BAMBOO AS A GREEN ALTERNATIVE TO STEEL FOR REINFORCED CONCRTE ELEMENTS OF A LOW-COST RESIDENTIAL BUILDING

PROJECT REPORT SUBMITTED IN THE PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

UNDER THE SUPERVISION OF

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BY

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TO

DEPARTMENT OF CIVIL ENGINEERING

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY,

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SYMBOLS & ACRONYMS

Symbol/Abbreviation **Description**

ϵ..Strain

σ..Stress

σ_1..Major principle stress

σ_2..Minor principle stress

τ..Shear stress

θ..Inclination of principle planes

E ....Young's modulus of elasticity

f_b ....Modulus of rupture

f_{ck} ....Characteristic compressive strength of concrete

γ_w ....Specific density of water

Δ ....Elongation/Displacement

a ....Distance between line of fracture and nearest support

BMD ....Bending Moment Diagram

PCC ....Plain Cement Concrete

BRCC ....Bamboo Reinforced Cement Concrete

MBRCC.......................................Modified Bamboo Reinforced Cement Concrete

(V)

CERTIFICATE

This is to certify that project report entitled **"BAMBOO AS A GREEN ALTERNATIVE TO STEEL FOR REINFORCED CONCRETE ELEMENTS OF A LOW-COST RESIDENTIAL BUILDING",** submitted by **ANKIT SINGH MEHRA-111684** in the partial fulfillment for the award of degree of Bachelor of Technology in Civil Engineering, to Jaypee University Of Information Technology, Waknaghat, has been carried out under our supervision.

This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

Dr. Rajiv Ganguly	**Prof. Ashok Kumar Gupta**
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(VI)

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Signature...........................

Date..................................

(VII)

ABSTRACT

The project is focused on finding out the feasibility and reliability of using bamboo as a reinforcing material in concrete structures by investigating the various physical and mechanical properties of bamboo and plain cement concrete beams reinforced with bamboo splints, by conducting a variety of laboratory test like-density test, initial moisture content test, water absorption test, tension test, compression test, durability test and IS 516:1959 Third Point Loading Flexure Test.

The test were conducted on the specially crafted specimen of 3-4 years old air dried bamboo culm of "Bambusa-Bamboo" specie, purchased from the local market of Shimla, Himachal Pradesh .The observations and results were reported and analyzed in form of figures, tables and graphs as required.

The mass specific density of bamboo came in the range of 0.57-0.85. The initial moisture content of bamboo splints comes out between 7%-13.5% .The water absorption capacity of bamboo splint comes out to be as high as 59.23% by weight of saturated sample after 30 days of complete immersion in water. The compressive strength of bamboo culm came out as high as 84.58Mpa for specimen with 0 internode and 90.72Mpa for specimen with 1 internode. The tensile strength of bamboo comes out to be as high as 298.33Mpa, most of the specimen of tension test failed at node showing that node is the most critical failure section of bamboo clum under tensile loads. The stress-vs.-curve in tension was plotted which shows that bamboo is a visco-elastic material. Durability test performed on bamboo splints shows that bamboo splints looses almost 25% of their ultimate tensile strength when they undergo alternate swelling and shrinking in presence of humidity, alkalinity and chlorides. IS 516:1959 Third Point Loading Flexure Test on plain cement concrete beams singly and doubly reinforced with bamboo splints shows that, the load carrying capacity of plain cement-concrete beams increased by 2.3 times to 3.8 times, the modulus of elasticity of beams got increased by 1.66 times to 2.21 times, the modulus of rupture of beams got increased by 2.33 times to 4.60 times, on reinforcing the beams with

bamboo splints. Significant amount of deflections were observed in the beams reinforced with bamboo splints, before ultimate failure, hence reinforcing concrete beams with bamboo splints imparted sufficient ductility to the beams preventing sudden brittle failure at ultimate loads.

1. INTRODUCTION

1.1 General

A big part of population in India is still homeless due to raising unaffordability of housing structures. People sleeping on roadsides and living in slums is a common sight in Indian cities. To overcome this problem India today needs millions of houses for their growing population, making concrete as the most widely to be used material in the country.

Concrete has found to have excellent compressive strength but poor in tensile strength, to take care of the tensile stresses steel is commonly used as reinforcing material in concrete. Production of steel is a very costly business and its use in concrete as reinforcing material increases the cost of construction by many folds. Also production of steel emits a large amount of green house gases causing considerable deterioration of the environment.

The above mentioned socio-economic and environmental factors creates a necessity for finding an appropriate environment friendly and cheap material that can successfully substitute steel as reinforcement in concrete elements of a low cost dwelling for the poor and homeless people of the country.

It is here that engineered bamboo can be of great value to Civil Engineers owning to its several net worthy features. Production of every tone of bamboo consumes about a tone of atmospheric CO_2 in addition to releasing fresh O_2. From structural point of view bamboo has been used as a structural material from the earlier times as it possesses excellent flexure and tensile strength as well as high strength to weight ratio.

The use of bamboo for housing is perhaps as old as mankind; however the superior strength and mechanical properties of bamboo and its potential use as reinforcement for cement matrices started at the beginning of 20th century. This was followed by several field experiments in China. It is known that during world war-II, the Americans and

Japanese armed forces had used bamboo as reinforcement in emergency military concrete structures.

All this necessitates examining bamboo in detail for its appropriateness as a structural material for construction of a low cost dwelling unit.

1.2 Bamboo

Bamboo is a versatile, strong, renewable and environmental friendly material. It is a member of the grass family, *Gramineae* and the fastest growing plant on earth. Most bamboo species produce mature fiber in 3 years, sooner than any other tree species. Some bamboo grows up to 1 meter in a day, with many reaching culm lengths of 25 meter or more. Bamboo can be grown quickly and easily and sustainably harvested in 3 to 5 years cycle. It grows on marginal and degradable land, elevated ground, along with acting as a soil stabilizer it is also helps to counter the green house effect.

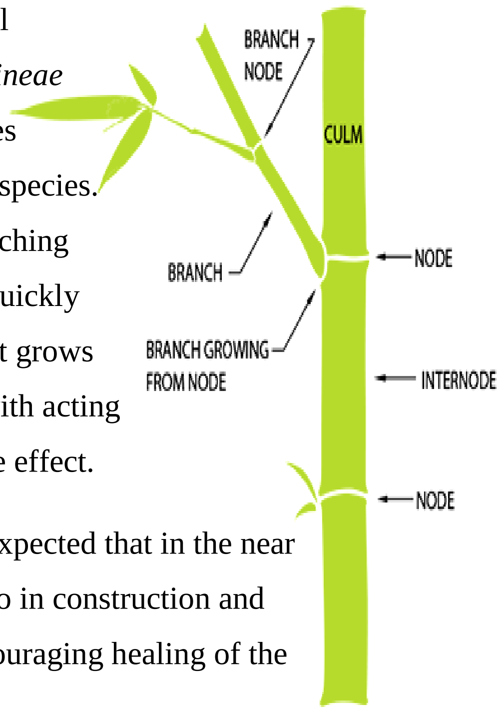


Fig. 1.1

Bamboo seems to be a promising material for future. It is expected that in the near future the world will witness more participations of bamboo in construction and creation of simple yet aesthetically pleasing buildings, encouraging healing of the environment to some extent.

1.3 Bamboo Diversity in India

India is the second richest country in bamboo genetic resource after China. Sharma(1987) reported 136 species of bamboo occurring in India. 58 species of bamboo belonging to 10 genera are distributed in the North-Eastern states alone.

The forest area, over which bamboos occur in India, on a conservative estimate, is 9.57 million hectares, which constitutes about 12.8% of the total area under forests (Bahadur & Verma 1980). The important genera are *Arundinaria*, *Bambusa, Cephalostachyum, Dendrocalamus, Dinochloa, Gigantochloa, Melocanna, Ochlandra, Oxytenanhthera, Phyllostachys and Pseudostachyum etc.* of the nearly 136 species, only about 10 are being commercially exploited today. These are *Bambusa, Arundinaria, B.affinis, B.balcooa, B.tulda, Dendrocalamusstrictus, D.hamiltoni, D.asper, Oxytenantherastocksii and O.travancorica.*

1.4 Properties of Bamboo

1.4.1 Shrinkage and Swelling

Dimensional stability is very important in structural members because the safety and comfort in a structure usually depends on them. Bamboo, like wood, changes its dimension when it loses or gains moisture. Bamboo is a hygroscopic material, thus it's moisture content changes as per the relative humidity and temperature of the surrounding environment.. Free water and bound water exists in bamboo, however the amount of free water is small as compared to bound water. This explains the phenomena why the bamboo starts to shrink as soon as it loses moisture. The shrinkage occurs in the direct proportion to the amount of water lost from the cell wall.

1.4.2 Tension parallel to grain

Tension tests parallel to the grain are seldom investigated for bamboo. Tensile strength values of bamboo cannot be utilized as such in practical work as bamboo will fail by shear long before its full tensile strength is developed. The tensile strength value is a fundamental criterion in order to design bamboo tension members.

1.4.3 Bending

Bending is an important parameter, deciding the suitability of bamboo as a construction material, because of this ability bamboo can be used as a substitute for reinforcement in construction of buildings.

1.4.4 Elasticity

The enormous elasticity of bamboo makes it to a very good building material for earthquake endangered areas. Another advantage of bamboo is its low weight. It can be transported and worked easily, thus rendering the use of cranes and other big machines unnecessary.

14.5 Fire resistance

The fire resistance of bamboo is very good because of its high content of silicate acid. Filled up with water, it can stand temperature of 400^0 C while the water boils inside.

1.5 Reinforced cement concrete

Concrete is strong in compression but weak in tension. Its tensile strength is almost one tenth of compressive strength. Reinforced concrete is a type of concrete with reinforcement embedded in it. The reinforcement embedded in the tension zone of concrete, revives concrete of any tensile stress and takes all tension without separating from concrete. The bond between the reinforced material and concrete ensures strain compatibility. Reinforcement imparts ductility to concrete which otherwise is brittle. Ductility means large observable deflections owning to yielding of reinforcing material, thereby giving ample warning of impending collapse.

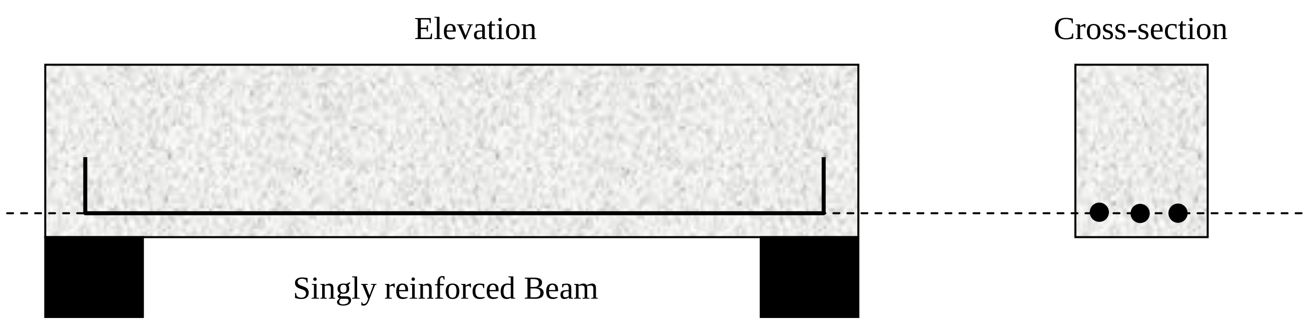
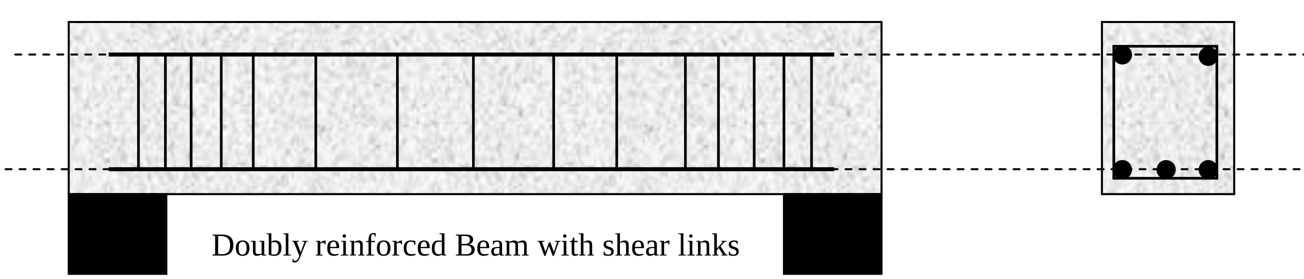


Fig. 1.2



1.6 Induction of tensile stresses in cement-concrete

Tensile stresses in cement-concrete arise due to any of the following phenomena:-

- Direct tension.
- Flexure tension.
- Diagonal tension due to shear.
- Temperature effects.
- Shrinkage effects.
- Restrain to deformation.

Under these conditions, reinforcement is provided in concrete across potential tensile crack.

1.7 Flexure strength of concrete (Modulus of rupture)

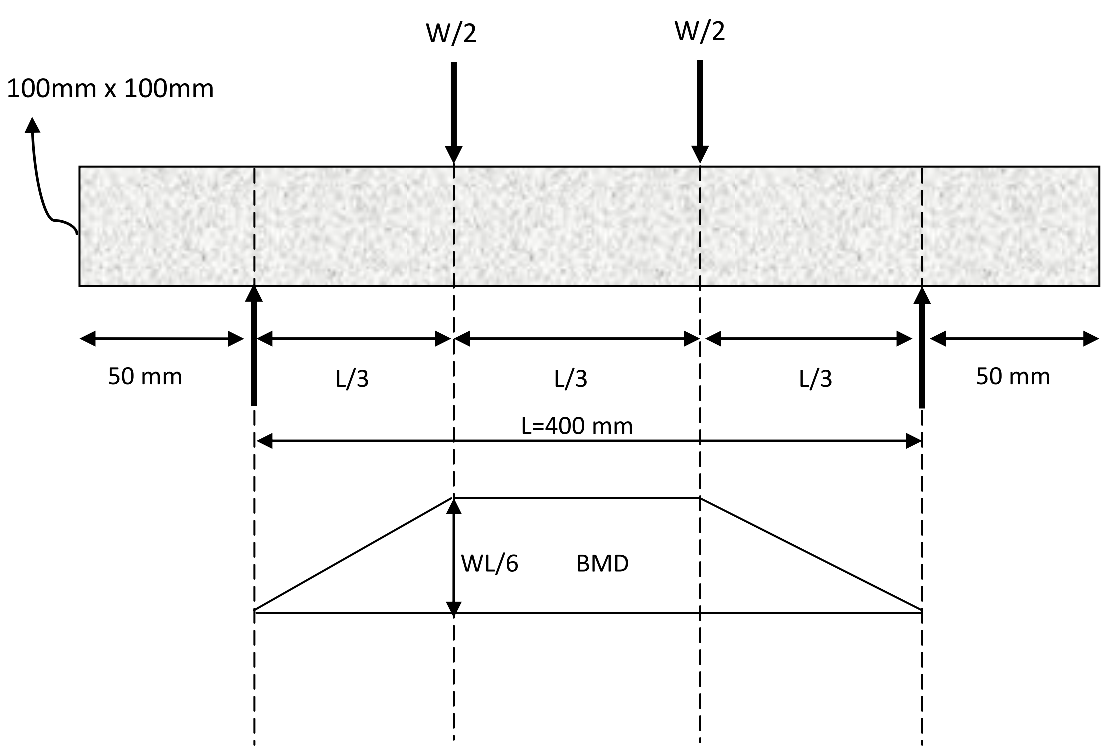


Fig. 1.3

IS 516:1959 Third Point Loading Flexure Test

Tensile strength of concrete in flexure is called as flexure strength which is expressed as modulus of rupture $f_{b.}$

$$\therefore \ \frac{M}{I} = \frac{f_b}{y}$$

$$\therefore \ \frac{WL/6}{\frac{100 \times 100^3}{12}} = \frac{f_b}{\frac{100}{2}}$$

$$\therefore \ 0.4\,W = f_b$$

Flexure strength is used to determine the onset of cracking or the loading at which the cracking starts in a structure.

