Experimental Study on Strength and Durability of Bamboo Reinforced Concrete Beams

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Abstract - *The present study reports the flexural strength of BRC (Bamboo Reinforced Concrete) beams and the durability of bamboo as structural reinforcement. In this study, normal bamboo and modified bamboo were used in 1.25% and 2.50% as reinforcement in the beams. Also, bamboo splints without coating and with bitumen coating were dipped in normal water, magnesium sulphate and potassium chloride solution for an alternate wetting and drying of 7,14,28,56 and 72 cycles for the durability analysis. Flexural strength of the BRC beams was studied after 7,14,28 days of curing. Durability of the bamboo was determined through Tensile strength test.*

From the results, it is found that the flexural strength of the modified bamboo reinforced beams with 2.50% reinforcement carried more load than the normal concrete beams and untreated bamboo reinforced beams. The Tensile strength of the bamboo splint got reduced after 56 cycles and 72 cycles of alternate wetting and drying in magnesium sulphate and potassium chloride solutions.

It could be concluded that bamboo can be used as an alternative material to the rebars in low cost housing projects. Treated bamboo is more efficient and economical in the low-cost housing projects. Suitable treatment must be done for bamboo rebars, if incase it is to be used in coastal areas.

Key Words: **Bamboo reinforced concrete beams, Bamboo splints, Magnesium sulphate solution, Potassium chloride solution, Flexural strength, Tensile strength**.

1. INTRODUCTION

A large portion of India's population is homeless owing to the inadequacy of providing suitable residential systems. In cities of India, citizens dwelling on roadside is common site to watch. To provide homes for this large population, making concrete would be a challenge

It is discovered that concrete has great strength in compression but lacks strength of tension. So, steel rebars are widely used as reinforcement in concrete matrix to take care of the tensile stresses. Steel rebars production is expensive and its utilization in concrete matrix as reinforcement increases building costs through many folds. Steel production also liberates abundant quantity of greenhouse gases such aCO_2, Sulphur, Methane etc.. Causing significant environmental pollution. It was in favor of bamboo when comparing embodied energy and CO_2 footprint during the production of bamboo and steel.

The above-mentioned socio-economic and environmental variables create a need to find suitable eco-friendly and inexpensive material that can effectively replace steel as reinforcement in concrete components of low-cost housing. In addition to releasing O_2, every piece of bamboo production consumes at least a tone of global CO_2. Bamboo has been used from the ancient times as a structural material from a structural point of perspective because it has great flexural (bending) and strength in tension as well as a strong S/W (Strength to Weight) ratio. All of this requires a detailed examination of bamboo-reinforced cement concrete for its suitability as a structural material for a low-cost dwelling unit construction.

2. OBJECTIVES

The primary objectives are to study:

- The flexural strength of BRC beams with variation in percentage of reinforcement and coating on bamboo.
- To determine the durability of bamboo for suitability in marine condition by alternate wetting and drying the splints in water, magnesium sulphate solution and potassium chloride solution.

3. EXPERIMENTAL PROGRAM

As the study is inclined towards the low-cost housing elements, the chosen materials of construction and the treatment should be cheaper with locally available material and should not demand high skilled labors. Inexpensive treatments such as: Coating the bamboo with bitumen are less effective due to reduction in bond strength and on the other hand, costly treatments such as epoxy coating hampers the economy.

So, in order to enhance the bond between concrete and bitumen coated bamboo, coarse sand was sprinkled over the coated bamboo surface.

3.1 Materials

Approximately 4-year-old naturally grown 10 m long two bamboo culms of Pannangi variety from forest of Bangalore-

Tamil Nadu (India) were used in present experiment. The outer diameter of the culm used was ranged between 30-50 mm at the base with average node spacing of 350mm. The culms were then chopped to the splints of size 450mm in length, 25mm in width and thickness in size of the wall thickness of bamboo. The chopped splints shown in Figure-1 were utilized as reinforcement in beams.

Fig -1: Bamboo splints chopped for reinforcement in beams

Thirty-six well-seasoned, defect free and randomly chosen splints were purchased from local market.

53 grade Ordinary Portland cement with ISI mark was used for concrete. Crushed stone sand with specific gravity of 2.66, fineness modulus of 2.92, water absorption of 2%, bulk density of 1716 kg/m^3 was used. The crushed stone sand belonged to Zone-II gradation based on IS:383-2016.20 mm downsize coarse aggregates were obtained from the local stone crusher with granite origin. The specific gravity of coarse aggregate is 2.68 and water absorption was found out to be 0.2%. Potable water with pH of 7.1 was used.

The concrete mix used was M20 with mix proportion of 1:1.4:3.1(Cement: Fine Aggregate: Coarse Aggregate) with w/c ratio of 0.5 being adopted and is shown in Table-1. The mix design was done as per IS:10262-2009. The concrete was prepared using the above ingredients to investigate the flexural strength of bamboo reinforced concrete beams. The compressive strength values of the designed concrete mix, determined as per the test procedures mentioned in IS:516-1959 are 13.53 N/mm^2 for 7 days of curing, 19.63 N/mm^2 for 14 days of curing and 26.46 N/mm^2 for 28 days of curing.

Table-1: Concrete mix design quantities

Concrete mix design Grade of concrete = M20 F_{ck}= 20Mpa (All the quantities for 1m^3 volume of concrete)				
Materials	Water	Cement	Fine Aggregate	Coarse Aggregate
Quantities	191.6 ltrs	383.0 kg	546.0 kg	1188 kg
Mix design	1:1.4:3.1		W/C ratio = 0.5	

Tensile strength of bamboo

The tensile test specimens were prepared from culms of bamboo of Pannangi variety. Whole bamboo was divided along its length into bamboo splints. Such splints from different portions of culms of length 450mm were used for the tensile strength tests. Aluminum tabs of 3mm thickness were firmly pasted with industrial adhesive on either side of the bamboo specimen to avoid crushing in the jaws. The digital universal testing machine (UT100) of 1000KN capacity was used for the experimental program. The test specimen details are shown in Figure-2a and 2b.

