mm. To avoid getting wet, concrete cylinder coated in plastic for 28 days. Before the test, the specimens were weighed. The materials were placed in a 2,000 kN compressive testing equipment. At which point the compressive stress

at ultimate load is measured, the load had been applied parallel to the concrete in small increments until the sample fails.

2. Tension Testing of Bamboo

400 mm long Apus bamboo samples were used whose cross-sections are 8 mm by 8 mm. The tension test process for bamboo is the same as for steel. Load and elongation values are taken for each sample placed in the UTM.

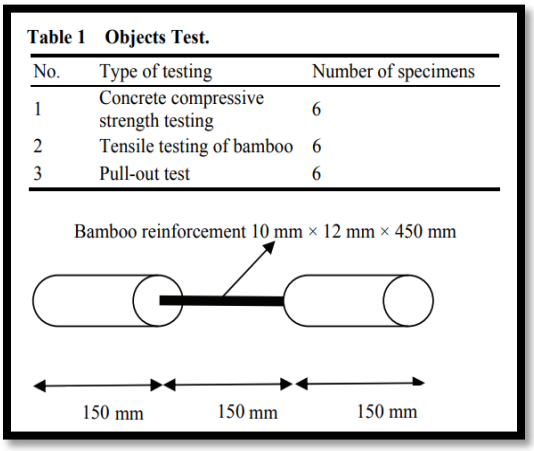
3. Pull-Out Tests Specimen

Apus bamboo with a length of 450 mm and a split of 8 mm by 8 mm is utilised. Bamboo was painted and dusted with sand. Concrete cylinders 75 mm in diameter and 150 mm in length are utilised for testing. While casting, the bamboo specimens were inserted in the centre of concrete cylinders. The samples were evaluated after 28 days of curing in a machine with a capacity of 15 kN. Bond length (l_d) is the length of bamboo in a cylinder that is in touch with concrete. The bond stress is calculated from the ultimate load using the formula shown below.

$$u = \frac{P}{\pi \cdot d_b \cdot l_d} \quad (\text{unit in N/mm}^2)$$

Table 1 Objects Test.

No.	Type of testing	Number of specimens
1	Concrete compressive strength testing	6
2	Tensile testing of bamboo	6
3	Pull-out test	6



Half bamboo culms and bamboo splints are used in the bond strength test. Before being sprinkled with dry sand on samples, bamboo splints are first painted with oil paint. In various ways with GI wire, a few specimens were then wrapped. It is guaranteed that the paint coat is uniform over the surface. With the aids for better bonding with concrete, coating keep bamboo specimens water repellent. The complete casting of cubes embedded

with prepared half bamboo culms and bamboo splints is done with M30 grade concrete mix. (Vijay R. (2019))

Fig.
3 Bamboo splints for pull out test

Pattern considering the spacing of cross wire in both directions, for half bamboo culms, GI wire is wrapped in various.

Fig. 5 Pull out test specimens

Fig. 4 Wire wrapped culms for pull out test

Throughout the entire investigation, design mix of M30 graded concrete is employed. IS 10262:2009 had been used as guideline for design. The typical compressive strength of M30 is specified in IS 456:200 as 30 MPa. Half bamboo culms inserted in concrete cubes of varying sizes were tested for bonding strength. Painting of oil over the bamboo surface has a high degree of adherence to sand and has a low shrinkage after curing. The following day, these specimens are demoulded and stored in a curing tank for 28 days prior to the pull-out test. The test had been performed using a 400 KN Universal Testing Machine. A total of 27 samples were analysed, 12 for half culm and 15 for splints, and the average results are provided in section III. IS 2770 (part I): 2007 referred for test method.


Fig. 6 Pull out testing in UTM


Fig. 7 Pull out testing in UTM

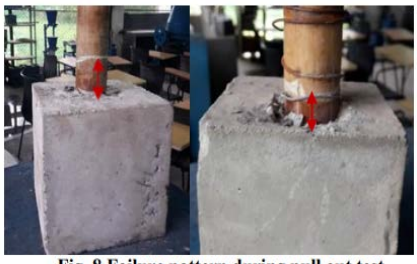


Fig. 8 Failure pattern during pull out test

Bamboo Preservation Methods-

1. Traditional or Non-chemical Preservation of Bamboo

People far from cities or towns have preserved bamboo using traditional ways such as soaking bamboo in both running and still water. This process is utilised to minimise starch in bamboo, which have been used to make building materials. Soaking bamboo in water for more than one month is not recommended. When the colour of the bamboo is pale (rather than yellow, green, or black) and it has an acidic odour, this preservation method is deemed complete. Traditional methods result in greater bamboo strength. (Athiyyah H. (2020))