1.8 Transformation of Stresses

Major Principle Stress

$$\sigma_1 = \frac{\sigma}{2} + \sqrt{\left(\frac{\sigma}{2}\right)^2 + (\tau)^2}$$

Minor Principle Stress

$$\sigma_2 = \frac{\sigma}{2} - \sqrt{\left(\frac{\sigma}{2}\right)^2 + (\tau)^2}$$

Inclination of Principle Planes

$$\tan 2\theta = \frac{2\tau}{\sigma}$$

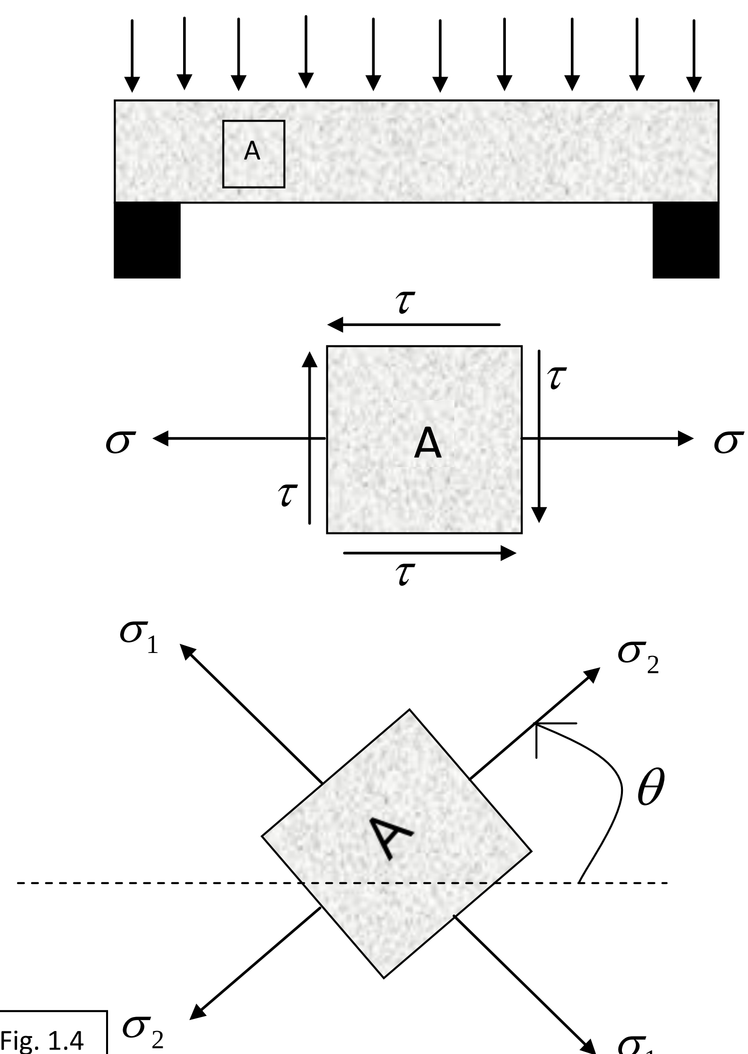
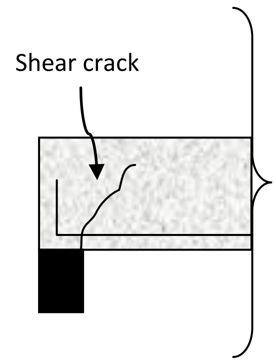
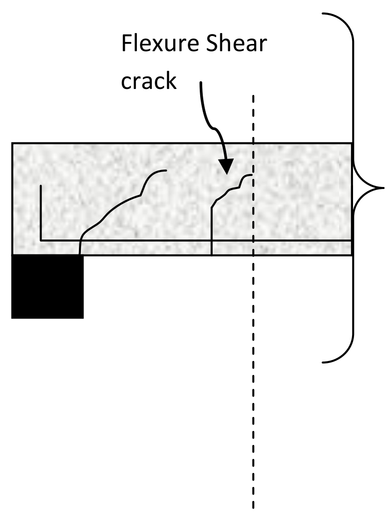
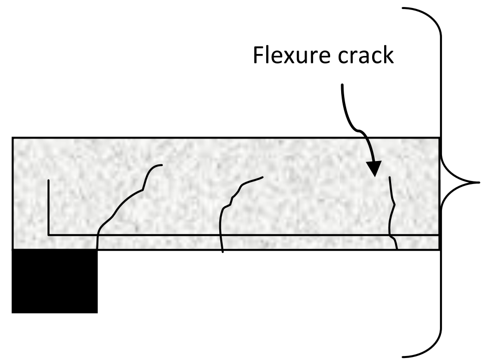


Fig. 1.4

1.9 Modes of Failure in a Reinforced Cement-Concrete Flexure Element

At Supports	At Supports Bending Moment is zero hence, $\sigma = 0 \;\; \therefore \;\; \sigma_1 = \tau \, , \sigma_2 = -\tau$ $tan2\theta = \infty \;\; \therefore \;\; \theta = 45^0 or 135^0$ This is called as diagonal tension, as concrete is weak in tension the concrete near the support cracks at 45 degrees with the horizontal.	 Fig. 1.5
Between Support & Mid Section	Between support and mid section neither bending stresses nor shear stresses are zero hence, $\sigma \neq 0 \; and \; \tau \neq 0$ $\sigma_{1,2} = \frac{\sigma}{2} \pm \sqrt{\left(\frac{\sigma}{2}\right)^2 + (\tau)^2}$ $\tan 2\theta = \frac{2\tau}{\sigma}$ The cracks changes from a vertical direction at a point of zero shear to a direction inclined at an angle of 45 degrees at a point where bending stress is zero.	 Fig. 1.6

At Mid Section	At mid section bending stress is predominant hence, $\tau = 0, \quad \sigma_1 = \sigma_2 = \sigma$ $tan2\theta = 0 \therefore \theta = 90^0$ Principle plane is perpendicular to beam, principle tensile stresses acts in horizontal direction and cracks will be vertical.	 Fig. 1.7

1.10 Formation of cracks in a Reinforced Cement Concrete flexure element under bending stresses

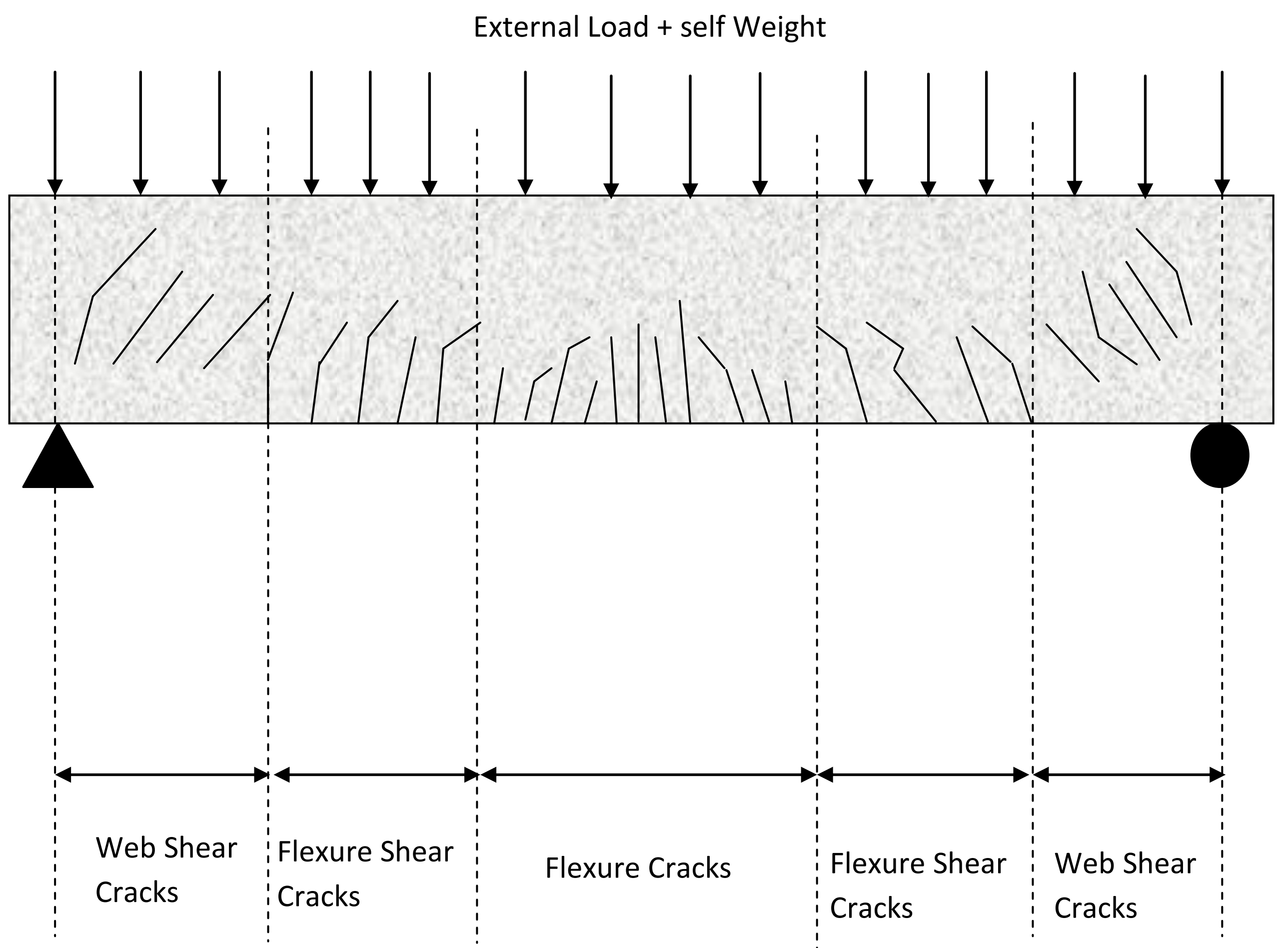


Fig. 1.8

2. LITERATURE REVIEW

Due to its several net worthy features researchers have found application of bamboo as a structural material. ***Francis E. Brink*** **and** ***Paul J. Rush*** has presented about the procedure of the selection and the preparation of the bamboo. They have also described about the construction principles and the design principles. ***Harish Sakaray, N.V. Vamsi Krishna Togati and I.V. Ramana Reddy*** carried out investigations on the Moso type Bamboo tensile stress, compressive stress, modulus of elasticity, water absorption capacity, shear stress and bonding stress. They concluded that the node posses ductile behavior. The compressive strength of the bamboo is similar to the tensile strength and the behavior is same as that of steel. The water absorption in bamboo is high so the water proofing to bamboo is required. ***Khosrow Ghavami*** in his study has focused about the summary of the information about the Bamboo as a structural member. His study also reflects about the design of the flexure and axially loaded elements. The conclusion part of study throws light on the satisfactorily substitution of bamboo against steel. ***Leela Khare*** has conducted four point bending test on the bamboo reinforced beam. Also the tensile test on the bamboo was conducted, the study reflects that the moso bamboo reinforced beam shows better results than that of solid bamboo reinforced beam. ***Markos Alitohas*** very well describes the various usefulness of the bamboo in various areas. He also describes about the various physical and mechanical properties of bamboo and its various tests. He has presented his study on the test performed on the RCC beam reinforced with bamboo. The mid span test was performed. He concluded that the bamboo reinforced concrete design is similar to steel reinforced concrete design if its mechanical properties are properly utilized. It identifies the potential for an alternative method for low-cost construction for areas where steel reinforcement is costly. ***Maulik D.Kakkad and Capt. C.S.Sanghvihave*** presented their studies on comparison of bamboo construction with the modern construction practices. They concluded that the seismic force in bamboo housing system is very less as compared to the modern housing system. ***M.M.Rahman, M.H. Rashid, M.A. Hossain, M.T. hasan and M.K. Hasan*** *has* carried out tensile test on bamboo and flexure test on the bamboo reinforced flexure element. The study reflected that the bamboo has a low modulus of elasticity and it can't prevent cracking of concrete. ***IS8242:2004*** provides the methods of test for bamboo splints. ***IS6874:2008*** provides the detailed methods for conducting various tests on bamboo culm for determining its physical and mechanical properties.

3. OBJECTIVES OF STUDY

The study focuses on the following objectives:-

1) To investigate the various physical, mechanical and durability properties of Bamboo by conducting a variety of laboratory test in order to:-

    a) Check the feasibility and reliability of using Bamboo as a reinforcing material in concrete structures.
    b) To select and prepare the most appropriate kind of Bamboo specimen to be used in concrete element as reinforcement.

2) To study the mechanical behavior of hardened cement concrete flexure elements, singly reinforced by bamboo splints without shear links, by subjecting them to IS 516:1959 Third Point Loading Flexure Test.

3) To study the mechanical behavior of hardened cement concrete flexure elements, doubly reinforced by bamboo splints with shear links, by subjecting them to IS 516:1959 Third Point Loading Flexure Test.

4) To find out the various techniques for enhancing the Bamboo-Cement Concrete Bond Strength, hence worth improving the performance of Bamboo reinforced Cement Concrete flexure element under bending stresses.

4. METHODOLOGY

4.1 Density Test

4.1.1 Importance of work

The density test was performed to find out the basic mass per volume or density of bamboo. The density of bamboo can be used as an appropriate parameter for classification of bamboo because unlike other physical and mechanical properties of bamboo, density is independent of the moisture content and do not change due to weather conditions; it depends only on the green volume and the oven dry mass. Hence density is an indicator of purity of a material. Density value of bamboo is also required for calculating the dead load coming on the concrete element due to bamboo reinforcement.

4.1.2 Parameters used

Parameter	Value	Reference
Temperature at which the specimens were kept in oven	100^0C	[12]
Duration for which the specimens were kept in oven	24 hours	[12]
Number of Specimens	12	[12]

Table-4.1

4.1.3 Preparation of specimens [12]

The test specimens for determining the basic mass per volume was taken from different positions of the Culm (base, middle, top). The samples were 25mm in length and 25mm in width with full wall thickness.

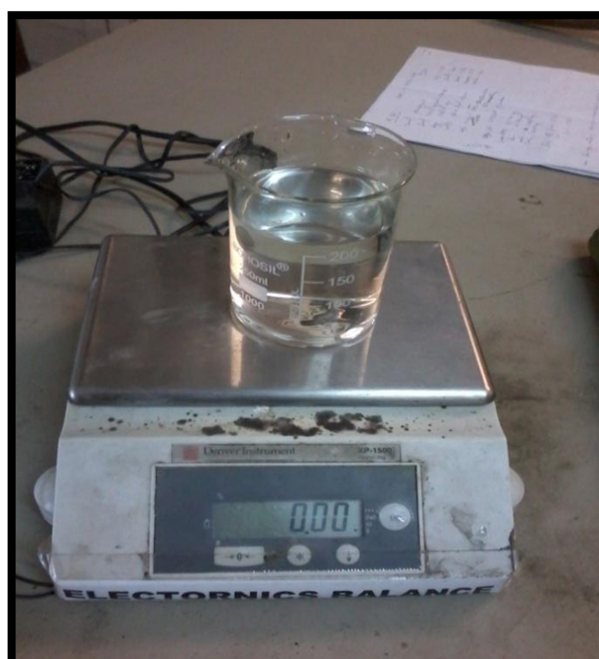
4.1.4 Test procedure as per IS 6874:2008[12]

<table>
<tr><th>STEPS</th><th>PROCEDURE</th></tr>
<tr><td></td><td></td></tr>
<tr><td>STEP #1</td><td>All the 12 specimens were kept in an oven at 100^0C for 24 hours.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>STEP #2</td><td>After 24 hours the specimen were taken out from the oven and the oven dry mass of each of the 12 specimens was measured on a digital weight machine, individually.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>STEP #3</td><td>The volume of each specimen was measured using water displacement method.
<table>
<tr><th>Steps</th><th>Procedure-water displacement method</th></tr>
<tr><td>#3.1</td><td>A beaker containing water was placed on a digital weight machine and the weight was tare to zero.</td></tr>
<tr><td>#3.2</td><td>A sharp needle was attached to each of the test specimen and each of the specimen was completely immersed in the water individually, while ensuring that the specimen do not touch the beaker.</td></tr>
<tr><td>#3.3</td><td>The reading in the electronic weight machine indicated the mass of the displace water, considering the specific gravity of water as 1.0, the reading was considered as the volume of the test specimen.</td></tr>
</table>
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>STEP #4</td><td>Using an appropriate mathematical expression the mass density of each of the 12 specimens was determined individually.</td></tr>
</table>

STEP #1 → STEP #2

TEST PROCEDURE

STEP #3.2/3.3 ← STEP #3.1



4.2 Initial Moisture Content Test

4.2.1 Importance of work

Moisture content affects almost all of the physical and mechanical properties of bamboo. The rotting process is fastest in bamboo having more water content. Bamboo is a hygroscopic material which means moisture content changes with change in relative humidity and temperature of surroundings. Free and bound water exists in bamboo, however the amount of free water is small as compared to bound water hence bamboo starts to shrink as soon it losses moisture. The shrinkage of bamboo occurs in the direct proportion to the amount of water content lost.

When bamboo splints present inside the concrete elements as reinforcement losses moisture, the bamboo splints shrinks creating additional stresses and creating spaces or gaps between the bamboo and concrete, eventually decreasing the bamboo-concrete bond and member fails in bond.

4.2.2 Parameters used

Parameter	Value	Reference
Types of specimen taken for test	Type-1 Type-2 Type-3	[8]
Temperature at which the specimens were kept in oven	100^0C	[12]
Duration for which the specimen were kept in oven	24 hours.	[12]

Table-4.2

4.2.3 Preparation of specimens[8]

Three different types of total 12 bamboo splints were taken from different portions of bamboo culm for the test.

TYPE-1: Zero internodes present

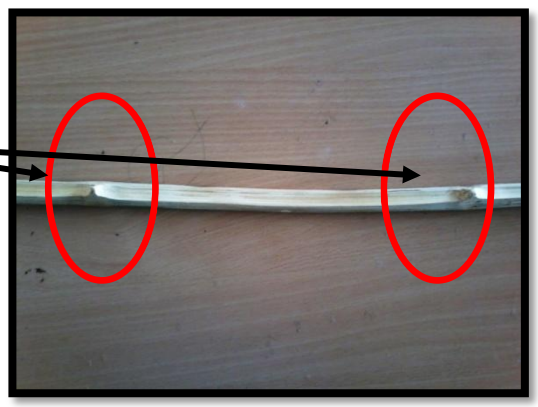
(4-such specimen of different thickness and different initial weight were taken for the test)

TYPE-2: One internodes present

(4-such specimen of different thickness and different initial weight were taken for the test)

TYPE-3: Two internodes present

(4-such specimen of different thickness and different initial weight were taken for the test)



4.2.4 Test procedure[12]

STEPS	PROCEDURE
STEP #1	The initial weight of all the specimen was taken individually on a digital weight machine.
STEP #2	All the specimen were kept in an oven at 100^0C for 24 hours.
STEP #3	After 24 hours the specimen were taken out from the oven and the final dry weight of all the specimen was measured individually on a digital weight machine.
STEP #4	Using an appropriate mathematical expression the initial moisture content of all the specimen was obtained and was expressed in terms of percentage by weight.

STEP #1 → STEP #2

TEST PROCEDURE

STEP #3

4.3 Water Absorption Test

4.3.1 Importance of work

Bamboo like wood changes its dimension when it loses or gains moisture. Bamboo is a hygroscopic material, tending to absorb moisture from air and surroundings. The water absorption capacity of bamboo splints is more than 50% by weight, hence it absorbs and reduces a part of water added in the concrete mix for hydration reactions. In green concrete bamboo splints absorb moisture and swells, when the concrete becomes dry the bamboo splints contracts and creates spaces between the contacts the bamboo-concrete bond strength decreases and member fails in bond.