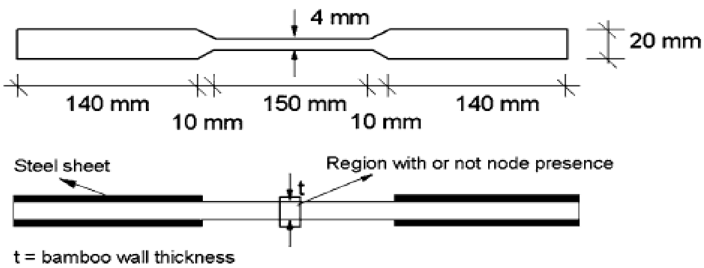


Fig-2a: Specimen detailing for tensile test

Fig-2b: Tensile test specimen in jaws of UTM(UT100)

It was also intended to compare the tensile strength of bamboo along with its other mechanical properties with mild steel (Fe-250) and thermo mechanically treated (TMT) steel. The average results of mechanical properties of bamboo and steel are presented in

Table-2.

Table-2: Mechanical properties of bamboo and M-Steel

Mechanical property	Mild steel (Fe250)	TMT steel	Bamboo
Unit weight, kN/m^3	77.00	77.00	8.82
Young's modulus, MPa	2×10^5	2×10^5	0.20×10^5
Ultimate tensile stress, MPa	400	560	321
Percentage elongation, %	23	16	1.27

The bamboo specimen from the internodes of bottom and middle region resulted into optimum tensile strength and hence the tensile strength was 153 MPa.

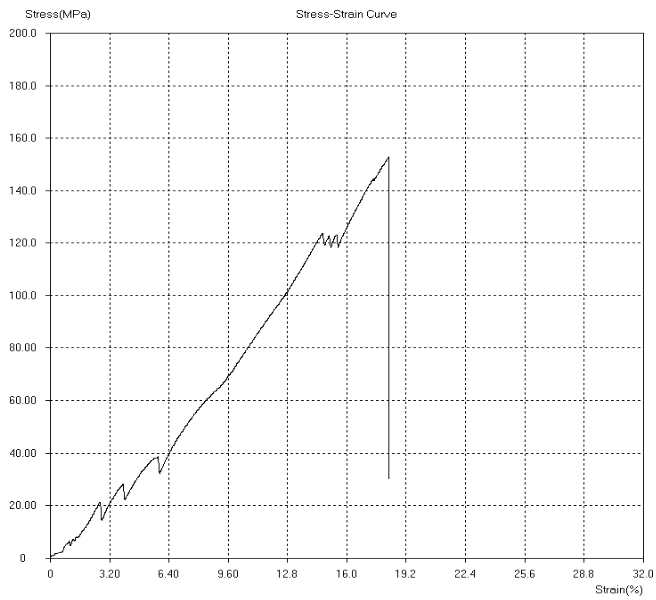


Fig 3: Stress-Strain curve of Bamboo Splint

3.2 Sample Preparation and Test methods

A) Preparation of Beam specimens for flexural test

In this study, 24 beam specimens were casted to study the variation in flexural strength of the bamboo reinforced beams. The Table-3 gives the information about the bamboo reinforced concrete beam details. The beams were casted in 4 set of different specification viz: normal concrete beams, beams reinforced with untreated bamboo, beams reinforced with bitumen coated bamboo, beams reinforced with plywood polymer coated bamboo. The plywood polymer being used is shown in Figure-4 below. The bamboo splints were placed in 1.25% and 2.50% as reinforcement. The beams size was 500mm in length and 100mm width and 100 mm depth with 20-25mm as cover to the bamboo reinforcement. Figure-5,6,7,8,9,10 shows the beam specimens casted in laboratory.

Fig-4: Pidilite plywood-based polymer coat as waterproofing for bamboo reinforcement

Fig-5: Placement of 1.25% of Uncoated Bamboo reinforcement in beam mould

Fig-6: Placement of 1.25% of Uncoated Bamboo reinforcement in beam mould

Table-3: Bamboo reinforced concrete beams details

BAMBOO SPECIMEN ADOPTED	ABBREVATIONS	% RFTMNT	COVER (mm)	RFTMNT DIMENSION (mm)
Unreinforced Beams	URB-1	1.25 and 2.5	20	450x25x5
	URB-2	1.25 and 2.5	20	450x25x5
	URB-3	1.25 and 2.5	20	450x25x5
Bamboo reinforced beams	BRB-1	1.25 and 2.5	20	450x25x5
	BRB-2	1.25 and 2.5	20	450x25x5
	BRB-3	1.25 and 2.5	20	450X25x5
Modified Bamboo reinforced beams (Bitumen coating with coarse sand sprinkled on top)	MBBRB-1	1.25 and 2.5	20	450x25x5
	MBBRB-2	1.25 and 2.5	20	450x25x5
	MBBRB-3	1.25 and 2.5	20	450x25x5
Modified Bamboo reinforced beams (Polymer Coating with coarse Sand sprinkled on top)	MEBRB-1	1.25 and 2.5	20	450x25x5
	MEBRB-2	1.25 and 2.5	20	450x25x5
	MEBRB-3	1.25 and 2.5	20	450x25x5

Fig-7: Polymer based Plywood coating being applied on splint

Fig-8: Coarse Sand sprinkled on top of Coated Bamboo Specimen

Fig-9: Hardened Beam specimens

Fig-10: Hardened Beam specimens ready for testing

The beams were demoulded and were cured by water immersion at laboratory temperature, for a period of 28 days. The instrumentation for the flexural strength test is shown in Figure-11. As shown in the setup, the samples were positioned with required spacing intervals, and load setup was fixed on top of beam, with a load indicator, which denotes the load attained. The loading method was load control measurement.