1. Modern or Chemical Preservation of Bamboo-

The possibilities for bamboo preservation are limitless due to this easy process. Chemical techniques are more expensive, but they provide superior surface protection. Now a days, chemical

preservatives are frequently used to strengthen the resistance performance of bamboo against termite infestations. Despite the fact that this procedure successfully increases the durability of bamboo. The accuracy of the concentration of the preservative solution provided is critical to the effectiveness of this approach. The open tank method, the Butt Treatment method, fumigation and the Boucherie method are some of the recognised of bamboo preservation chemical mechanisms (with methyl bromide compounds). In India, Taiwan, and Japan, chemical procedures are commonly used on a large scale.

RESULTS AND DISCUSSIONS

Findings by different researchers explores different properties of bamboo. **(Bui et al., (2017))** finds various sub results and concludes that the best compressive strength was obtained for the samples treated by heat, at 180 ^{o}C (during 1 hour or 2 hours) without oil (oil was used only for cooling), and the best resistance to fungi and to water sorption were for specimens treated at 180 ^{o}C for 1 hour or 2 hours. Apart from the main result, various sub results like a long treatment (more than 2 h) at a high temperature (180 ^{o}C) may have deteriorated the microstructure of bamboo. Weight loss was also observed during the treatment and it was higher for the treatment at 180 °C (22%) than for treatment at 100 °C (16%). So, it is suggested that the amount of destroyed organic components is more important at 180 °C than at 100 °C. After humidity tests, fungi attack was observed and it was also concluded that temperature of treatment is the predominant factor for the fungi resistance. The Young's modulus for the bamboo specimens comes out to be in the range of 8.8 to 9.6 GPa.

The bamboo reinforced concrete test done by **(Nurharniza et al., (2022))** concludes that bamboo reinforced concrete beam has 74% lower strength compared to steel reinforced concrete beam. Therefore, bamboo is not able to completely replace steel as main structural member same as something concludes by **(Hector et al., (2018))**. However, they find that it can be an economical option for columns of compound walls as bamboo is good under compression force. They emphasized the need for treated bamboo to protect it from pest, temperature, and moisture to improve the durability of bamboo.

(Parkkeeree et al., (2015)) finds that

- Soaking of the bamboo specimen in water to attain the saturated condition was beneficial in the flattening process of half-tubular bamboo culms in hot linseed oil. Moisture reduced the temperature at which the deformation began and increased the rate of deformation and the final value of degree of flatness.
- Deformation of the bamboo specimens with higher volume fraction of vascular bundles occurred at a slower rate than those with lower volume fraction of vascular bundles.
- At least 120 ^{o}C was required, avoiding immediate spring back, to get flattened bamboo specimens with the final degree of flatness higher than 90 %.

The most optimal method for preserving bamboo used for wall construction is the traditional water-soaking method. In terms of productivity, the chemical method is more productive because it can be done quickly. However, in terms of durability, the traditional process results in more reliable and more durable bamboo. These are the findings by **(Dewi et al., (2020))**.

Bond failure occurs during the pull-out test, and the bond strength obtained was 28% of the bond beam reinforcement (1.49 MPa). To account for true bond strength reinforcement in beams, the direct tension pull-out bond test should be modified. (Nindyawati U. et al. (2016))

Table 4 Pull-out Test.

Sample No.	Load (N)	Bond strength (N/mm^2)
1	2,500	0.33
2	4,000	0.48
3	3,000	0.39
4	3,500	0.45
5	2,600	0.34
6	3,500	0.45

The equation F/(S*L) is used to calculate the interfacial strength of all 27 specimens. In this equation, S indicates the perimeter of the bamboo splints, L represents the length of the bonded interface and F indicates the pull-out force. The details of all 27 cubes, as well as the findings, are provided below. (Vijay R. (2019))