4.3.2 Parameters used

Parameter	Value	References
Types of specimens taken	Type-1 Type-2 Type-3	[8]
Temperature at which the specimen were kept in oven	100^0C	[12]
Duration for which the specimen were kept in oven	24 hours	[12]
Water proofing material used	Bitumen	[8]
Duration for which the specimens were kept immersed in water	30 days	[4]

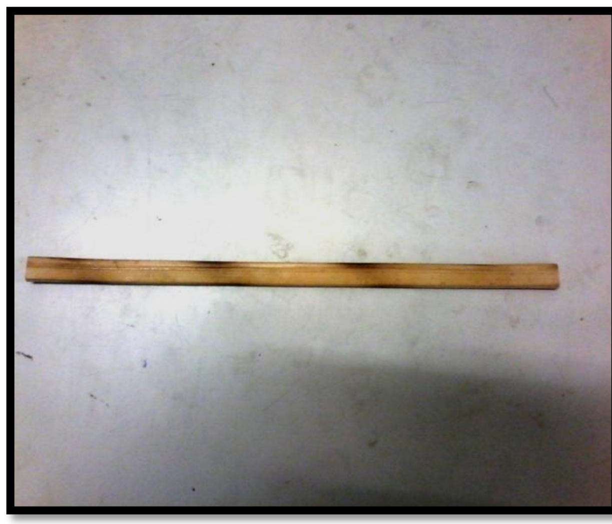
Table-4.3

4.3.3 Preparation of specimens [8]

TYPE-A-NON TREATED	TYPE-B-TREATED (BITUMEN COATED)
TYPE-A-1: zero internodes present	**TYPE-B-1**: zero internodes present
TYPE-A-2: one internodes present	**TYPE-B-2**: one internodes present
TYPE-A-3: Two internodes present	**TYPE-B-3**: Two internodes present

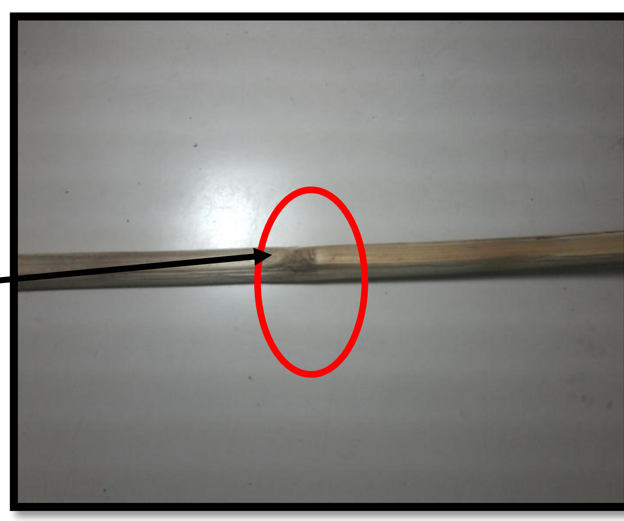
TYPE-A-1: Zero internodes present

(2-such specimen of different thickness and different initial weight were taken for the test)



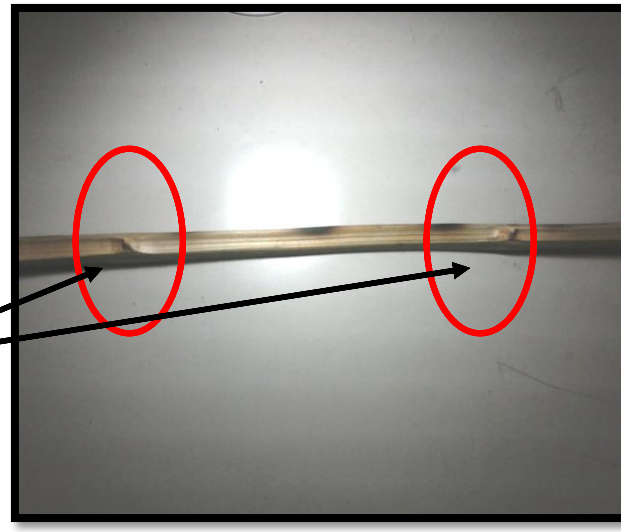
TYPE-A-2: One internodes present

(2-such specimen of different thickness and different initial weight were taken for the test)



TYPE-A-3: Two internodes present

(2-such specimen of different thickness and different initial weight were taken for the test)

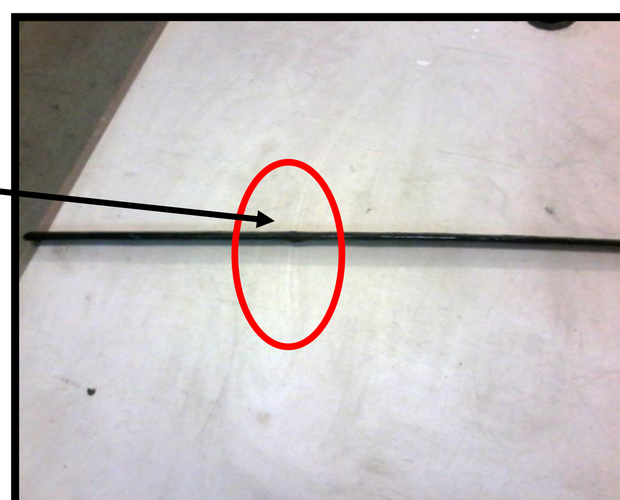


TYPE-B-1: Zero internodes present

(2-such specimen of different thickness and different initial weight were taken for the test)

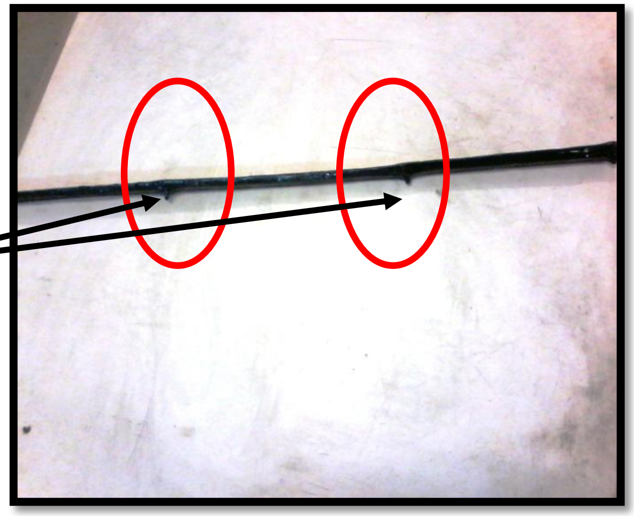
TYPE-B-2: One internodes present

(2-such specimen of different thickness and different initial weight were taken for the test)



TYPE-B-3:Two internodes present

(2-such specimen of different thickness and different initial weight were taken for the test)



4.3.4 Test procedure [12]

STEPS	PROCEDURE
STEP #1	To remove all the initial moisture content present in the bamboo splints, the specimen were kept in an oven at 100^0C for about 24 hours.
STEP #2	Type-A and Type-B kind of specimens were prepared
STEP #3	The initial dry weight and initial thickness of all the specimens were taken individually on a digital weight machine and using a ruler respectively.
STEP #4	All the specimen were kept immersed in water at room temperature for 30 days in a curing water tank.
STEP #5	The specimen were taken out from the water curing tank at consecutive intervals of 15 days and 30 days, their surface was wiped off properly using a dry cloth.
STEP #6	The final saturate weigh and increase thickness of all the specimen were measured individually on a digital weight machine and a ruler respectively.
STEP #7	Using an appropriate mathematical expression the amount of water absorbed by both types of samples was calculated.




STEP #1 → STEP #2 → STEP #3 ↓

TEST PPROCEDURE

STEP #6 ← STEP #5 ← STEP #4




4.4 Compression Test

4.4.1 Importance of work

The compression test was carried out on hollow bamboo culms to determine the compressive strength of bamboo .The compressive strength of bamboo is of utter importance to calculate the maximum allowable stresses in bamboo, when bamboo is being used as compressive reinforcement in the upper fiber of a doubly reinforced concrete beam.

4.4.2 Parameters used

Parameters	Value	Reference
Type of specimen	Type-A Type-B	[4]
Rate of loading	0.05KN/Sec.	[9]

Table-4.4

4.4.3 Preparation of specimens [4]

Specimen	Nodes	Dimensions			Cross-Sectional Area, A(mm^2) $A=\frac{\pi}{4}\left(D^2-(D-2t)^2\right)$
		Gauge length, L(mm)	Outer diameter, D(mm)	Thickness t(mm)	
A-1	0	145	47	6	772.832
A-2	0	142	43	8	879.646
A-3	0	117	44	10	1068.142
B-1	1	148	47	5	659.735
B-2	1	146	43	8	879.646
B-3	1	143	44	9	989.602

Table-4.5

SPECIMEN :A-1, A-2, A-3

ZERO-internodes present

SPECIMEN :B-1, B-2, B-3

ONE-internode present

4.4.4 Test procedure[4]

STEPS	PROCEDURES
STEP #1	Type-A and Type-B kind of specimens were prepared. The end were filed properly to ensure a smooth surface to achieve a uniform stress application over the entire cross-section.
STEP #2	A compressive load was applied on the cross section of all specimens individually on a universal testing machine. The loading rate for all of the specimen was kept constant i.e. 0.05KN/Sec.
STEP #3	The load and displacement readings were taken at regular intervals for each specimen, using a digital indicator.
STEP #4	The load at which the specimen failed was divided with the cross-sectional area to obtain the ultimate compressive strength of the specimen.
STEP #5	Stress and strain values were calculated using the load and displacement values and a stress-vs.-strain graph was plotted for each of the specimen.

TEST PROCEDURE

STEP #1

STEP #2

STEP #3

4.5 Tension Test

4.5.1 Importance of work

The tension test was carried out on bamboo splints to determine the ultimate tensile strength of bamboo. The ultimate tensile strength of bamboo is of utter importance to calculate the maximum allowable tensile stress in bamboo, when bamboo is being used as reinforcement in concrete elements to take the tensile loads. Using the data of tension test stress-vs.-strain curve was plotted for all specimens. The stress-vs.-strain curve is a characteristic property of a material and is used to study the properties of a material like modulus of elasticity, ductility, creep, relaxation, resilience, toughness etc.

4.5.2 Parameters used

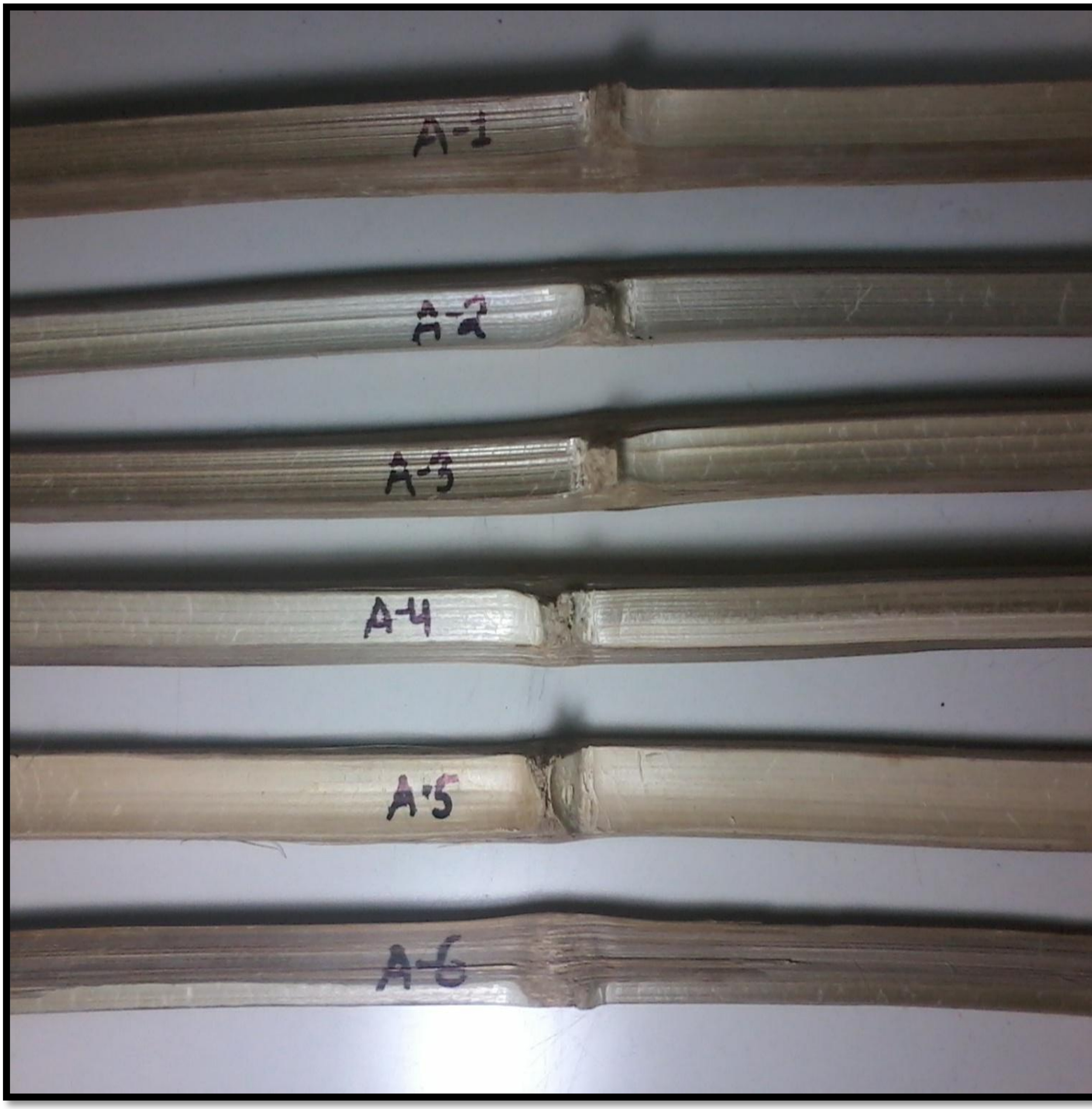
Parameter	Value	References
Type of specimen	Type-A	[12]
Rate of strain	0.6mm/min.	[12]

Table-4.6

4.5.3 Preparation of specimens [4]

Specimen No.	Nodes	Dimensions			Cross-sectional area, $A(mm^2)$ A=T x B
		Gauge Length, L(mm)	Width, B(mm)	Thickness, T(mm)	
A-1	1	150	20	12	240
A-2	1	150	20	5	100
A-3	1	150	20	9	180
A-4	1	150	20	6	120
A-5	1	150	20	12	240
A-6	1	150	20	5	100

Table-4.7



SPECIMENS FOR TENSION TEST

A-1, A-2 ,A-3, A-4, A-5, A-6

ONE-internode or central node present

4.5.4 Test procedure [12],[4]

STEPS	PROCEDURE
STEP #1	Specimens A-1 to A-6 were prepared.
STEP #2	A tensile load was applied on the cross section of all specimens individually on a universal testing machine. The strain rate for all of the specimen was kept constant i.e. 0.06mm/min.
STEP #3	The load and displacement readings were taken at regular intervals for each specimen, using a digital indicator.
STEP #4	The load at which the specimen failed was divided with the cross-sectional area to obtain the ultimate tensile strength of the specimen.
STEP #5	Stress and strain values were calculated using the load and displacement values and a stress-vs.-strain graph was plotted for each of the specimen.

TEST PROCEDURE

STEP #1

STEP #2

STEP #3

4.6 Durability Test on Bamboo Splints

4.6.1 Importance of work

As reinforcement in concrete structures, bamboo's durability was questioned by some researchers. Doubts about bamboo durability were based on studies concerning the durability of natural fibers working as Portland cement-based composites reinforcement. Conversely, Cordero and Lopez concluded that bamboo degradation is only observed in a construction when the correct procedures were not applied, and they added that this material was widely used as reinforcement in load bearing walls in Brazil, with durability lasting more than 100 years. Gram studied the mechanism of natural fiber degradation in an alkaline environment and suggested that the mechanical property loss of natural fiber within a concrete mass is associated with the chemical decomposition of the *lignin* and *hemicelluloses* from the intermediate lamella. Those substances are dissolved by the alkaline water from the concrete pores, breaking the links among the fiber-cells. As a result of this, the long fibers are decomposed into small unitary cells, where the fiber-cell lumen is filled with calcium hydroxide. This phenomenon not only reduces the fiber tensile strength, but also causes the fiber flexibility to decrease.

Despite these conclusions, the fibers durability studies cannot be directly extended to bamboo-splints, firstly, because the bamboo macrostructure is different from the fibers and secondly, the bamboo-splint length used in concrete reinforcement presents a much higher area/perimeter ratio, thus making the penetration of cement hydration products in the bamboo fibers very difficult.