Fig-11: Flexural testing of Bamboo reinforced beam Specimen

B) Preparation of bamboo splints for durability analysis

The uncoated bamboo with node and node-free splints, bitumen-coated bamboo splints with node and node-free in the center were dipped in normal water, magnesium sulphate and potassium chloride solution for alternative cycles of drying and wetting. The alternative drying and wetting was performed as 1 cycle per day i.e. 12 hours drying from morning till evening and 12 hours wetting from evening till morning till next day. In this investigation 7th, 14th, 28th, 56th and 72nd alternate wetting and drying cycles were performed for the durability analysis.

Table-4: Details of uncoated splints dipped in water

SPECIMENS DIPPING IN NORMAL WATER				
SPECIMEN	LENGTH in MM	WIDTH in MM	THICKNESS in MM	C/S AREA in MM^2
W-1	500	25	5	125
W-2	500	25	5	125
W-3	500	25	5	125
W-4	500	25	5	125
W-5	500	25	5	125
W-6	500	25	5	125
W-7	500	25	5	125
W-8	500	25	5	125
W-9	500	25	5	125
W-10	500	25	5	125
W-11	500	25	5	125
W-12	500	25	5	125
W-13	500	25	5	125
W-14	500	25	5	125
W-15	500	25	5	125

Table-5: Details of uncoated splints dipped in Potassium chloride solution

SPECIMENS DIPPING IN SOLUTION OF KCl at CONCENTRATION OF 33g/l				
SPECIMEN	LENGTH in MM	WIDTH in MM	THICKNESS in MM	C/S AREA in MM2
K-1	500	25	5	125
K-2	500	25	5	125
K-3	500	25	5	125
K-4	500	25	5	125
K-5	500	25	5	125
K-6	500	25	5	125
K-7	500	25	5	125
K-8	500	25	5	125
K-9	500	25	5	125
K-10	500	25	5	125
K-11	500	25	5	125
K-12	500	25	5	125
K-13	500	25	5	125
K-14	500	25	5	125
K-15	500	25	5	125

Table-6: Details of uncoated splints dipped in Magnesium sulphate solution

SPECIMENS DIPPING IN SOLUTION OF MgSO4 at CONCENTRATION OF 33g/l				
SPECIMEN	LENGTH in MM	WIDTH in MM	THICKNESS in MM	C/S AREA in MM2
M-1	500	25	5	125
M-2	500	25	5	125
M-3	500	25	5	125
M-4	500	25	5	125
M-5	500	25	5	125
M-6	500	25	5	125
M-7	500	25	5	125
M-8	500	25	5	125
M-9	500	25	5	125
M-10	500	25	5	125
M-11	500	25	5	125
M-12	500	25	5	125
M-13	500	25	5	125
M-14	500	25	5	125
M-15	500	25	5	125

The above tables-4,5,6 gives the details of the splints dipped in normal water, potassium chloride solution, magnesium sulphate solution. Similarly, the bitumen coated splints were also dipped in the normal water, Potassium chloride solution, Magnesium sulphate solution for the test. The bitumen coated splints are abbreviated as: WB-Bitumen coated splints dipped in water, KB-Bitumen coated splints dipped in potassium chloride solution, MB- Bitumen coated splints dipped in magnesium sulphate solution.

Fig-12: Bamboo splints ready for bitumen coating

Fig-13: Bitumen coated bamboo splints

Fig-14: Bamboo splints dipped in solution

Fig-15: Uncoated bamboo splints drying in sunlight

Fig-16: Bitumen coated bamboo splints drying in sunlight

Fig-17: Tensile testing of bamboo splint subjected to alternate wetting and drying

The tensile test was carried out after 0^{th}, 7^{th}, 14^{th}, 28^{th}, 56^{th}, 72^{nd} cycles of alternate wetting and drying. Afterwards, they were tested in a controlled machine with maximum capacity of 1000KN at a constant load rate of about 2KN/min. The applied load and specimen strains were measured by a stress transducer and a clip gauge. The data reading was fed to a data acquisition system in a frequency of 10Hz during the entire test and stored on hard disk.

4. RESULTS AND DISCUSSIONS

4.1 FLEXURAL STRENGTH OF BRC BEAMS

A) Flexural strength results of 1.25% reinforced beams

Table-7: Results of flexural test for 1.25% of bamboo reinforcement

SPECIMEN DETAILS	ABBREVATIONS	CURING DAYS	ULTIMATE FAILURE LOAD in KN	BEAMS FLEXURAL STRENGTH IN N/mm^2
Unreinforced Beam	URB-1	7 Days	0.2	0.1
	URB-2	14 Days	0.6	0.29
	URB-3	28 Days	5	2.47
Bamboo Reinforced Beam	BRB-1	7 Days	14.5	7.17
	BRB-2	14Days	15.1	7.425
	BRB-3	28Days	16.3	8.06
Modified Bamboo reinforced beams (Bitumen Coating with Coarse sand)	MBBRB-1	7 Days	15.2	7.52
	MBBRB-2	14Days	16.14	8.08
	MBBRB-3	28Days	19.5	9.625
Modified Bamboo reinforced beams (Polymer Coating with Coarse sand)	MEBRB-1	7 Days	16.3	8.06
	MEBRB-2	14Days	17.63	8.72
	MEBRB-3	28Days	20.42	10.1