Table 3 Pull out test results of bamboo splints

Sr.No.	Type	Treatment	Specimen	Sample No.	Width (mm)	Thickness (mm)	Contact Perimeter (mm)	Contact Length (mm)	Contact Area (mm^2)	Pull out Load (KN)	Bond stress (Mpa)	Average Bond stress (Mpa)
1	Splint	Plain	Culm 1	P1	19	6	50	260	13000.0	5.9	**0.45**	**0.45**
2			Culm 2	P2	20	6	52	260	13520.0	5.7	**0.42**	
3			Culm 3	P3	18	7	50	260	13000.0	6.2	**0.48**	
4		Oil paint	Culm 1	P4	18	5	46	260	11960.0	5.6	**0.47**	**0.50**
5			Culm 2	P5	20	6	52	260	13520.0	6.6	**0.49**	
6			Culm 3	P6	19	6	50	260	13000.0	7.2	**0.55**	
7		Oil paint + sand	Culm 1	P7	16	5	42	260	10920.0	6.4	**0.59**	**0.58**
8			Culm 2	P8	17	6	46	260	11960.0	7.2	**0.60**	
9			Culm 3	P9	20	8	56	260	14560.0	7.9	**0.54**	
10		Oil paint & wire in one direction	Culm 1	P10	19	6	50	260	13000.0	11.2	**0.86**	**0.80**
11			Culm 2	P11	20	5	50	260	13000.0	10.8	**0.83**	
12			Culm 3	P12	18	7	50	260	13000.0	9.2	**0.71**	
13		Oil paint & wire in cross	Culm 1	P13	18	5	46	260	11960.0	10.4	**0.87**	**0.87**
14			Culm 2	P14	17	6	46	260	11960.0	9.4	**0.79**	
15			Culm 3	P15	19	9	56	260	14560.0	13.8	**0.95**	

Table 4 Pull out test results of half bamboo culms

Sr.No.	Type	Treatment	Specimen	Sample No.	Thickness (mm)	Diameter (mm)	Contact Perimeter (mm)	Contact Length (mm)	Contact Area (mm^2)	Pull out Load (KN)	Bond stress (Mpa)	Average Bond stress (Mpa)
16	Half Round	Plain	Culm 1	P16	7	45	133.32	260	34663.2	21.2	**0.61**	**0.56**
17			Culm 2	P17	7	42.7	126.098	260	32785.5	16.9	**0.52**	
18			Culm 3	P18	8	38.3	111.142	260	28896.9	16	**0.55**	
19		Oil paint	Culm 1	P19	8	44	129.04	260	33550.4	18.1	**0.54**	**0.60**
20			Culm 2	P20	6	43.7	130.378	260	33898.3	26	**0.77**	
21			Culm 3	P21	7	42	123.9	260	32214.0	16.2	**0.50**	
22		wire in one direction	Culm 1	P22	9	43.3	125.702	260	32682.5	25.2	**0.77**	**0.89**
23			Culm 2	P23	8	41.7	121.818	260	31672.7	28.7	**0.91**	
24			Culm 3	P24	9	39.7	114.398	260	29743.5	29.9	**1.01**	
25		wire in cross	Culm 1	P25	7	38.3	112.282	260	29193.3	32.4	**1.11**	**1.12**
26			Culm 2	P26	7	36.3	106.002	260	27560.5	30.1	**1.09**	
27			Culm 3	P27	9	34	96.5	260	25090.0	28.7	**1.14**	

The Indonesian Bamboo Foundation does not utilise them to preserve their bamboo, because chemical treatments are inefficient and unsatisfactory. Nusantara Bamboo Academy, on the other hand, uses both traditional and gravitational chemical methods for bamboo preservation. And Nusantara Bamboo Academy believes that the chemical preservation approach is more efficient in terms of time.

Traditional Method Parameters	The Indonesian Bamboo Foundation	Nusantara Bamboo Academy
Preservation Media	Pond	River
Preservation Duration	1-2 months	30 days
The signs of the preservation being done	The bamboo odour resembles that of a thick vinegar	--
Bamboo Types	All types of bamboo	All types of bamboo
Bamboo's Durability	10-20 years	10-20 years

Source: (Author, 2019)

Chemical Method Parameters	The Indonesian Bamboo Foundation	Nusantara Bamboo Academy
Preservation Media	-	Gravity system
Preservation Duration	-	7-14 days
The signs of the preservation being done	-	--
Bamboo Types	-	All types of bamboo
Bamboo's Durability	-	1-3 years

Source: (Author, 2019)

The chemical approach is more productive, in terms of production; because it can be done fast, allowing it to preserve vast amounts of bamboo. However, in terms of durability, the conventional approach yields more dependable and long-lasting bamboo. Traditional methods are said to be better for bamboo building construction in a hot, humid climate.