4.6.2 Parameters used

Parameter	Value	References
Solutions Used	1) H_2O-Ph:7 2) NaCl-Ph:7.5,Conc.:33.3gm/l 3) $Ca(OH)_2$ –Ph:14,Conc.:33.3gm/l	[5]
Wetting Period	12 hrs. per day	[5]
Drying Period	12 hrs. per day	[5]

Duration of test	60 days	[5]

Table-4.8

4.6.3 Preparation of specimens [5]

A. Specimens kept in H_2O solution:Ph-7				
Specimen	**Length(l), cm**	**Width(b), cm**	**Thickness(t), cm**	**Cross-section area(Acm^2) A=b x t**
W-1	71.0	1.60	0.60	0.96
W-2	74.4	2.00	0.90	1.80
W-3	74.6	2.00	1.20	2.40
B. Specimens kept in NaCl solution:Ph-7.5, Conc.-33.33gm/l				
Specimen	**Length(l), cm**	**Width(b), cm**	**Thickness(t), cm**	**Cross-section area(Acm^2) A=b x t**
S-1	74.5	2.20	0.40	0.88
S-2	74.0	1.90	0.80	1.52
S-3	76.0	2.20	1.00	2.2
C. Specimens kept in $Ca(OH)_2$ solution:Ph-14, Conc.-33.33gm/l				
Specimen	**Length(l), cm**	**Width(b), cm**	**Thickness(t), cm**	**Cross-section area(Acm^2) A=b x t**
C-1	71.5	1.60	0.50	0.80
C-2	74.0	2.20	0.80	1.76
C-3	73.7	2.10	1.00	2.10

Table-4.9

Samples-C-1, C-2, C-3 Wetted for 12hrs./day in 33.33mg/l concentrated solution of $Ca(OH)_2$, Ph-14
For a period of 60 days

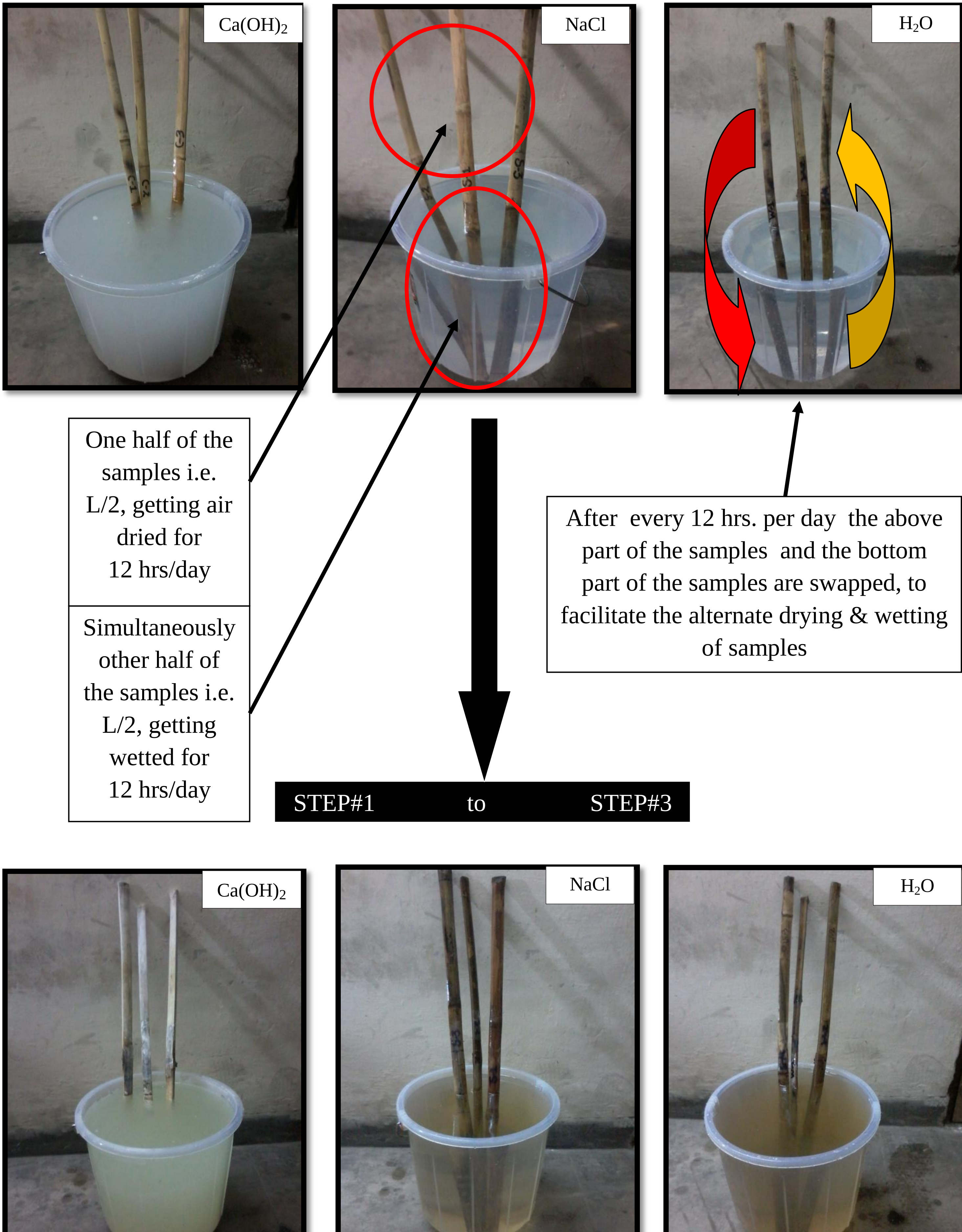
Samples-S-1, S-2, S-3 Wetted for 12hrs./day in 33.33mg/l concentrated solution of NaCl , Ph-7.5
For a period of 60 days

Samples-W-1, W-2, W-3 Wetted for 12hrs./day in a solution of H_2O, Ph-7
For a period of 60 days

4.6.4 Test procedure [5]

STEPS	PROCEDURE
STEP #1	Specimens W-1 to W-3, S-1 to S-3, and C-1 to C-3 were prepared.
STEP #2	33.33gm/L solution of $Ca(OH)_2$ with a Ph of 14 , 33.33gm/L solution of NaCl with a Ph of 7.5 and tap water with a Ph of 7 were prepared (or taken) in three separate containers.
STEP #3	The samples W-1, W-2 and W-3 were wetted by submerging in tap water for 12 hours per day and successively air dried for another 12hours per day, continuously for a period of 60 days.
	The samples S-1, S-2 and S-3 were wetted by submerging in NaCl solution for 12 hours per day and successively air dried for another 12hours per day, continuously for a period of 60 days.
	The samples C-1, C-2 and C-3 were wetted by submerging in $Ca(OH)_2$ solution for 12 hours per day and successively air dried for another 12hours per day, continuously for a period of 60 days
STEP #4	After 60 days of undergoing alternate wetting and drying cycles, the samples were taken out from their respective containers and air dried for 24 hours. After getting air dried the samples were subjected to tension test to find if there was any loss in their tensile strength or not.
STEP #5	A tensile load was applied on the cross section of all specimens individually on a universal testing machine. The strain rate for all of the specimen was kept constant i.e. 0.06mm/min.

STEP #6	The load and displacement readings were taken at regular intervals for each specimen, using a digital indicator.
STEP #7	The load at which the specimen failed was divided with the cross-sectional area to obtain the ultimate tensile strength of the specimen.



SAMPLES AFTER UNDERGOING 60 DAYS OF ALTERNATE WETTING & DRYING CYCLE

W-1, W-2, W-3

C-1, C-2, C-3

S-1, S-2, S-3

STEP #4

TEST PROCEDURE

STEP #6

STEP #5

4.7 IS 516:1959 Third Point Loading Flexure Test on hardened Cement Concrete Flexure Elements Doubly Reinforced by Bamboo Splints, with Shear Links

4.7.1 Importance of work

Concrete is strong in compression but weak in tension. Its tensile strength is almost one tenth of compressive strength. The reinforcement embedded in the tension zone of concrete, revives concrete of any tensile stress and takes all tension without separating from concrete. The bond between the reinforced material and concrete ensures strain compatibility. Reinforcement imparts ductility to concrete which otherwise is brittle. Ductility means large observable deflections owning to yielding of reinforcing material, thereby giving ample warning of impending collapse.

The study was carried out to find out by what amount the modulus of rupture and ductility of cement concrete beam gets improved on doubly reinforcing it with a cage of bamboo stirrups.

To take care of shear cracks equally spaced shear links of bamboo are provided at regular intervals.

To firstly, reduce the water absorption capacity of the bamboo and secondly, to improve the bamboo concrete bond strength one part of the samples tested were reinforced with modified bamboo splints i.e. bamboo splints coated with a layer of bitumen and sand mixture (1 part bitumen in 2 parts of sand).

4.7.2 Parameters used

Parameter	Value	References
Grade of concrete	M20	[7]
Type of specimens	3-Plain cement concrete beams(PCC), 3-Bamboo reinforced cement concrete beams(BRCC), 3-Modified bamboo reinforced cement concrete beams (MBRCC)	[8]
No. or reinforcement bars	2 in compression region 2 in tension region	[1]
Spacing of reinforcement bars	02.00 cm	[7]
Spacing of stirrups	13.33cm	[7]
Clear cover	02.00cm	[8]
Loading type	IS 516:1959 Third Point Loading Flexure Test	[8],[1]

Table-4.10

4.7.3 Preparation of specimens

4.7.3.1 Concrete Mix design as per IS 10262:1982 procedure [14]

Concrete mix design-IS 10262:1982 Grade of Concrete-M20 f_{ck} = 20 MPa (All quantities for 1m^3 volume of concrete)				
Materials	**Water**	**Cement**	**Fine Aggregate**	**Coarse Aggregate**
Quantities	191.6 kg	383.0kg	546.0kg	1188kg
Ratio	0.5	1	1.4	3.1

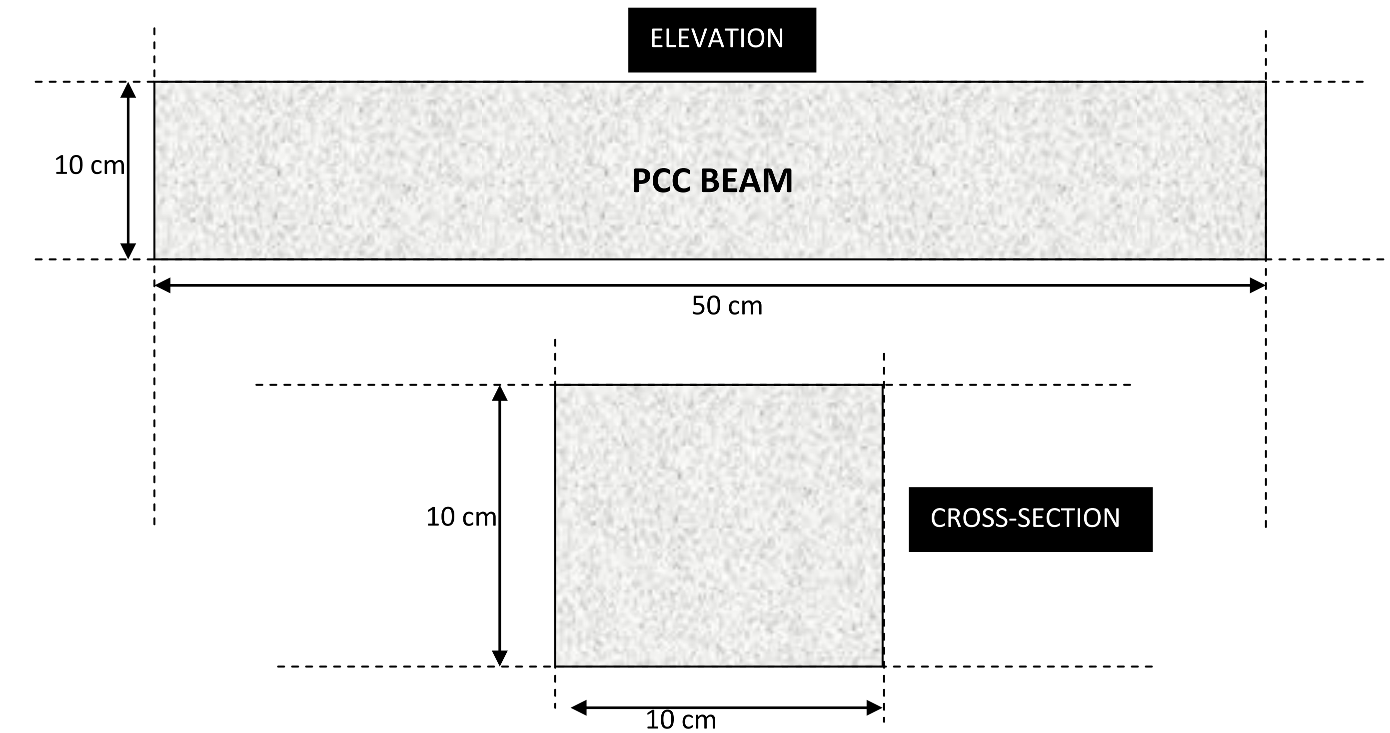
Table-4.11

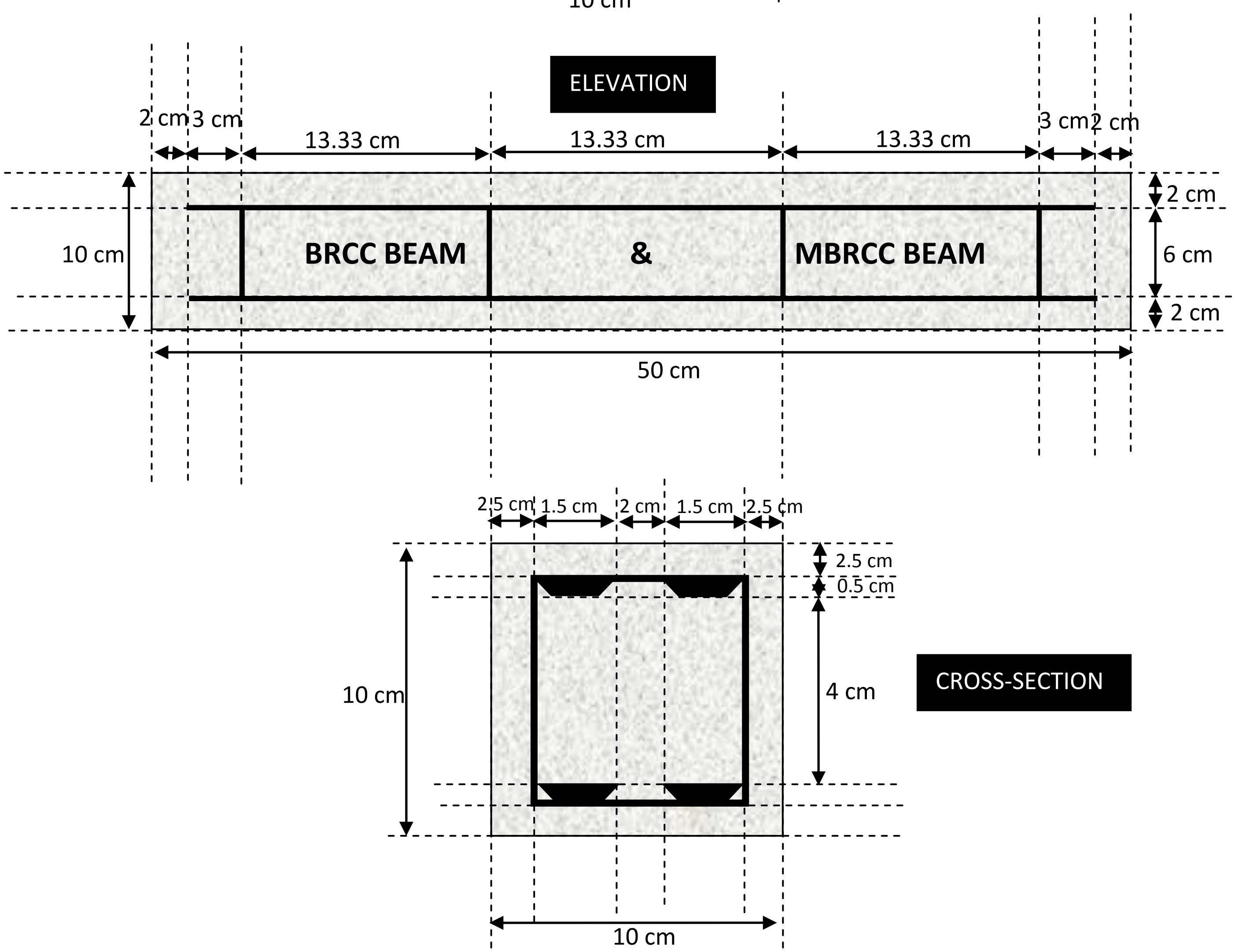
4.7.3.2 Cement Concrete Beam Details [1], [7], [8]

Table-4.12

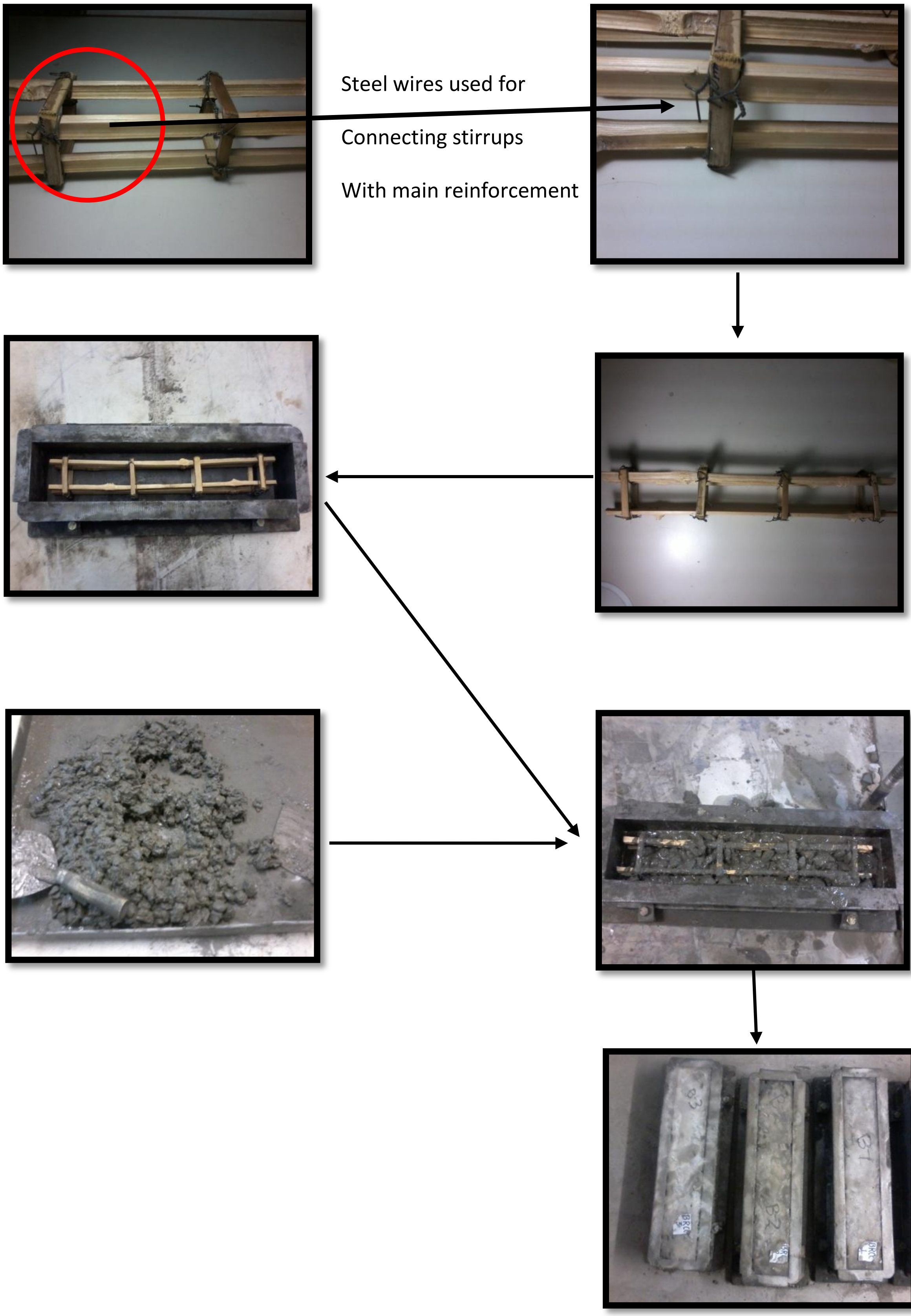
Beam Specimens	Beam Dimensions L x B x H (cm)	Clear cover (cm)	Grade of Concrete f_{ck} MPa	Reinforcement Dimensions l x b x t (cm)	Percentage reinforcement		Thickness of stirrups (cm)	No. of stirrups @ 13.33 cm
					Tension	Compression		
PCC-1	50 X 10 X 10	-	13.12	-	-	-	-	-
PCC-2	50 X 10 X 10	-	16.31	-	-	-	-	-
PCC-3	50 X 10 X 10	-	20.75	-	-	-	-	-
BRCC-1	50 X 10 X 10	2.0	13.12	46 X 1.5 X 0.80	2.40%	2.40%	0.50	4
BRCC-2	50 X 10 X 10	2.0	16.31	46 X 1.5 X 0.80	2.40%	2.40%	0.50	4
BRCC-3	50 X 10 X 10	2.0	20.75	46 X 1.5 X 0.55	1.65%	1.65%	0.50	4
MBRCC-1	50 X 10 X 10	2.0	13.12	46 X 1.5 X 0.85	2.55%	2.55%	0.50	4