B) Flexural strength results of 2.50% reinforced beams

Table-8: Results of flexural test for 2.50% of bamboo reinforcement

SPECIMEN DETAILS	ABBREVATIONS	CURING DAYS	ULTIMATE FAILURE LOAD IN KN	BEAMS FLEXURAL STRENGTH IN N/mm^2
Unreinforced	URB-1	7 Days	0.2	0.1
	URB-2	14 Days	0.6	0.29
	URB-3	28 Days	5	2.47
Bamboo Reinforced	BRB-1	7 Days	13.6	6.85
	BRB-2	14Days	20.2	10.12
	BRB-3	28Days	25.6	12.82
Modified Bamboo reinforced beams (Bitumen Coating with Coarse sand)	MBBRB-1	7 Days	12.5	6.85
	MBBRB-2	14Days	22.8	11.35
	MBBRB-3	28Days	27.2	13.62
Modified Bamboo reinforced beams (Polymer Coating with Coarse sand)	MEBRB-1	7 Days	15.8	8.01
	MEBRB-2	14Days	25.6	12.9
	MEBRB-3	28Days	28.8	14.25

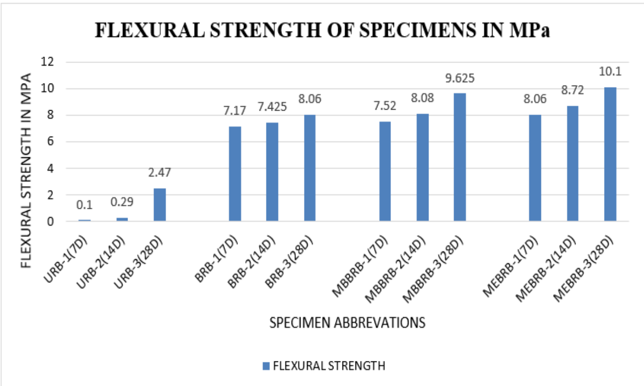


Chart-1: Flexural strength of different beam specimen with 1.25 % of reinforcement

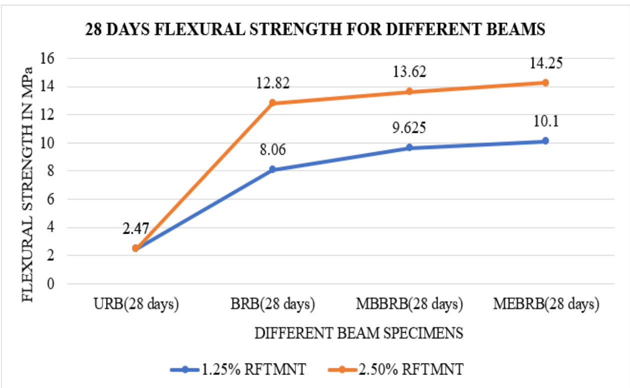


Chart-2: 28 days flexural strength of different beam specimen with varying % of reinforcement

The experimental values shown in Table-7,8 and Charts-1,2 offer us a clear concept that the beam strengthened with 2.50 percent bamboo reinforcement carries more load than the plain concrete beam and 1.25 percent bamboo strengthened beams. The uncoated bamboo strengthened beam's flexural failure load improved by 5.12 times that of unreinforced beam.

The beams containing modified bamboo reinforcement also carry more load than the reinforced beams of normal uncoated bamboo. The waterproofing covered bamboo strengthened beam's load carrying ability improved by 1.06 times that of uncoated bamboo strengthened beam.

The reason is that the modified bamboo strengthened beams contain covered bamboo with coarse sand sprinkled on top of bamboo reinforcement which provides better bonding between the concrete surrounding and bamboo reinforcement for load transfer. Also, it prevents the bamboo specimen from absorbing water. The flexural strength of the beams is improved by raising the proportion of reinforcement in beams

4.2 DURABILITY ANALYSIS OF BAMBOO AS REINFORCEMENT

A) RESULTS OF TENSILE STRENGTH OF BAMBOO WITHOUT ANY COATING

SPECIMENS DIPPED IN NORMAL WATER

Table-9: Results of tensile test for uncoated bamboo specimen dipped in water

SPECIMEN	NO OF CYCLES	INITIAL AVG TENSILE STRENGTH (Fi) AT 0 CYCLES IN MPa	ACTUAL TENSILE STRENGTH (Ft) IN MPa	LOSS OF TENSILE STRENGTH (Fi-Ft) IN MPa	% LOSS OF TENSILE STRENGTH (Fi-Ft)/Fi X100	AVERAGE %LOSS OF TENSILE STRENGTH
W-1	7	282	272.6	9.4	3.33	4.90
W-2	7		268.7	13.3	4.71	
W-3	7		263.3	18.7	6.63	
W-4	14	282	270.4	11.6	4.64	5.23
W-5	14		263.4	18.6	4.25	
W-6	14		255.3	26.7	6.80	
W-7	28	282	268.9	13.1	4.11	6.72
W-8	28		270	12	6.59	
W-9	28		262.8	19.2	9.46	
W-10	56	282	253.7	28.3	10.03	10.38
W-11	56		254.6	27.4	9.71	
W-12	56		249.8	32.2	11.4	
W-13	72	282	250.8	31.2	11.06	11.54
W-14	72		249.2	32.8	11.63	
W-15	72		248.3	33.7	11.95	