CONCLUSIONS

From these research articles mentioned above, we can conclude some properties or behavior of bamboo like-

- Soaking of bamboo specimen in water or in any chemical is highly beneficial for use of it as a structural component, to increase its durability, etc.
- As a conclusion by **(Dewi et al., (2020))**, in terms of productivity, the chemical method is more productive because it can be done quickly. However, in terms of durability, the traditional process results in more reliable and more durable bamboo.
- Bamboo reinforcement, without proper and advanced methods, cannot be used as a complete replacement for conventional steel reinforcement.

- Heating the bamboo, in oil or without oil can increase its compressive strength, fungi resistance, etc.
- Alkali treatment can have a significant effect on the tensile properties of bamboo strips. When bamboo strips are treated with alkali, such as sodium hydroxide (NaOH) solution, it causes changes to the bamboo's chemical composition and structure, which in turn influences its mechanical properties. The researchers concluded that NaOH treatment of bamboo fibers can effectively enhance the bonding properties and mechanical performance of bamboo-fiber-reinforced geopolymer composites. The treatment resulted in improved surface characteristics of the fibers, leading to enhanced adhesion and interfacial bonding with the geopolymer matrix.

Boric acid solution treatment can have several effects on the tensile properties of bamboo strips. When bamboo strips are treated with boric acid solution, it imparts certain benefits that can enhance their mechanical performance. Here are some effects of boric acid treatment on the tensile properties of bamboo strips:

- Increased tensile strength: Boric acid treatment can lead to an increase in the tensile strength of bamboo strips. Boric acid acts as a crosslinking agent, forming bridges between cellulose molecules in the bamboo structure. This crosslinking strengthens the bonds between the fibres, resulting in higher tensile strength.
- Improved resistance to biological degradation: Bamboo is susceptible to biological degradation by insects, fungi, and bacteria. Boric acid is known for its insecticidal and fungicidal properties, making it an effective treatment to protect bamboo against these organisms. By inhibiting biological degradation, boric acid treatment helps maintain the integrity and tensile properties of bamboo strips over time.

It has also been found that bamboo acts very well in buckling but due to low stresses than compared to steel and due to it not being straight it may not be very good. Further, it has been established that in seismic zones the failure of bamboo is very less as the maximum absorption of the energy is at the joints. Cellulose is the main component present in bamboo which is the main source of mechanical properties of bamboo.

Major points:-

1. Bamboos that are used for construction must go through a preservation process before being applied.
2. Chemical method is more productive because it can be done quickly, so it can preserve bamboo in large quantities.
3. In terms of durability, the traditional process results in more reliable and more durable bamboo.
4. Traditional methods are considered to be more optimal for the bamboo building construction in a hot, humid climate.
5. Bond strength reinforcement calculations based on direct tension pull-out bond test is less than bond strength reinforcement that occurs on the beam.
6. Bond strength reinforcement by direct tension pull-out bond test should be adapted to take account of the real bond strength reinforcement in beams.
7. Oil paint is the significant and economical alternative to increase the bond strength between concrete and reinforcement.

REFERENCES

1. Bui, Q. B. & Grillet, Anne-Cécile & Tran, Hoang-Duy. (2017). A Bamboo Treatment Procedure: Effects on the Durability and Mechanical Performance. Sustainability. 9. 1444. 10.3390/su9091444.

2. Dewi, Ova & atiaharivi19@gmail.com, (2020). Overview of Bamboo Preservation Methods for Construction Use in Hot Humid Climate. 10.24853/ijbesr.4.1.1-10.

3. Parkkeeree, T., Matan, N. & Kyokong, B. Mechanisms of bamboo flattening in hot linseed oil. Eur. J. Wood Prod. 73, 209–217 (2015). https://doi.org/10.1007/s00107-015-0889-x

4. Abdul Rahman, Nurharniza & Rong, Choo & Lee, Hoong-Pin. (2022). Bamboo Reinforced Concrete Beam. 10.1007/978-981-16-7924-7_32.

5. Hector A., Sebastian K., David T., Edwin Z. E., Kent A. H.: Bamboo reinforced concrete: a critical review, Journal of Materials and Structures, Vol. 51, Issue 102, (2018).

6. ES 6417:2021 Preservation of bamboo- Part 1: for construction purpose- Ethiopian standard

7. Aachen, R., Evelin and Aachen, R. (2002) 'Mechanical properties of bamboo introduction', *Mechanical Properties of bamboo*, (11), pp. 1–11. Available at: www.bambus.com/new/eng/reports/mechanical_properties/referat2.html.)