MBRCC-2	50 X 10 X 10	2.0	16.31	46 X 1.5 X 0.80	2.40%	2.40%	0.5	4
MBRCC-3	50 X 10 X 10	2.0	20.75	46 X 1.5 X 0.83	2.49%	2.49%	0.5	4


ELEVATION
PCC BEAM
10 cm
50 cm
CROSS-SECTION
10 cm
10 cm


ELEVATION
2 cm
3 cm
13.33 cm
13.33 cm
13.33 cm
3 cm
2 cm
BRCC BEAM
&
MBRCC BEAM
10 cm
2 cm
6 cm
2 cm
50 cm
2.5 cm
1.5 cm
2 cm
1.5 cm
2.5 cm
2.5 cm
0.5 cm
4 cm
10 cm
CROSS-SECTION
10 cm

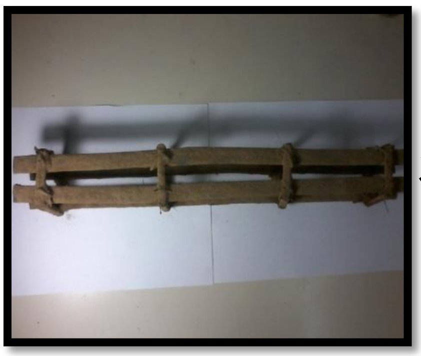
Preparation of BRCC Beams



Preparation of MBRCC Beams

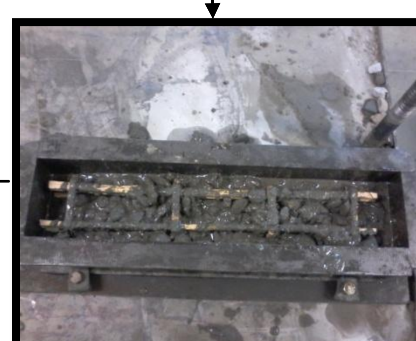
Bamboo Splints coated with bitumen & sand mixture

Sand being applied over wet bitumen & sand mixture

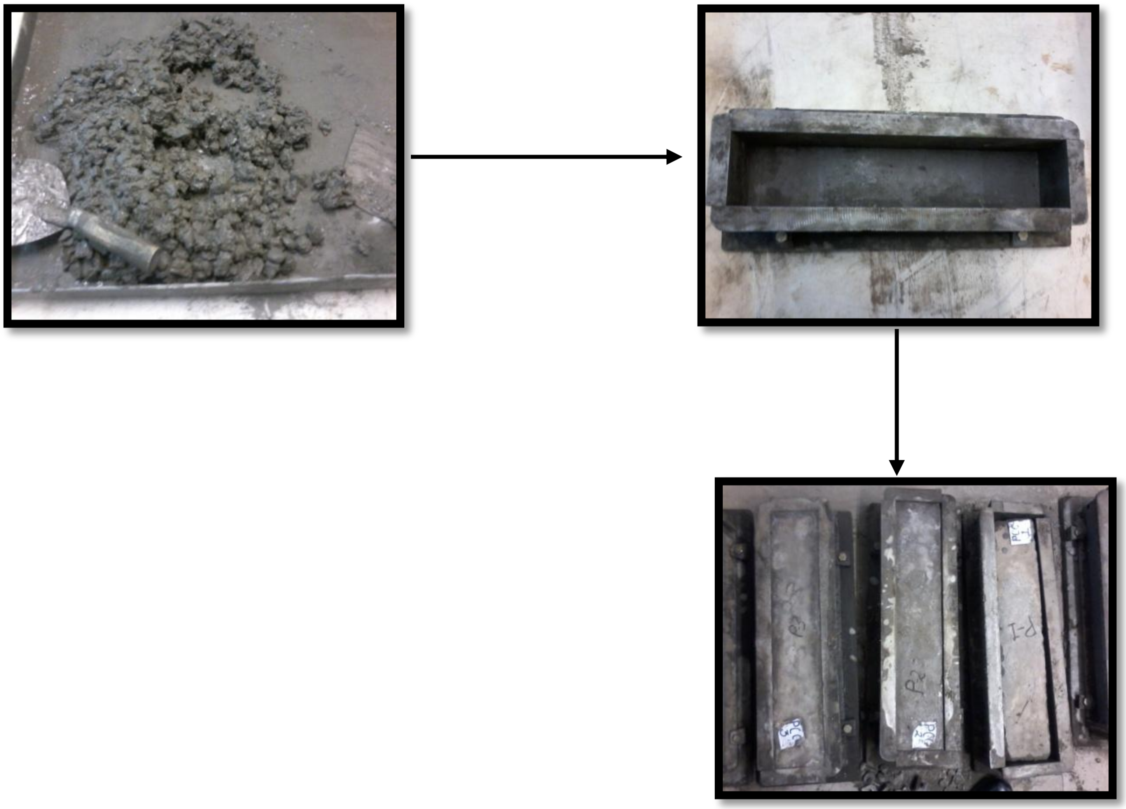


Steel wires used for connecting stirrups

With main reinforcement



Preparation of PCC Beams



4.7.4 Test procedure [13]

STEPS	PROCEDURE
STEP #1	9 Flexure Specimens PCC-1, PCC-2, PCC-3 BRCC-1, BRCC-2, BRCC-3 MBRCC-1, MBRCC-2, MBRCC-3 Were prepared
STEP #2	All the specimens were subjected to Third Point Loading as per IS 516:1959 procedure, individually on a universal testing machine, at a constant strain rate.
STEP #3	The load and displacement readings were taken at regular intervals for each specimen, using a digital indicator and the load vs. deflection curves were plotted.
STEP #4	Modulus of rupture and Modulus of elasticity values were calculated using proper mathematical for each specimen.

TEST PPROCEDURE

STEP #1

STEP #2

STEP #3

4.8 IS 516:1959 Third Point Loading Flexure Test on hardened Cement Concrete Flexure Elements Singly Reinforced by Bamboo Splints, without Shear Links

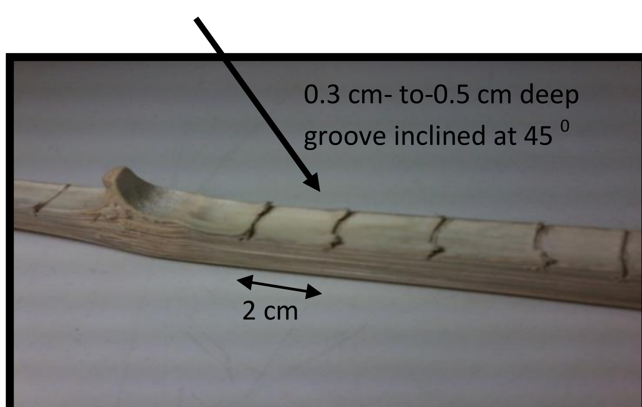
4.8.1 Importance of work

Concrete is strong in compression but weak in tension. Its tensile strength is almost one tenth of compressive strength. The reinforcement embedded in the tension zone of concrete, revives concrete of any tensile stress and takes all tension without separating from concrete. The bond between the reinforced material and concrete ensures strain compatibility. Reinforcement imparts ductility to concrete which otherwise is brittle. Ductility means large observable deflections owning to yielding of reinforcing material, thereby giving ample warning of impending collapse.

The study was carried out to find out by what amount the modulus of rupture and ductility of cement concrete beam gets improved on singly reinforcing it with bamboo stirrups.

To firstly, reduce the water absorption capacity of the bamboo and secondly, to improve the bamboo concrete bond strength one part of the samples tested were reinforced with modified bamboo splints i.e. bamboo splints coated with a layer of bitumen and sand mixture (1 part bitumen in 2 parts of sand).

To improve the bamboo concrete bond strength, 0.3cm-to-0.5cm deep grooves inclined at 45^0 were made on the inner part of bamboo stirrups at a spacing of 2cm.



4.8.2 Parameters used

Parameter	Value	References
Grade of concrete	M20	[7]
Type of specimens	3-Plain cement concrete beams(PCC), 3-Bamboo singly reinforced cement concrete beams(BSRCC), 3-Modified bamboo singly reinforced cement concrete beams (MBSRCC)	[8]
No. or reinforcement bars	2 in tension region	[1]
Spacing of reinforcement bars	02.00 cm	[7]
Clear cover	02.00cm	[8]
Loading type	IS 516:1959 Third Point Loading Flexure Test	[8],[1]

Table-4.13

4.8.3 Preparation of specimens

4.8.3.1 Concrete Mix design as per IS 10262:1982 procedure **[14]**

Concrete mix design-IS 10262:1982 Grade of Concrete-M20 f_{ck} = 20 MPa (All quantities for 1m^3 volume of concrete)				
Materials	**Water**	**Cement**	**Fine Aggregate**	**Coarse Aggregate**
Quantities	191.6 kg	383.0kg	546.0kg	1188kg
Ratio	0.5	1	1.4	3.1

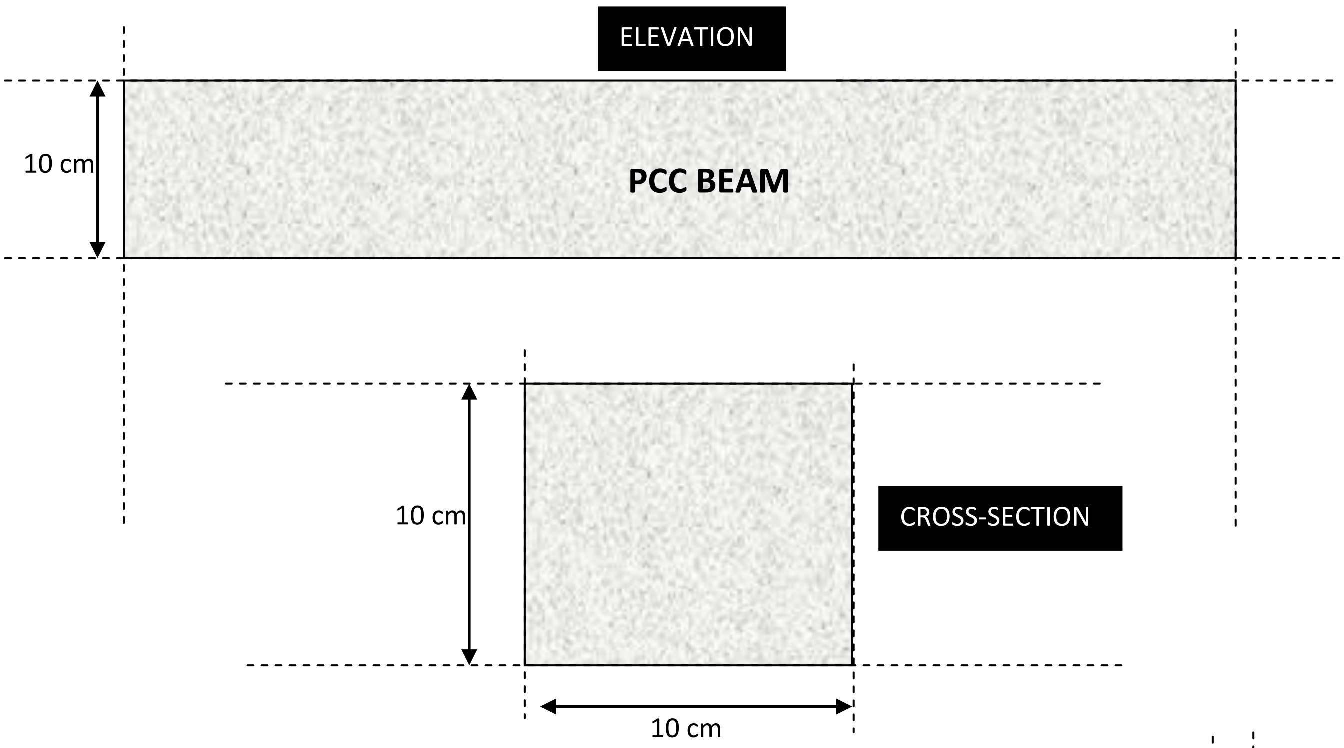
Table-4.14

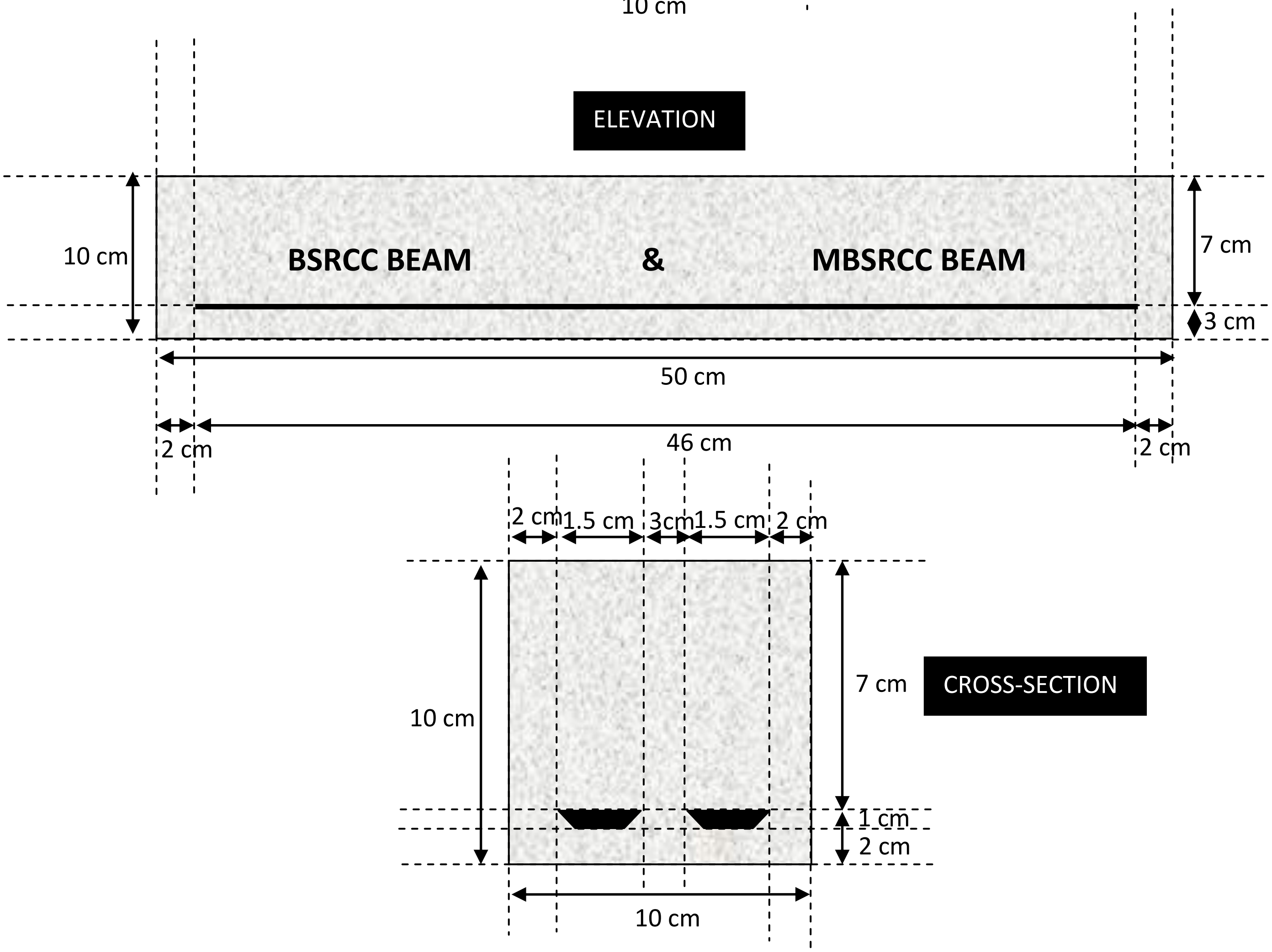
4.8.3.2 Cement Concrete Beam Details [1], [7], [8]