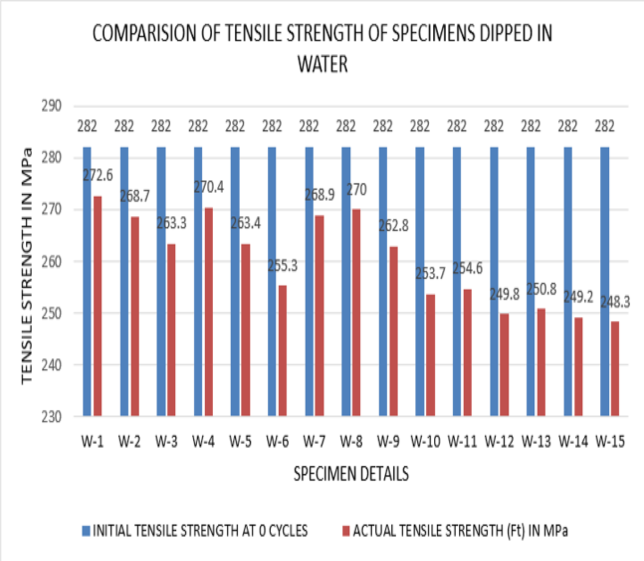


Chart-3: Variation of tensile strength in different specimens

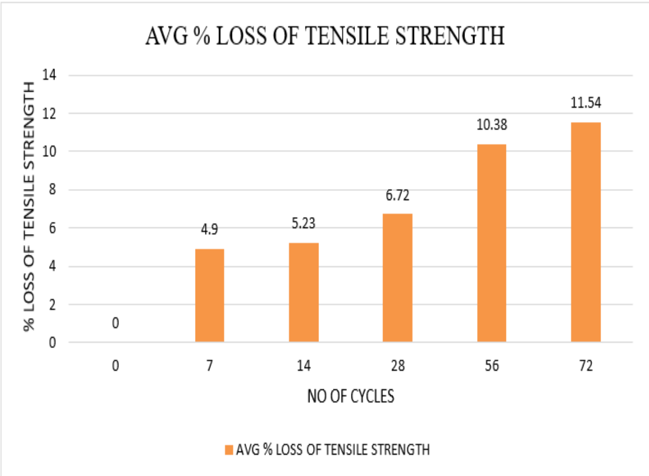


Chart-4: Average % Loss of tensile strength of specimens dipped in water with increasing no of cycles.

The above table-9 and chart-3,4 demonstrates the tensile strength of each of the bamboo splints for 7th ,14th ,28th ,56th and 72nd cycles. As the number of alternating wetting and drying cycles increases, one can see the tensile strength decreasing. This proves that the strength of the bamboo continues to degrade as it is subject to more wetting and drying cycles. As it continues to expand and shrink, it loses its fiber power and reduces the tensile strength of the entire bamboo splint.

SPECIMENS DIPPED IN MAGNESIUM SULPAHTE

Table-10: Results of tensile test for uncoated bamboo specimen dipped in magnesium sulphate solution

SPECIMEN	NO OF CYCLES	INITIAL AVG TENSILE STRENGTH (Fi) AT 0 CYCLES IN MPa	ACTUAL TENSILE STRENGTH (Ft) in MPa	LOSS OF TENSILE STRENGTH (Fi-Ft) IN MPa	%LOSS OF TENSILE STRENGTH (Fi-Ft)/Fi X100	AVERAGE % LOSS OF TENSILE STRENGTH
M-1	7	282	270.8	11.2	3.97	4.70
M-2	7		276.3	5.7	2.02	
M-3	7		259.2	22.6	8.08	
M-4	14	282	260.4	21.6	7.65	9.85
M-5	14		252.8	29.2	10.35	
M-6	14		249.4	32.6	11.56	
M-7	28	282	250.8	31.2	11.06	12.53
M-8	28		245.9	36.1	12.80	
M-9	28		243.2	38.8	13.75	
M-10	56	282	227.8	54.2	19.21	25.90
M-11	56		203.3	78.7	27.90	
M-12	56		195.7	86.5	30.60	
M-13	72	282	204.8	77.2	27.37	30.86
M-14	72		192.6	89.4	31.70	
M-15	72		187.5	94.5	33.51	

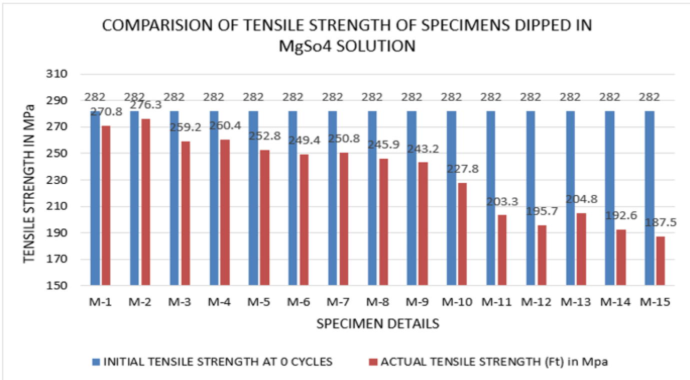


Chart-5: Variation of tensile strength in different specimens

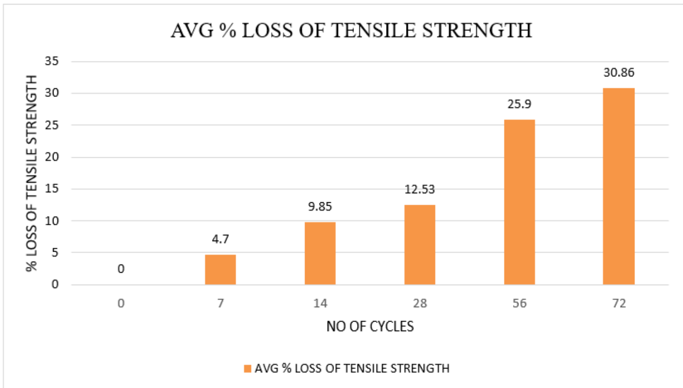


Chart-6: Average % Loss of tensile strength of specimens dipped in magnesium sulphate solution with increasing no of cycles.