8. Adier, M. F. V., Sevilla, M. E. P., Valerio, D. N. R., & Ongpeng, J. M. C. (2023). Bamboo as Sustainable Building Materials: A Systematic Review of Properties, Treatment Methods, and Standards. *Buildings*,

9. Agarwal, A., Nanda, B., & Maity, D. (2014). Experimental Investigation on Chemically Treated Bamboo Reinforced Concrete Beams and Columns. *Construction and Building Materials, 71*, 610-617

10. Ali, K. A., et al. (2020). Issues, Impacts, and Mitigations of Carbon Dioxide Emissions in the Building Sector, *12*(18), 1-1

11. Apparatus, C.R. (2000). 'Standard Test Method for Determination of Liquid Water Absorption of Coated Hardboard and Other Composite Wood Products Via', *Current*, 11(December 1995), pp. 100–102.

12**.** Bamboo: A Strategic Crop for Climate Change Mitigation" by A. K. Singh et al., 2019.Source: Journal of Environmental Science, Computer Science and Engineering & Technology, Vol. 8, No. 3, pp. 1-9.

13. Beigh, I., & ul Haq, M. Z. (2024). A review of geopolymer concrete incorporating recycled aggregates,https://pubs.aip.org/aip/acp/article/3050/1/030004/3262669/A-review-of-geopolymer-concrete-incorporating (AIP Publishing)

14. Bhikshma, V., & Naveenkumar, T. (2014). Mechanical properties of fly ash-based geopolymer concrete with addition of GGBS. Proceedings of the Second International Symposium on Advances in Sustainable Engineering and Construction (ASEA-SEC 02) (pp. 183-188).

15. Bismi, M. B., Buhari, A. J., Anoop, S., & Muzammi, M. M. (2022), GeoPolymer Concrete Slab with Bamboo Reinforcement. *International Journal of Engineering Research & Technology (IJERT)*, 11(06). Retrieved from http://www.ijert.org

16.Bui, Q.-B., et al. (2017). A bamboo treatment procedure: Effects on the durability and mechanical performance.

17. Diaz-Loya, E. I., Allouche, E. N., & Vaidya, S. (2011). Mechanical Properties of Fly-Ash-Based Geopolymer Concrete.

18. Esparham, A., & Ghalatian, H. (2022), "Recent Progress in Geopolymer Concrete Technology: A Review."

19. Foo, S. T. et.al.(2018), Influence of alkali treatment on physico-chemical properties of Malaysian bamboo fibre

20. Ganta, K. B., et al. (2023). Performance studies on quaternary blended Geopolymer concrete. ELSEVIE

21. Ghavami, K. (2005). Bamboo as reinforcement in structural concrete elements. *Cement and Concrete Composites*, *27*(6), 637-649.

22. Ghavami, K. (2018). Bamboo as reinforcement in structural concrete elements. *Cement & Concrete Composites*. Retrieved from http://www.elsevier.com/locate/cemconcomp.

23. Goh, Z. Q. (2022). Chemically treated bamboo with sodium hydroxide and potassium hydroxide.. Haque, M. E. et.al (2021). Mechanical and bond properties of geopolymer-bamboo composites. Journal of Building Engineering, 44, 102955., 14(3), 44-49.

24. Rahim, N. L., et al. (2020). Investigation of bamboo as concrete reinforcement in the construction for low-cost housing industry. IOP Conference Series: Earth and Environmental Science, 476, 012058

25. Rajini, B., Narasimha Rao, A. V., & Sashidhar, C. (2020). Cost analysis of Geopolymer Concrete (GPC) over conventional concrete. *International Journal of Civil Engineering and Technology*, Volume

26.Ruy A. et.al Geopolymer Reinforced with Bamboo for Sustainable Construction Materials (2022).

27. Saba, N., Paridah, M. T., Jawaid, M., & Al-Oqla, F. M. (2016). Mechanical, morphological and thermal properties of kenaf fibrous biocomposite: An overview. Materials & Design, 103, 308-323

28. Santos, J. A., & Silva, F. A. (2019). Performance Assessment on Bamboo Reinforced Concrete Beams. *Construction and Building Materials*, 211, 1–8. DOI: 10.1016/j.conbuildmat.2019.03.019

29. Sánchez Vivas, L., Mullins, G., Cunningham, J. A., & Mihelcic, J. R. (2019). Mechanical properties of bamboo: A research synthesis of strength values and the factors influencing them, *Journal of the American Bamboo Society*, 33(1), 1-14.