Table-4.15

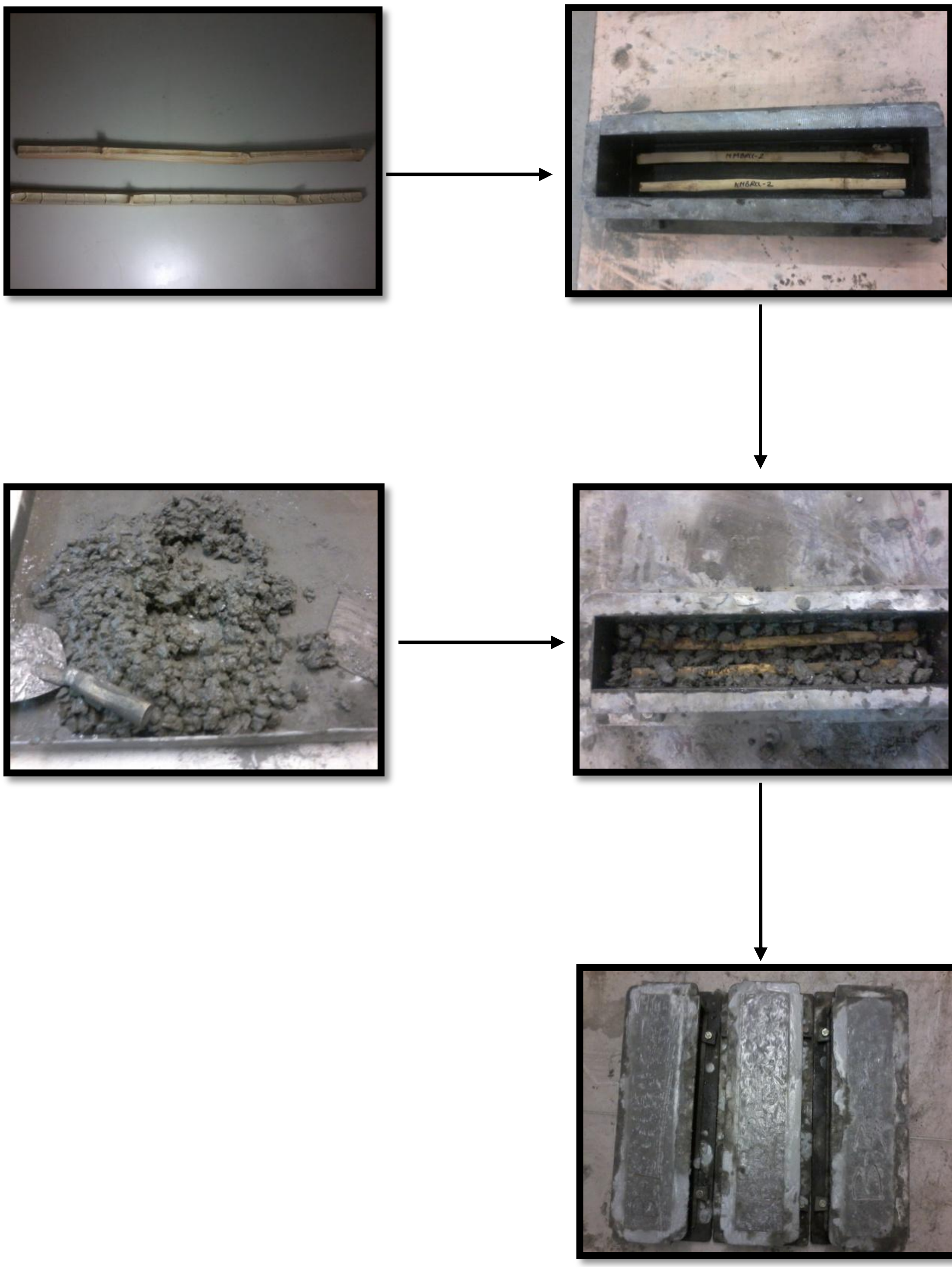
Beam Specimens	Beam Dimensions L x B x H (cm)	Clear cover (cm)	Grade of Concrete f_{ck} MPa	Reinforcement Dimensions l x b x t (cm)	Percentage reinforcement
PCC-1	50 X 10 X 10	-	13.12	-	-
PCC-2	50 X 10 X 10	-	16.31	-	-
PCC-3	50 X 10 X 10	-	20.75	-	-
BSRCC-1	50 X 10 X 10	2.0	13.12	46 X 1.5 X 1.00	1.50%
BSRCC-2	50 X 10 X 10	2.0	16.31	46 X 1.5 X 0.80	1.20%
BSRCC-3	50 X 10 X 10	2.0	20.75	46 X 1.5 X 0.90	1.35%
MBSRCC-1	50 X 10 X 10	2.0	13.12	46 X 1.5 X 0.80	1.20%

MBSRCC-2	50 X 10 X 10	2.0	16.31	46 X 1.5 X 1.00	1.50%
MBSRCC-3	50 X 10 X 10	2.0	20.75	46 X 1.5 X 0.90	1.35%


ELEVATION
10 cm
PCC BEAM
10 cm
CROSS-SECTION
10 cm


ELEVATION
10 cm
BSRCC BEAM
&
MBSRCC BEAM
7 cm
3 cm
50 cm
2 cm
46 cm
2 cm
2 cm
1.5 cm
3cm
1.5 cm
2 cm
10 cm
7 cm
CROSS-SECTION
1 cm
2 cm
10 cm

Preparation of BSRCC Beams

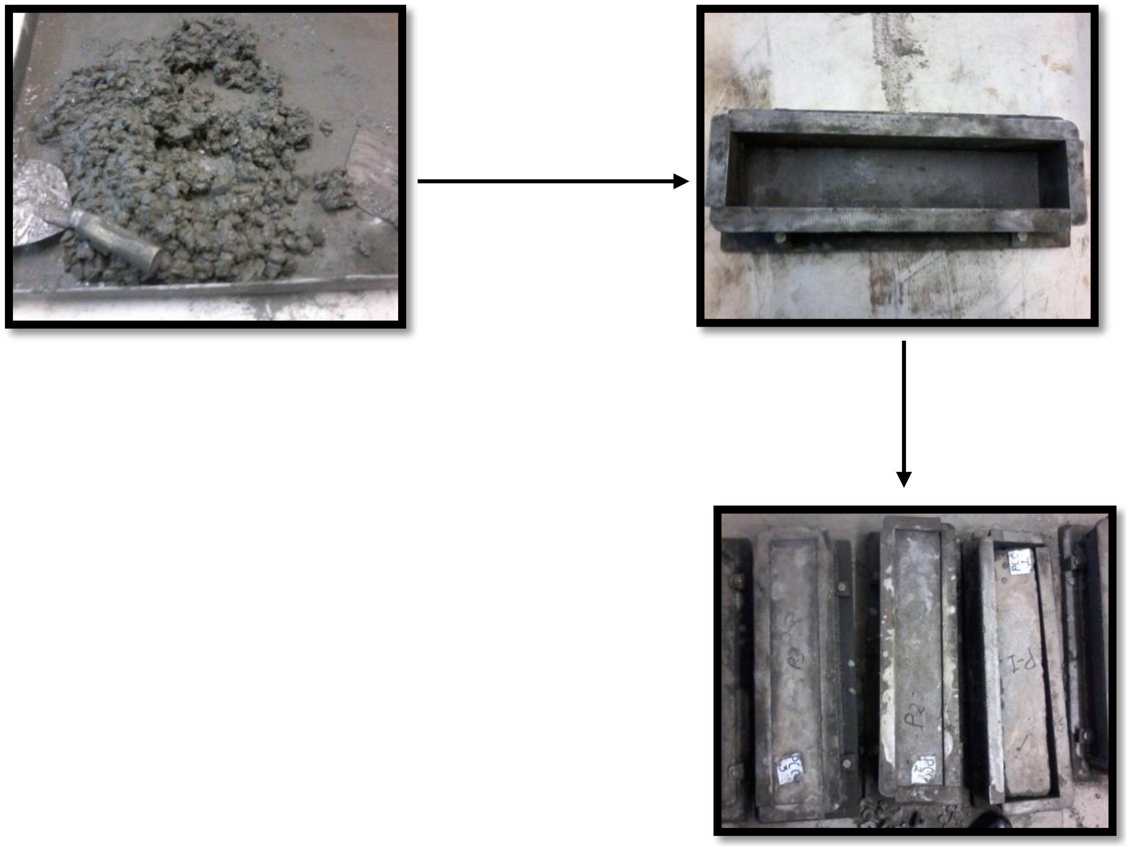


Preparation of MBSRCC Beams

Bamboo Splints coated with bitumen & sand mixture

Sand being applied over wet bitumen & sand mixture to enhance bonding

Preparation of PCC Beams



4.8.4 Test procedure [13]

STEPS	PROCEDURE
STEP #1	9 Flexure Specimens PCC-1, PCC-2, PCC-3 BSRCC-1, BSRCC-2, BSRCC-3 MBSRCC-1, MBSRCC-2, MBSRCC-3 Were prepared
STEP #2	All the specimens were subjected to Third Point Loading as per IS 516:1959 procedure, individually on a universal testing machine, at a constant strain rate.
STEP #3	The load and displacement readings were taken at regular intervals for each specimen, using a digital indicator and the load vs. deflection curves were plotted.
STEP #4	Modulus of rupture and Modulus of elasticity values were calculated using proper mathematical for each specimen.

TEST PPROCEDURE

STEP #1

STEP #2

STEP #3

OBSERVATIONS, CALCULATIONS, RESULTS & DISCUSSIONS

5.1 Density Test

5.1.1 Observation Table

Specimen No.	Thickness(cm)	Oven dry mass(gm)	Volume of specimen(cm^3)	Mass density (gm/cm^3)
1	0.4	1.60	2.70	**0.593**
2	0.5	1.60	2.80	**0.571**
3	0.5	1.50	2.60	**0.577**
4	0.5	1.85	2.60	**0.712**
5	0.6	2.25	3.50	**0.643**
6	0.7	2.30	3.55	**0.648**
7	0.8	3.25	3.85	**0.844**
8	0.9	3.60	4.25	**0.847**
9	1.0	3.65	4.55	**0.802**
10	1.1	3.80	5.10	**0.745**
11	1.3	4.25	5.85	**0.726**
12	1.4	4.15	5.65	**0.734**

Table-5.1

5.1.2 Mathematical Expressions used

$$\text{Volume of specimen} = \frac{\text{Mass of water displaced(gm)}}{\text{Specific density of water}(\frac{\text{gm}}{\text{cm}^3})}\ \text{cm}^3$$

$$\text{Mass density} = \frac{\text{oven dry mass of specimen(gm)}}{\text{Volume of specimen}(\text{cm}^3)}\ \text{gm/cm}^3$$

5.1.3 Results

The density of bamboo lies in the range of 0.571-0.874.

5.1.4 Discussions

The density of bamboo is very low which makes it a very light material hence it can be transported and worked easily, rendering the use of cranes and other big machines unnecessary.

5.2 Initial Moisture Content Test

5.2.1 Observation Table

Specimen No.	Nodes	Thickness, cm	Initial weight, gm	Oven dry weight, gm	Moisture content %
1	0	0.6	20.00	17.35	**13.25%**
2	0	0.7	20.00	17.30	**13.50%**
3	0	0.6	16.20	14.15	**12.65%**
4	0	0.6	16.90	15.00	**11.24%**
5	1	0.5	50.00	41.95	**16.10%**
6	1	0.5	40.00	39.75	**00.63%**
7	1	0.5	29.50	26.15	**11.35%**
8	1	0.6	30.25	26.85	**11.24%**
9	2	0.7	70.00	59.95	**14.36%**
10	2	0.6	60.00	55.75	**07.08%**
11	2	0.7	71.25	62.95	**11.65%**
12	2	0.5	55.50	48.95	**11.80%**

Table-5.2

5.2.2 Mathematical Expressions used

$$\text{Moisture content } \% = \frac{\text{Initial weight(gm)} - \text{Dry weight(gm)}}{\text{initial Weight(gm)}} \times 100$$

5.2.3 Results

The initial moisture content of bamboo specimens tested lies in the range of 00.63%-16.10%

The below tables and graphs shows how moisture content varies with no. of nodes and thickness of bamboo specimen.

5.2.3.1 Variation of Average Moisture Content with Nodes:-

Inter-Nodes	Average Moisture Content %
0	12.66%
1	09.83%
2	11.22%

Table-5.3

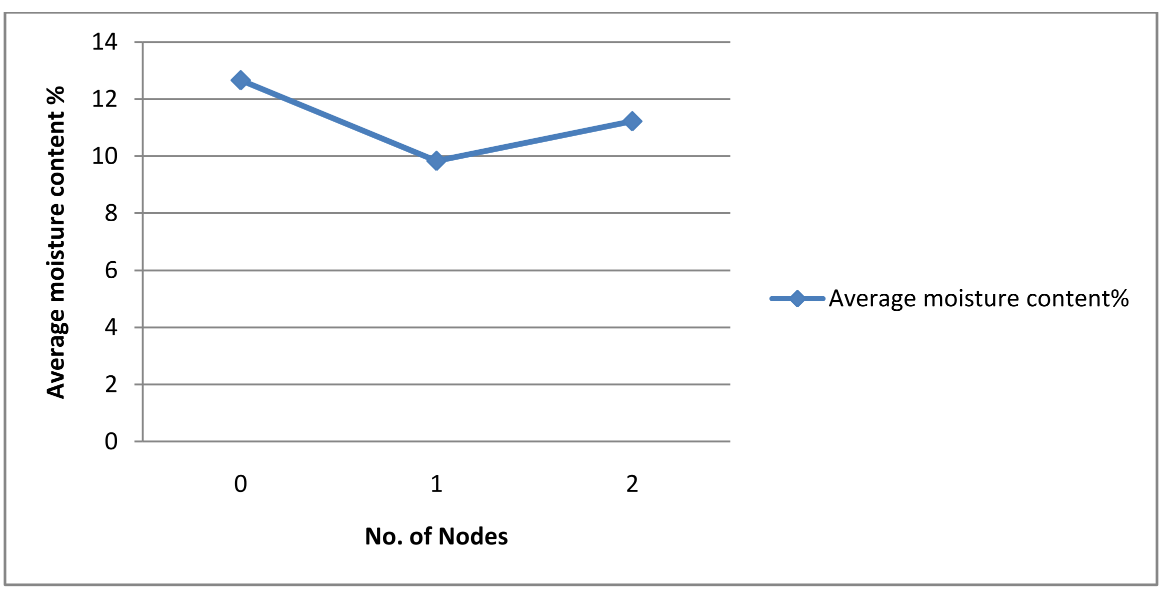


Fig. 5.1

5.2.3.2 Variation of Average Moisture Content with thickness of specimens:-

Thickness, cm	Average Moisture Content %
0.5	09.975
0.6	11.09%
0.7	13.17%

Table-5.4

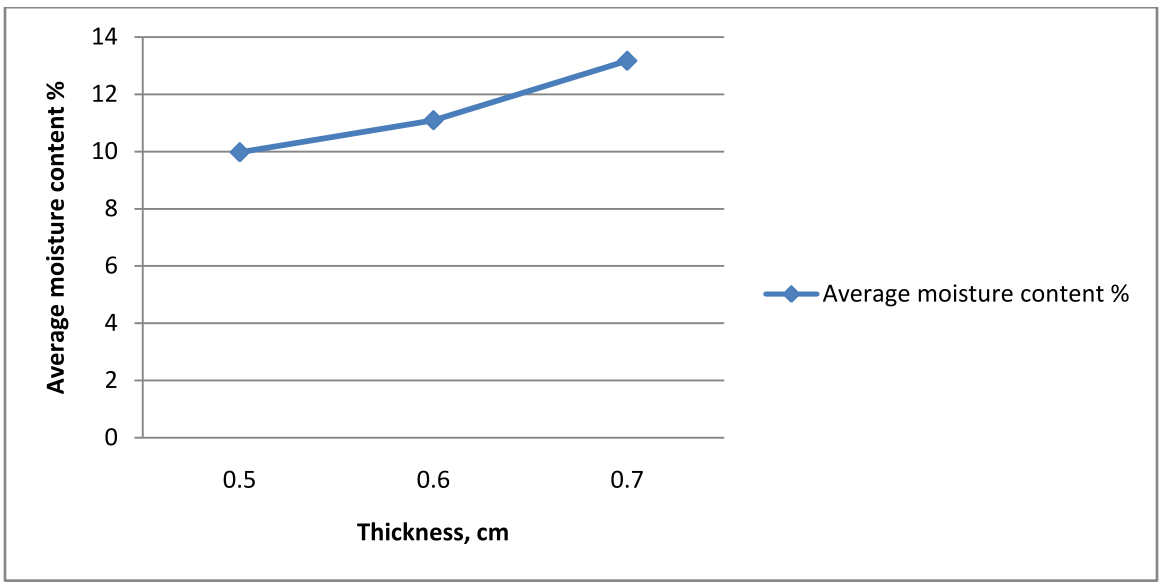


Fig. 5.2

5.2.4 Discussions

The graph between "Average moisture content%-vs.-No. of Nodes" comes out to be haphazard curve, hence no possible correlation can be drawn between the two from the obtained plot.The graph between “Average moisture content%-vs.-thickness” can be approximated as a straight line, hence a linear relation seems to exist between the two. The thickness of a bamboo plant is not constant it varies along the height being maximum at the bottom and minimum at the top.Hence the specimen obtained from the bottom portion of bamboo has maximum initial water content and should be either avoided for use as reinforcing material in concrete or if used should be properly seasoned i.e. air dried.

The average value of initial moisture content of all the 12 samples comes out to be 11.28% by weight which is less than 15%, hence according to *M.R. Wkchaure and S.Y. Kute(2012),effects of moisture content on physical and mechanical properties of bamboo,Asian journal of civil engineering(building and housing(vol.13,No.6(2012),* the mechanical properties of the bamboo tested will not get much affected by the presence of initial moisture content, the bamboo tested was well seasoned and aged and, the bamboo tested has less possibilities of mould and insect attacks.