The above table-10 and chart-5,6 demonstrates the tensile strength of each of the bamboo splints for 7th, 14th, 28th, 56th, 72nd alternate wetting and drying cycles in magnesium sulphate solution. As the number of alternate wetting and drying cycles increases, we can observe the tensile strength decreasing. This confirms that the bamboo strength goes on degrading as it is subjected to more cycles of wetting and drying.

Due to the affinity of magnesium to hydroxide ion (OH-), the magnesium sulphate solution is mildly acidic i.e. its pH is between 5.5 and 6.5. Hydroxide anions associate with magnesium as sulphate ion enters the solution, improving the relative ratio of hydrogen ion(H+) to hydroxide ion (OH-). This change results in a more acidic solution and it impacts the parenchyma of the fibre that is primarily accountable for the growth of bamboo fibre strength. It also loses its fibre strength as it continues to expand and shrink, leading to a reduction in the strength of the entire bamboo splint.

SPECIMENS DIPPED IN POTASSIUM CHLORIDE SOLUTION

Table-11: Results of tensile test for uncoated bamboo specimen dipped in potassium chloride solution

SPECIMEN	NO OF CYCLES	INITIAL AVG TENSILE STRENGTH (Fi) AT 0 CYCLES IN MPa	ACTUAL TENSILE STRENGTH (Ft) in MPa	LOSS OF TENSILE STRENGTH (Fi-Ft) IN MPa	%LOSS OF TENSILE STRENGTH (Fi-Ft)/Fi X100	AVERAGE % LOSS OF TENSILE STRENGTH
K-1	7	282	265.5	16.5	5.85	8.02
K-2	7		259.2	22.8	8.08	
K-3	7		253.4	28.6	10.14	
K-4	14	282	243.2	38.8	13.75	15.57
K-5	14		238.2	43.8	15.33	
K-6	14		232.2	49.2	17.44	
K-7	28	282	220.8	61.2	21.70	23.29
K-8	28		217.6	64.4	22.83	
K-9	28		210.5	71.5	25.35	
K-10	56	282	212.5	69.5	24.64	26.95
K-11	56		206.7	75.3	26.70	
K-12	56		198.7	83.3	29.53	
K-13	72	282	195.7	86.3	30.60	30.50
K-14	72		199.8	82.2	29.14	
K-15	72		192.4	89.6	31.77	

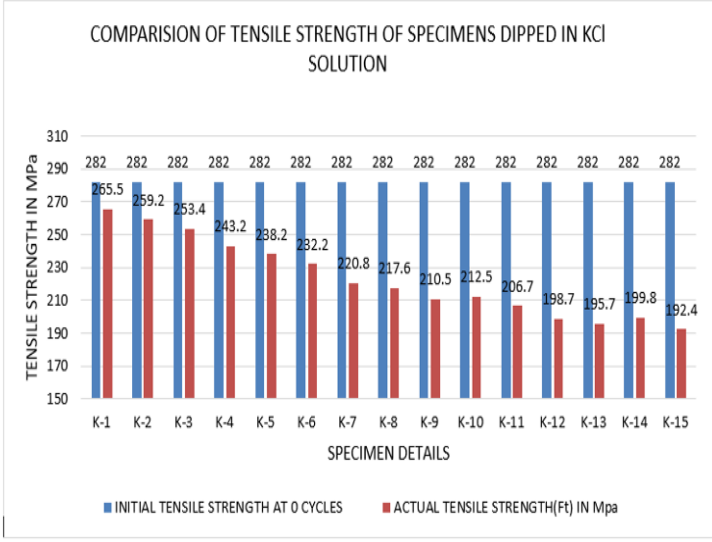


Chart-7: Variation of tensile strength in different specimens

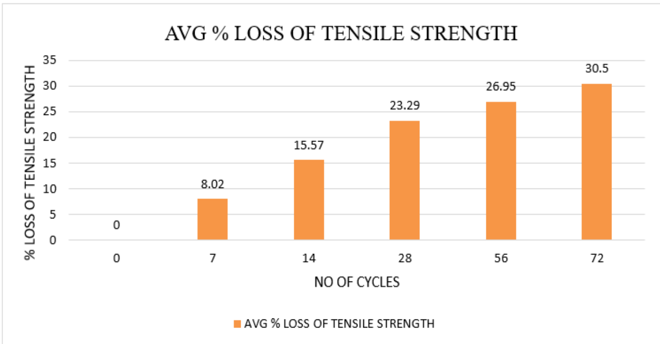


Chart-8: Average % Loss of tensile strength of specimens dipped in potassium chloride solution with increasing no of cycles.

The above table-11 and chart-7,8 shows the tensile strength of each of the bamboo splints in magnesium sulphate solution for 7th cycles, 14th cycles, 28th cycles , 56th cycles and 72nd cycles. As the number of alternate wetting and drying cycles increases, we can observe the tensile strength decreasing. This proves that the resistance of bamboo continues to degrade as we expose it to more and more wetting and drying cycles.

As a salt of powerful acid (HCl) and a powerful base (KOH), potassium chloride is neutral in nature, i.e. its pH is 7.0-7.2. However, owing to potassium affinity for hydroxide ion (OH-), it leaves behind some of the chloride ions that cause lipid breakage in the bamboo fibre parenchyma. The impact is damage in the parenchyma of fibre, which is primarily accountable for the growth of bamboo fibre strength. It also loses its fibre strength as it continues to expand and shrink, leading to a reduction in the strength of the entire bamboo splint.

RESULTS OF TENSILE STRENGTH OF BAMBOO WITH BITUMEN COATING

SPECIMENS DIPPED IN NORMAL WATER

Table-12: Results of tensile test for bitumen coated bamboo specimen dipped in water

SPECIMEN	NO OF CYCLES	INITIAL AVG TENSILE STRENGTH (Fi) AT 0 CYCLES IN MPa	ACTUAL TENSILE STRENGTH (Ft) IN MPa	LOSS OF TENSILE STRENGTH (Fi-Ft) IN MPa	% LOSS OF TENSILE STRENGTH (Fi-Ft)/Fi X100	AVERAGE %LOSS OF TENSILE STRENGTH
WB-1	7	295	285.6	9.4	3.18	4.67
WB-2	7		281.7	13.3	4.50	
WB-3	7		276.3	18.7	6.33	
WB-4	14	295	282.3	12.7	4.30	5.96
WB-5	14		276.5	18.5	6.27	
WB-6	14		273.4	21.6	7.32	
WB-7	28	295	269.5	25.5	8.64	9.88
WB-8	28		265.4	29.6	10.03	
WB-9	28		262.4	32.4	10.98	
WB-10	56	295	270.5	24.5	8.30	10.48
WB-11	56		262.5	32.5	11.01	
WB-12	56		259.2	35.8	12.13	
WB-13	72	295	269.5	25.5	8.64	11.85
WB-14	72		258.3	36.7	12.44	
WB-15	72		252.3	42.7	14.47	

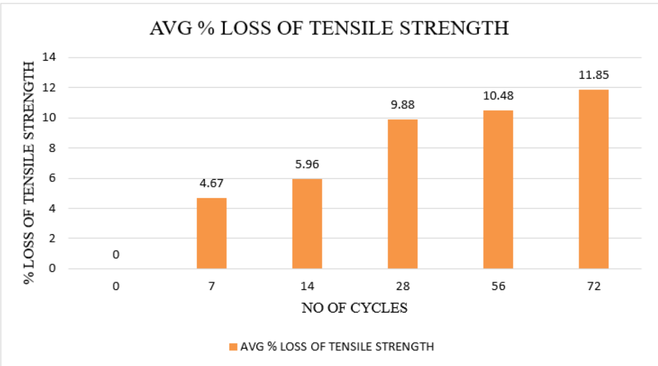


Chart-9: Average % Loss of tensile strength of specimens dipped in normal water with increasing no of cycles.

The above table-12 demonstrates the tensile strength of each of the bitumen-coated bamboo splints for 7th ,14th, 28th ,56th, 72nd cycles. As the number of alternating wetting and drying cycles increases, we can see the tensile strength decreasing. This proves that the strength of the bamboo continues to degrade as we subject it to more wetting and drying cycles. The reason is that the bamboo absorbs water, increases its volume size and shrinks when drying. As it continues to expand and shrink, it loses its fibre power and reduces the force of the entire splint. We can also see that the bitumen-coated bamboo splint and uncoated bamboo splint had the same power of tensile as the uncoated one.

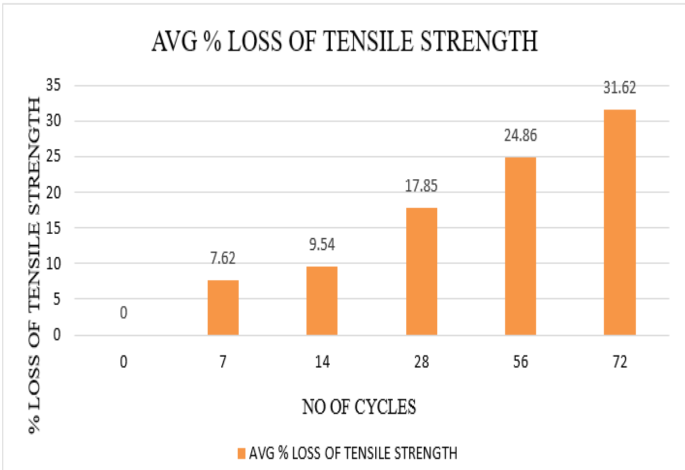
Chart-9 obviously shows us that at 56 and 72 cycles of alternating wetting and drying, the bamboo splint loses 10.48 percent and 11.85 percent of its original tensile strength. In 56 cycles and 72 cycles, there is not much loss of tensile strength compared to other cycles.

SPECIMENS DIPPED IN MAGNESIUM SULPAHTE

Table-13: Results of tensile test for bitumen coated bamboo specimen dipped in magnesium sulphate solution

SPECIMEN	NO OF CYCLES	INITIAL AVG TENSILE STRENGTH (Fi) AT 0 CYCLES IN MPa	ACTUAL TENSILE STRENGTH (Ft) in MPa	LOSS OF TENSILE STRENGTH (Fi-Ft) IN MPa	%LOSS OF TENSILE STRENGTH (Fi-Ft)/Fi X100	AVERAGE % LOSS OF TENSILE STRENGTH
MB-1	7	295	272.2	22.8	7.72	7.62
MB-2	7		269.5	25.7	8.64	
MB-3	7		275.8	19.2	6.50	
MB-4	14	295	270.8	24.2	8.20	9.54
MB-5	14		267.9	27.1	9.18	
MB-6	14		261.8	33.2	11.25	
MB-7	28	295	245.6	49.4	16.74	12.86
MB-8	28		243.2	51.8	17.56	
MB-9	28		238.2	56.8	19.25	
MB-10	56	295	228.2	66.8	22.68	24.86
MB-11	56		221.2	73.8	25.01	
MB-12	56		215.6	79.4	26.91	
MB-13	72	295	210.8	84.2	28.54	31.62
MB-14	72		198.9	96.1	32.57	
MB-15	72		195.4	99.6	33.76	

Chart-10: Average % Loss of tensile strength of specimens dipped in magnesium sulphate solution with increasing no of cycles.