5.3 Water Absorption Test

5.3.1 Observation Table

After – 15 Days of immersion in water									
Type	**Nodes**	**Initial Thickness (cm)**	**Initial dry weight (gm)**	**Saturated Weight, (gm)**	**Weight of water absorbed (gm)**	**% by weight of water absorbed**	**Average water absorbed %**	**Final thickness (cm)**	**% increase in thickness**
A-1	0	0.6	17.35	042.15	24.80	58.84%	58.35%	0.6	00.00%
A-2	1	0.5	41.95	098.65	56.70	57.47%		0.6	16.67%
A-3	2	0.7	59.95	145.35	85.40	58.75%		0.7	16.67%
B-1	0	0.7	27.60	035.85	08.25	23.01%	21.34%	0.7	00.00%
B-2	1	0.5	57.35	068.60	11.25	16.39%		0.5	00.00%
B-3	2	0.6	75.05	099.60	24.55	24.64%		0.6	00.00%

After – 30 Days of immersion in water									
Type	**Nodes**	**Initial Thickness (cm)**	**Initial dry weight (gm)**	**Saturated Weight, (gm)**	**Weight of water absorbed (gm)**	**% by weight of water absorbed**	**Average water absorbed %**	**Final thickness (cm)**	**% increase in thickness**
A-1	0	0.6	17.35	043.00	25.65	59.65%	59.23%	0.6	00.00%
A-2	1	0.5	41.95	099.75	57.80	57.95%		0.7	40.00%
A-3	2	0.7	59.95	150.20	90.25	60.08%		0.8	33.33%
B-1	0	0.7	27.60	037.65	10.05	26.69%	24.91%	0.7	00.00%
B-2	1	0.5	57.35	071.40	14.05	19.68%		0.5	00.00%
B-3	2	0.6	75.05	104.75	29.70	28.35%		0.7	16.67%

Table-5.5

5.3.2 Mathematical Expressions used

$$\text{Water absorbed(gm)} = \text{final saturated weight(gm)} - \text{Dry weight(gm)}$$

$$\%\text{by weight of water absorbed} = \frac{\text{Water absorbed(gm)}}{\text{Final Saturated weight(gm)}} \times 100$$

5.3.3 Results

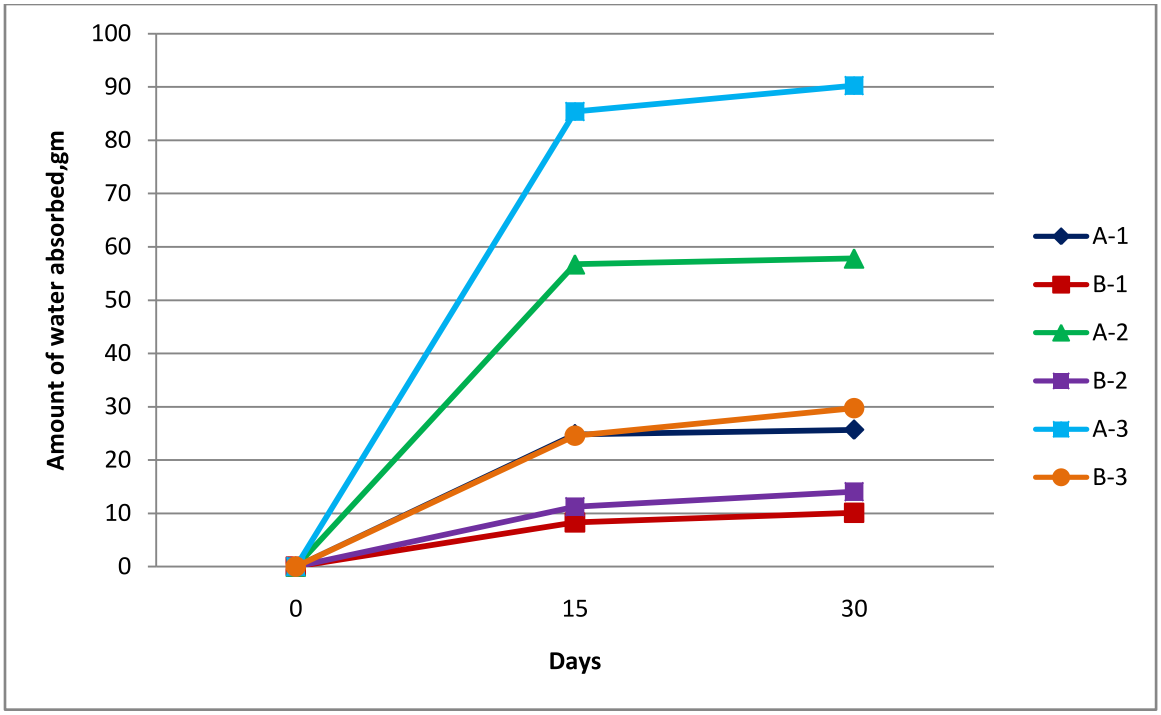
The water absorption capacity of untreated bamboo comes out to be 58.35% by weight after 15 days of immersion in water and 59.23% by weight after 30 days of immersion in water. The water absorption capacity of bamboo treated by bitumen get reduced to 21.34% by weight after 15 days of immersion in water and 24.91% by weight after 30 days of immersion in water.

The below tables and graphs shows how water absorption capacity of bamboo varies with days, nodes and , initial dry weight. The final table and graph shows how much % increase in thickess (indiaction of swelling of bamboo) is observed in the samples tested.

5.3.3.1 Variation of amount of water absorbed with no. of nodes & days:-

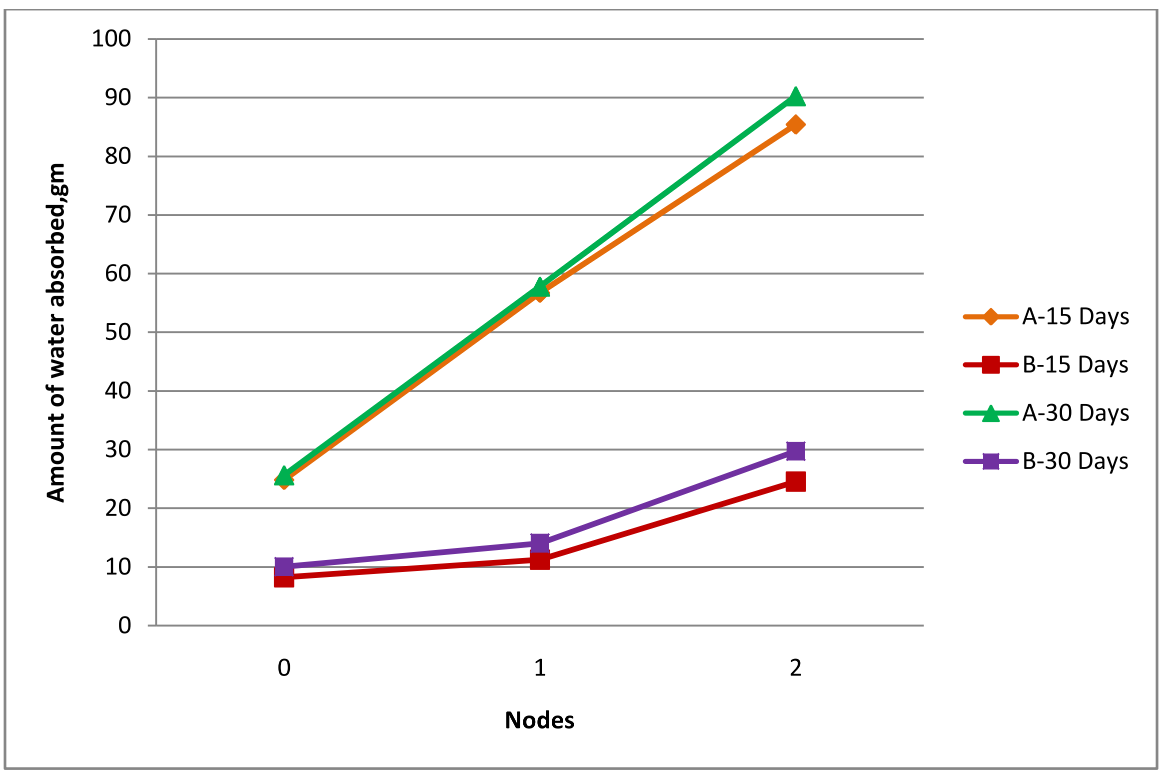
Type	Nodes	Water absorbed after 15 days	Water absorbed after 30 days
A-1	0	24.80 gm	25.65gm
A-2	1	56.70 gm	57.80gm
A-3	2	85.40gm	90.25 gm
B-1	0	08.25gm	10.05 gm
B-2	1	11.25gm	14.05gm
B-3	2	24.55gm	29.70gm

Table-5.6



100
90
80
70
60
50
40
30
20
10
0
Amount of water absorbed,gm
0
15
30
Days
A-1
B-1
A-2
B-2
A-3
B-3

Fig. 5.3



100
90
80
70
60
50
40
30
20
10
0
Amount of water absorbed,gm
0
1
2
Nodes
A-15 Days
B-15 Days
A-30 Days
B-30 Days

Fig. 5.4

5.3.3.2 Variation of %increase in thickness with types of samples & days:-

Type	% increase in thickness after 15 days	% increase in thickness after 30 days
A-1	00.00%	00.00%
A-2	16.67%	40.00%
A-3	16.67%	33.33%
B-1	00.00%	00.00%
B-2	00.00%	00.00%
B-3	00.00%	16.67%

Table-5.7

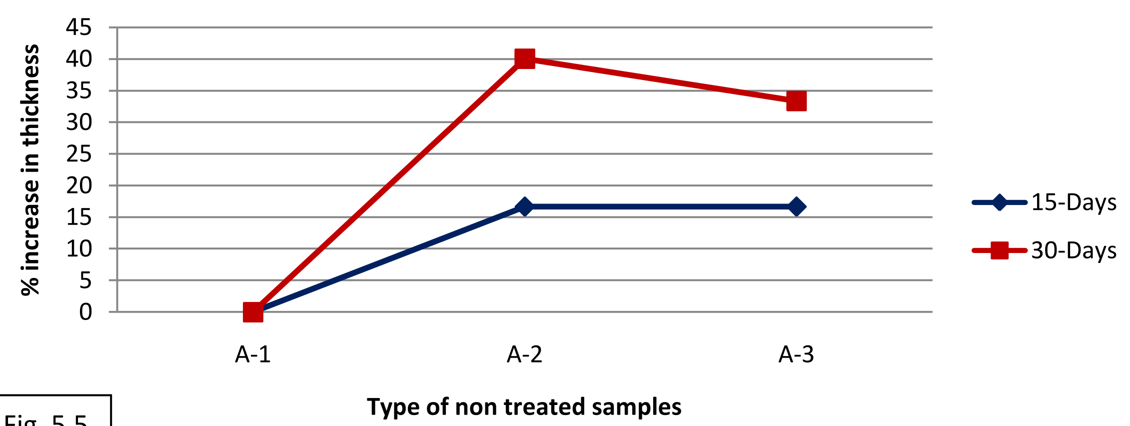


Fig. 5.5

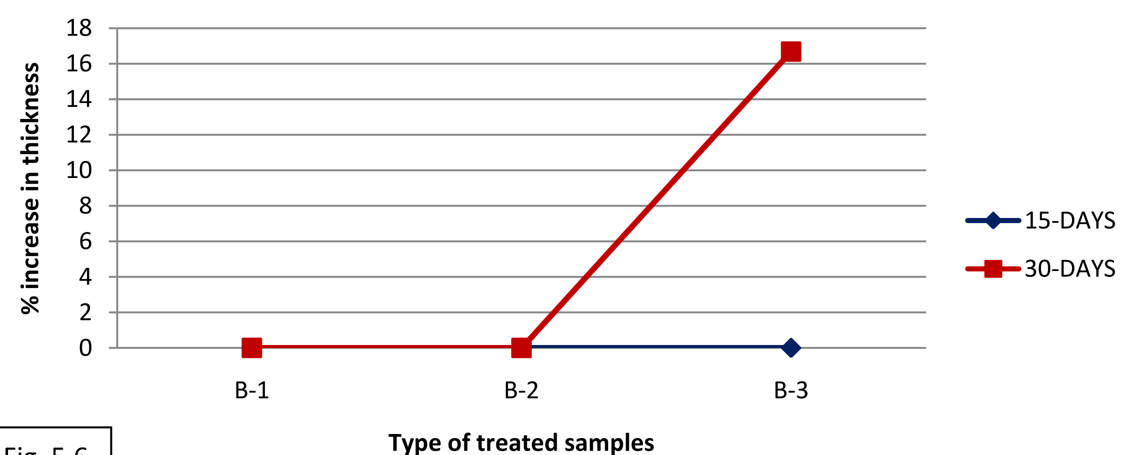


Fig. 5.6

5.3.4 Discussions

The graph between “amount of water absorbed-vs.-number of days of soaking”, shows that water is absorbed by the bamboo specimen at a faster rate for the initial 15 days, thereafter it declines for all types of specimens. %increase in thickness after 30 days of soaking comes out to be as high as 40% inn some of the non treated bamboo samples which shows that there is a high possibility of swelling of the bamboo splints once they absorb water from the surrounding, eventually generating additional stresses in reinforced concrete elements if used as reinforcing material.the water absorption capacity of bamboo is as high as 60% by weight as seen after 30 days pf soaking. Which gets reduced to about 25% by weight on coating with a water proofing material i.e. bitumen.which necessitates the use of a water proofing compound.The graph between amount of water absorbed-vs.-number of nodes” can be approximated as a straight line hence water absorption capacity of bamboo increase with increse in the number of nodes, this is due to the presence of powder like grains at nodes.

Though the water absorption capacity of bamboo get lowered to 25% from 60% on coating it with bitumen, but still there has been significant absorption of water in treated samples also which shows that bitumen is not a sucessful water coating material for bamboo because of its high viscosity and stripping property in presence of water.

5.4 Compression Test

5.4.1 Observation Table

Sample	Load at Failure (KN)	Displacement at Failure (mm)
A-1	44.80	1.0
A-2	74.40	1.1
A-3	79.70	1.0
B-1	47.50	0.6
B-2	79.80	0.8
B-3	87.60	0.6

Table-5.8

5.4.2 Mathematical Expressions used

$$\text{Stress}(\sigma) = \frac{\text{Load}(P)}{\text{crosssectioanl area}(A)}$$

$$\text{Strain}(\in) = \frac{\text{Displacement}(\Delta)}{\text{Gauge Length}(L)}$$

$$\text{Modulus of elasticity}(E) = \frac{\text{stress}(\sigma)}{\text{Strain}(\epsilon)}$$

5.4.3 Results

The ultimate compressive strength of specimens containing zero internode comes out in the range of 57.97Mpa-84.58Mpa while that of samples consisting of internode lies in the range of 72Mpa-90.72Mpa.The results of the test are summed up in the below mentioned table. Using the values of stress-vs.strain the stress-vs.-strain diagram in compression was plotted for each of the sample.

Sample	Nodes	Thickness (mm)	Outer diameter (mm)	Ultimate compressive Stress (MPa)	Strain	Modulus of Elasticity (GPa)
A-1	0	06.0	47.0	57.97	0.00689	69.60
A-2	0	08.0	43.0	84.58	0.00775	74.74
A-3	0	10.0	44.0	74.61	0.00855	25.63
B-1	1	05.0	47.0	71.99	0.00405	110.53
B-2	1	08.0	43.0	90.71	0.00548	89.96
B-3	1	09.0	44.0	88.52	0.00419	99.13