The above table-13 and chart-10 shows the tensile strength of each of the coated bamboo splines in magnesium sulphate solution for 7,14,28,56,72 cycles. As the no of alternate wetting and drying cycles increases, we can observe the tensile strength decreasing. This proves that the resistance of bamboo continues to degrade as we expose it to more and more wetting and drying cycles.

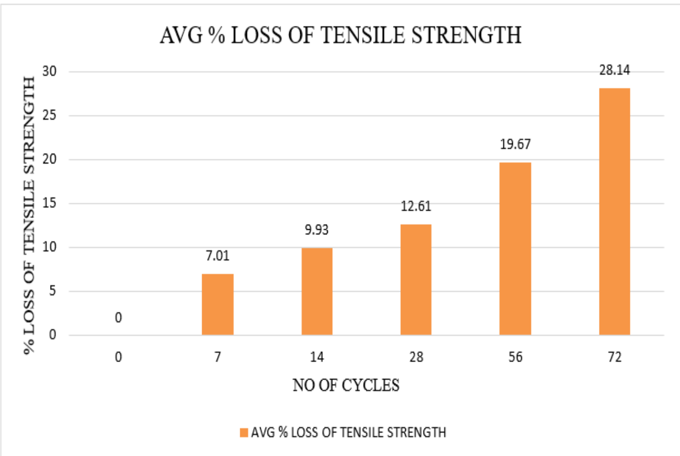
Chart-10 obviously shows us that at 56 and 72 cycles of alternate drying and wetting, the bitumen-coated bamboo splint loses 24.86 percent and 31.62 percent of its original tensile strength.

SPECIMENS DIPPED IN POTASSIUM CHLORIDE SOLUTION

Table-14: Results of tensile test for bitumen coated bamboo specimen dipped in potassium chloride solution

SPECIMEN	NO OF CYCLES	INITIAL AVG TENSILE STRENGTH (Fi) AT 0 CYCLES IN MPa	ACTUAL TENSILE STRENGTH (Ft) in MPa	LOSS OF TENSILE STRENGTH (Fi-Ft) IN MPa	%LOSS OF TENSILE STRENGTH (Fi-Ft)/Fi X100	AVERAGE % LOSS OF TENSILE STRENGTH
KB-1	7		282.5	12.5	4.23	
KB-2	7	295	275.5	19.5	6.61	7.01
KB-3	7		264.9	30.1	10.20	
KB-4	14		271.4	23.6	8.0	
KB-5	14	295	265.4	29.6	10.03	9.93
KB-6	14		260.3	34.7	11.76	
KB-7	28		262.3	32.6	11.050	
KB-8	28	295	258.4	36.6	12.40	12.61
KB-9	28		252.4	42.6	14.40	
KB-10	56		249.4	45.6	15.45	
KB-11	56	295	232.8	62.2	21.08	19.67
KB-12	56		228.6	66.4	22.50	
KB-13	72		219.9	75.1	25.45	
KB-14	72	295	210.6	84.4	28.61	28.14
KB-15	72		205.4	89.6	30.37	

Chart-11: Average % Loss of tensile strength of specimens dipped in potassium chloride solution with increasing no of cycles.



The above table-14 shows the tensile strength of each of the coated bamboo splints for 7^{th} ,14^{th} ,28^{th} ,56^{th} ,72^{nd} cycles in potassium chloride solution. As the number of alternating wetting and drying cycles increases, we can see the tensile strength decreasing. This proves that the resistance of bamboo continues to degrade as we expose it to more and more wetting and drying cycles.

Chart-11 shows us that at 56 and 72 cycles of alternate wetting and drying, the bitumen-coated bamboo splint loses 19.67 percent and 28.14 percent of its original tensile strength.

5. CONCLUSIONS

The findings below are taken from the above outcomes of the bamboo strengthened beam flexural strength test.

- The ultimate failure load and the strength in flexure of the unreinforced beams are 5KN and 2.47N/mm2, which is comparatively smaller than the Bamboo reinforced beams.
- Reinforcing beams with 1.25% bamboo improved beam load carrying ability relative to unreinforced beams.
- The load carrying capability of standard bamboo reinforced beams improved by 3.26 times compared to unreinforced beams.
- Furthermore, the load carrying ability improved by 16% when the bamboo was sprinkled on top with bitumen and coarse sand.
- The load carrying capacity increased by 4.5% when polymer was used as coating instead of bitumen coating.
- Reinforcing the beams with 2.5 percent bamboo improved the load carrying capacity of the beam compared to unreinforced beams and 1.25 percent reinforced one's.
- The load capability of standard bamboo strengthened beams improved by 5.2 times compared to unreinforced beams.
- Also, the load carrying capacity increased by 80.73% when the bamboo was coated with bitumen and coarse sand was sprinkled on top.
- The load carrying capacity increased by 4.42% when polymer was used as coating instead of bitumen coating.
- Modifying the bamboo reinforcement with bitumen coating and epoxy coating with coarse sand reduced the water absorption capacity of the bamboo.
- This increase in capacity of the modified BRC (Bamboo Reinforced Concrete) beams is due to the improved bonding between the surrounding concrete and the sand particles sprinkled.

The following findings of the durability assessment are derived from the above outcomes of the bamboo splints tensile strength test dipped into distinct alternatives.

- As the number of wetting and drying cycles increased, the tensile strength gradually decreased to a maximum of 30.86% of the initial tensile strength, in case of uncoated bamboo splints.
- Also, the tensile strength gradually decreased to a maximum of 31.86% of the initial tensile strength, in case of bitumen coated bamboo splints.

The findings below are derived from the impact of node on tensile strength from the above outcomes for bitumen-coated bamboo splints.

- The node at the centre of bamboo splints gradually decreased the tensile strength of the splints dipped in various alternatives.
- Bamboo culm is a region where the fibres are folded and complicated in the wild. This enhances the splints ' fragile behaviour.

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