Table-5.9

5.4.3.1 Stress-vs.-Strain curves of sample A-1:-

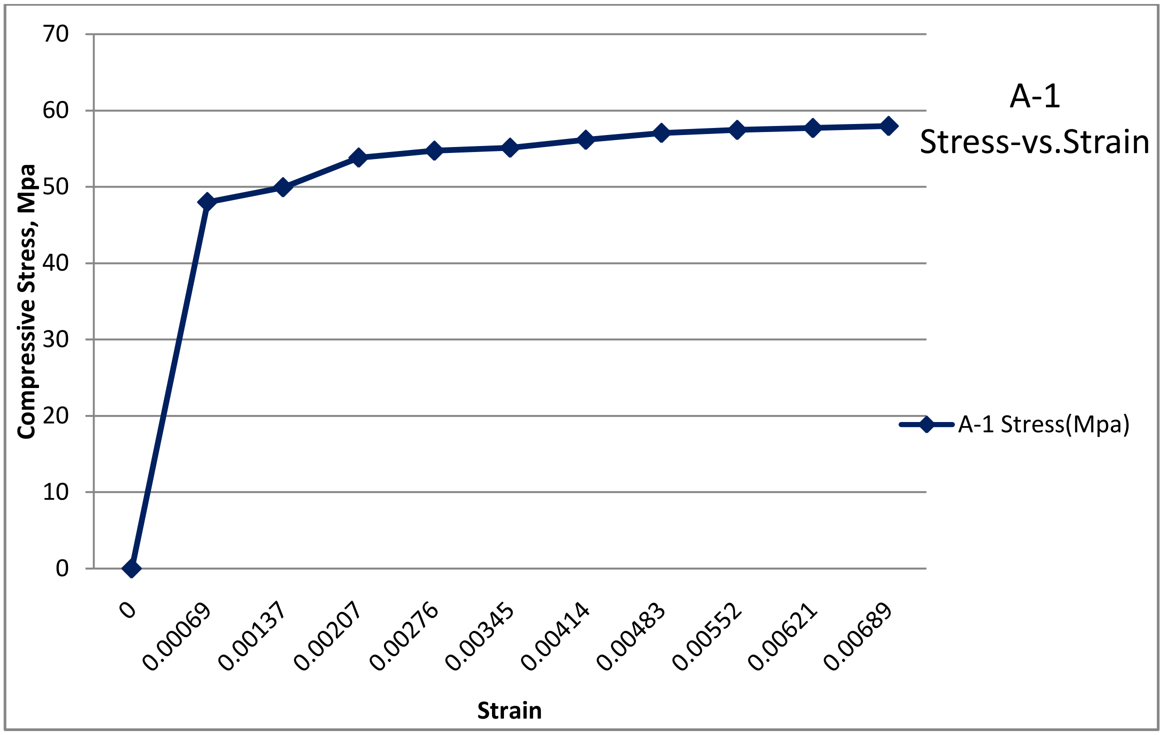


Fig. 5.7

5.4.3.2 Stress-vs.-Strain curves of sample A-2:-

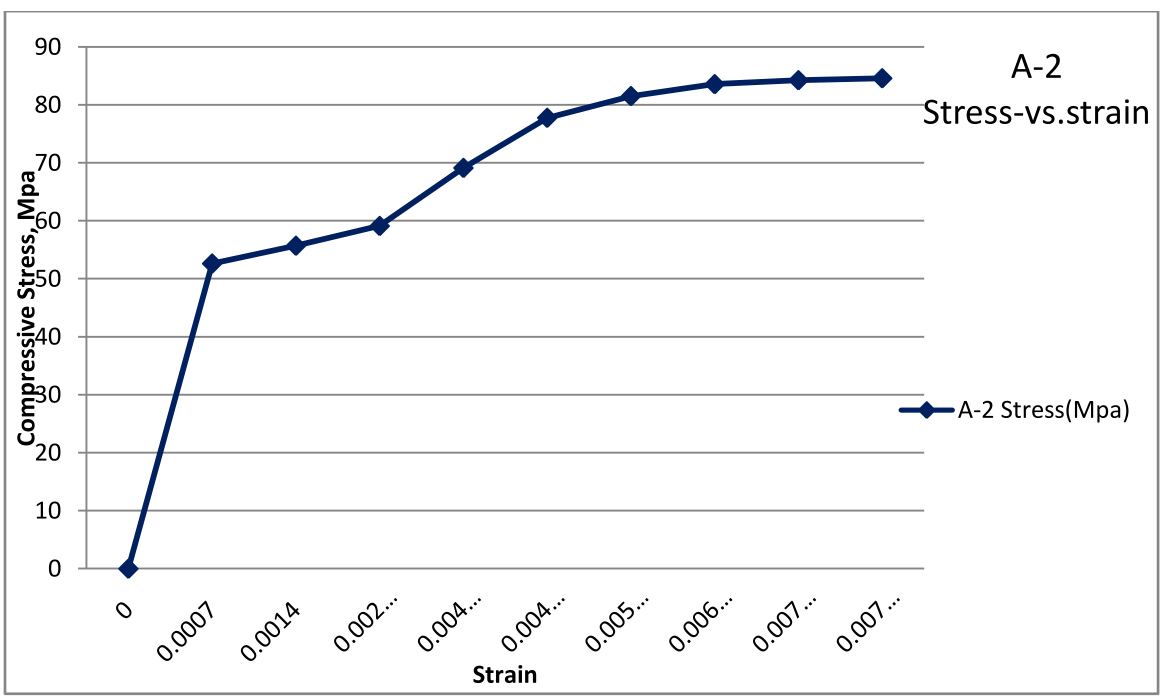


Fig. 5.8

5.4.3.3 Stress-vs.-Strain curves of sample A-3:-

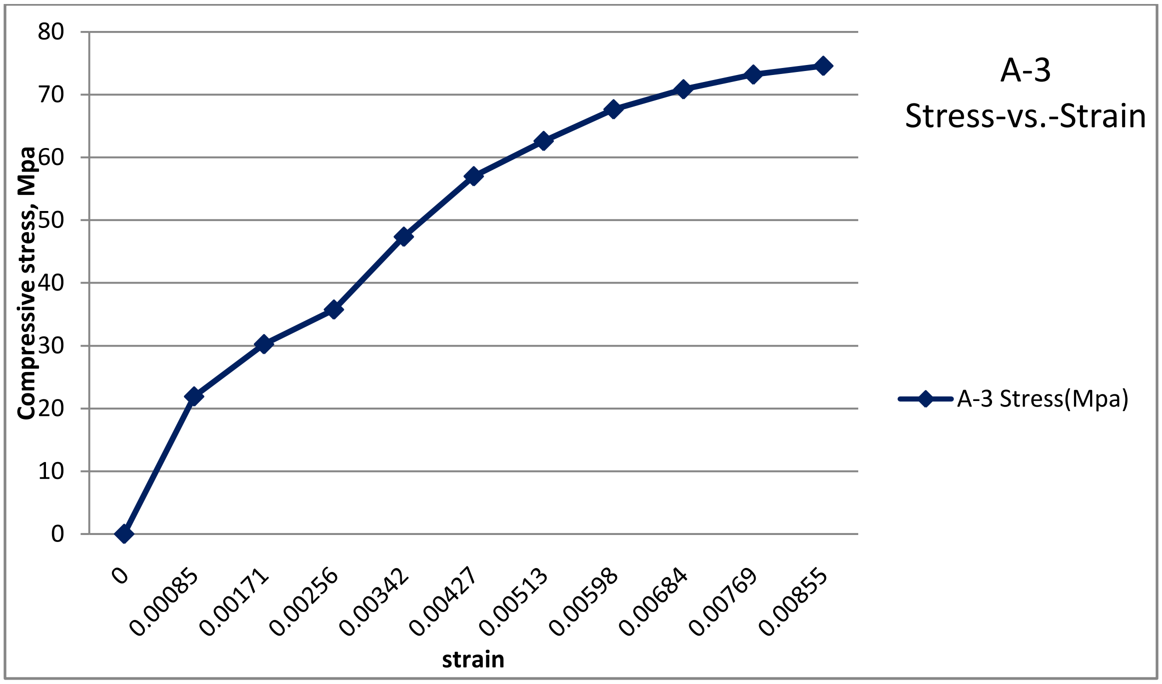


Fig. 5.9

5.4.3.4 Stress-vs.-Strain curves of sample B-1:-

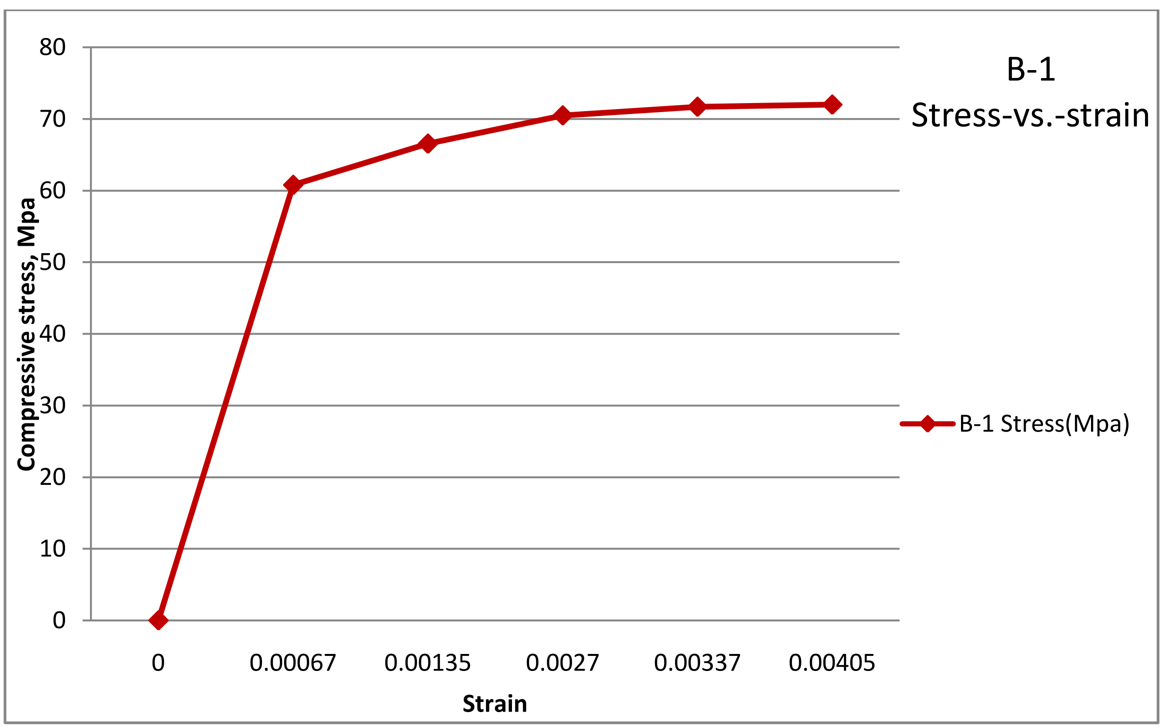


Fig. 5.10

5.4.3.5 Stress-vs.-Strain curves of sample B-2:-

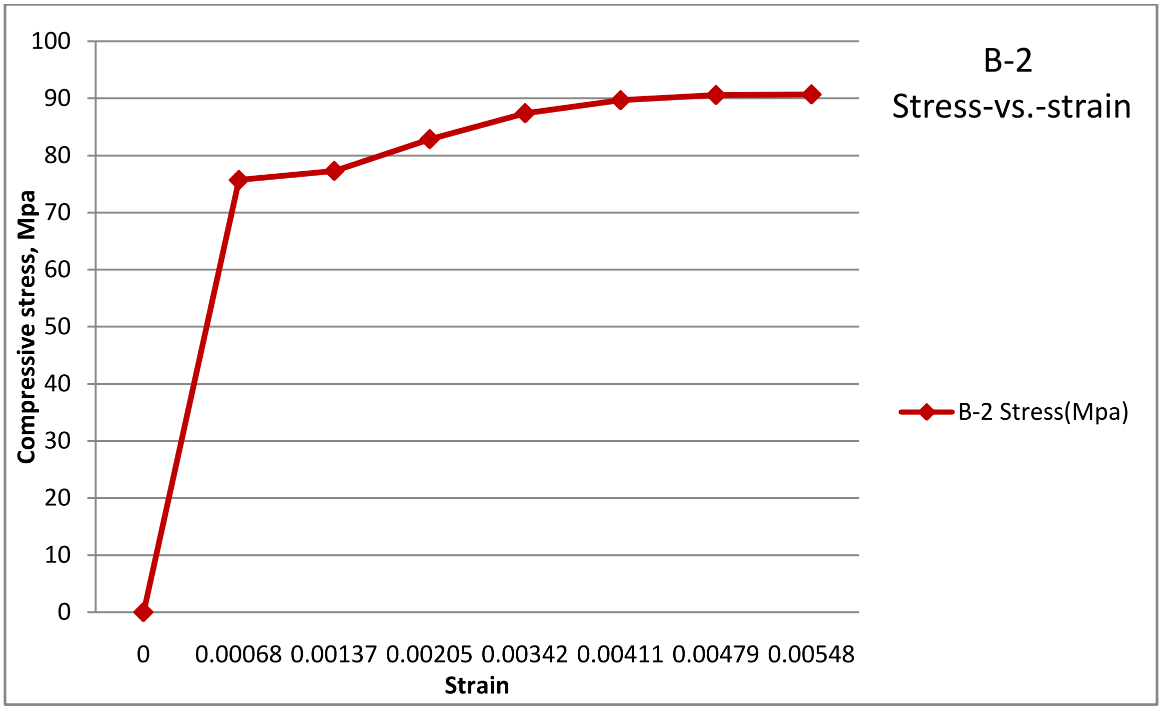


Fig. 5.11

5.4.3.6 Stress-vs.-Strain curves of sample B-3:-

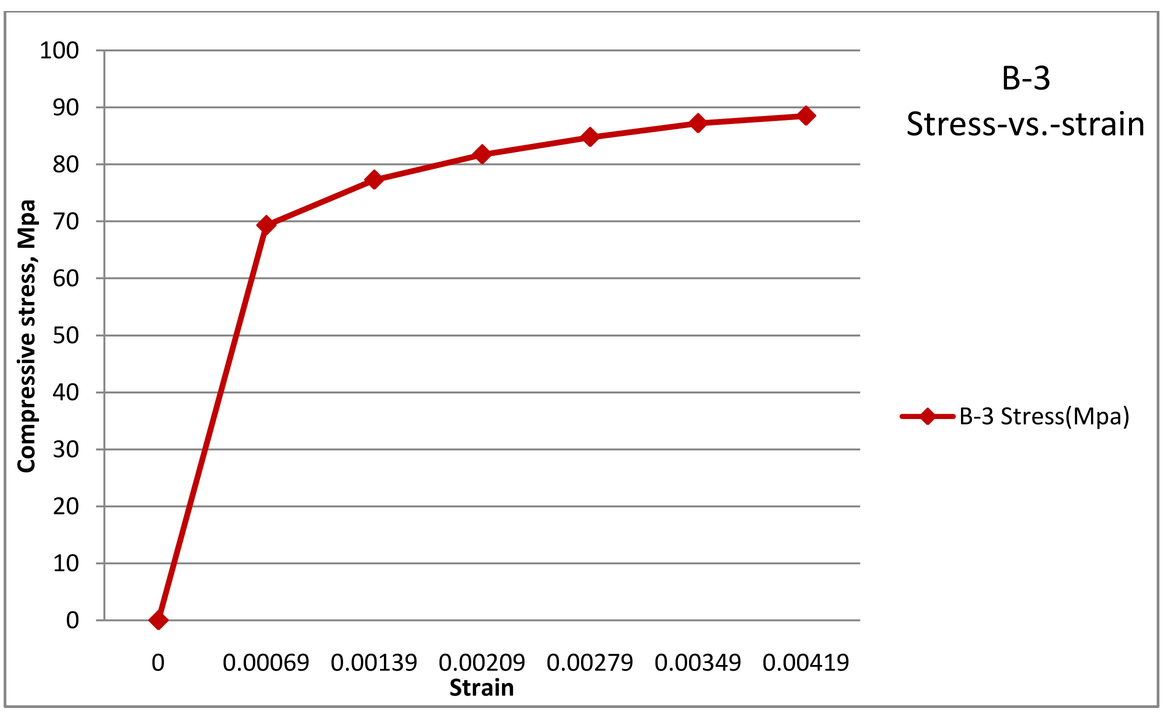


Fig. 5.12

5.4.4 Discussions

Bamboo in compression was seen to fail in two modes: Cracking of fiber and crushing. Most of specimens failed as a combination of both the modes.

A-1		**B-1**	
A-2		**B-2**	
A-3		**B-3**	

Fig. 5.13

Bamboo shows a high value of compressive strength which is comparable to steel and concrete.The compressive strength of bamboo specimen with internode has been found to be greater than that of specimens without and internode this could be because of additional crossectional area at nodes (as walls are thicker on both sides of the node) and due to the dense mass present at nodes. Some of the specimen showed an ideal faliure by cracking longitudinally but most of them showed a mixed mode of faliure wherein the specimen cracked as well as got crushed.

The stress-vs.-strain curve of specimens without an internode, seems to be fairly linear upto 40Mpa and its modulus of elasticity comes near about 56.7Gpa which is much less than steel(200 Gpa).whereas the stress-vs.-strain curve of specimens with an internode, seems to be fairly linear upto 102.9Mpa and its modulus of elasticity comes nearly about 99.87GPa, almost 50% of that of steel. Because of this low value of modulus of elasticity of bamboo culm, it becomes unable to prevent tensile cracking in concrete. This is the main reason why a flexure element reinforced with a whole bamboo culm performs poorly than a flexure element reinforced with bamboo splints.

5.5 Tension Test

5.5.1 Observation Table

Sample	Load at Failure (KN)	Displacement at Failure (mm)
A-1	40.40	31.80
A-2	25.20	16.90
A-3	47.40	33.40
A-4	35.80	22.40
A-5	43.10	32.60
A-6	28.20	18.20

Table-5.10

5.5.2 Mathematical Expressions used

$$\text{Stress}(\sigma) = \frac{\text{Load}(P)}{\text{crosssectioanl area}(A)}$$

$$\text{Strain}(\in) = \frac{\text{Displacement}(\Delta)}{\text{Gauge Length}(L)}$$

$$\text{Modulus of elasticity}(E) = \frac{\text{stress}(\sigma)}{\text{Strain}(\epsilon)}$$

5.5.3 Results

the ultimate compressive strength of bamboo comes in the range of 168.33Mpa – 298.33Mpa which is comparable to the yield stress of structural steel i.e. 250Mpa.the modulus of elasticity of bamboo splints comes in the range of 16.125Gpa- 207.0Gpa. which is again comparable to steel which is 200Gpa. The results of the test are summed up in the below mentioned table. Using the values of stress-vs.strain the stress-vs.-strain diagram in tension was plotted for each of the sample.

Sample	Nodes	Thickness (mm)	Width (mm)	Ultimate Tensile Stress (MPa)	Strain	Modulus of Elasticity (GPa)
A-1	1	12.0	20.0	168.333	0.212000	038.75
A-2	1	05.0	20.0	252.000	0.112667	205.50
A-3	1	09.0	20.0	263.333	0.222667	101.67
A-4	1	06.0	20.0	298.333	0.149333	156.25
A-5	1	12.0	20.0	179.583	0.217333	16.125
A-6	1	05.0	20.0	282.000	0.121333	207.00

Table-5.11

5.5.3.1 Stress-vs.-Strain curves of sample A-1:-

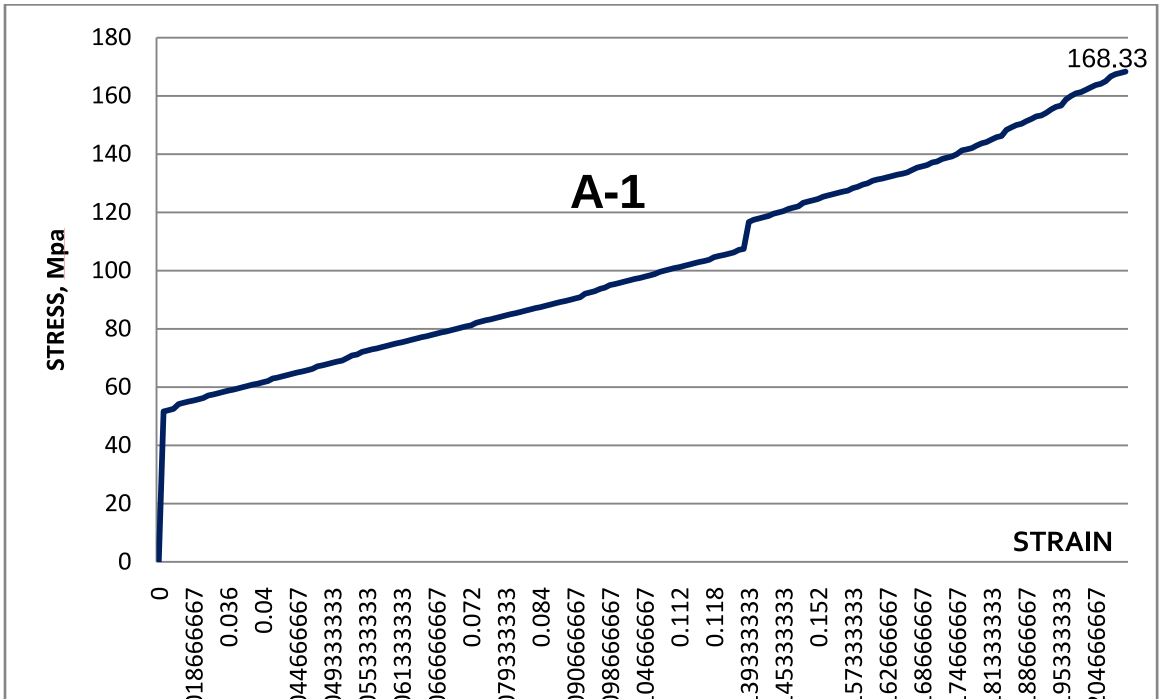


Fig. 5.14

5.5.3.2 Stress-vs.-Strain curves of sample A-2:-

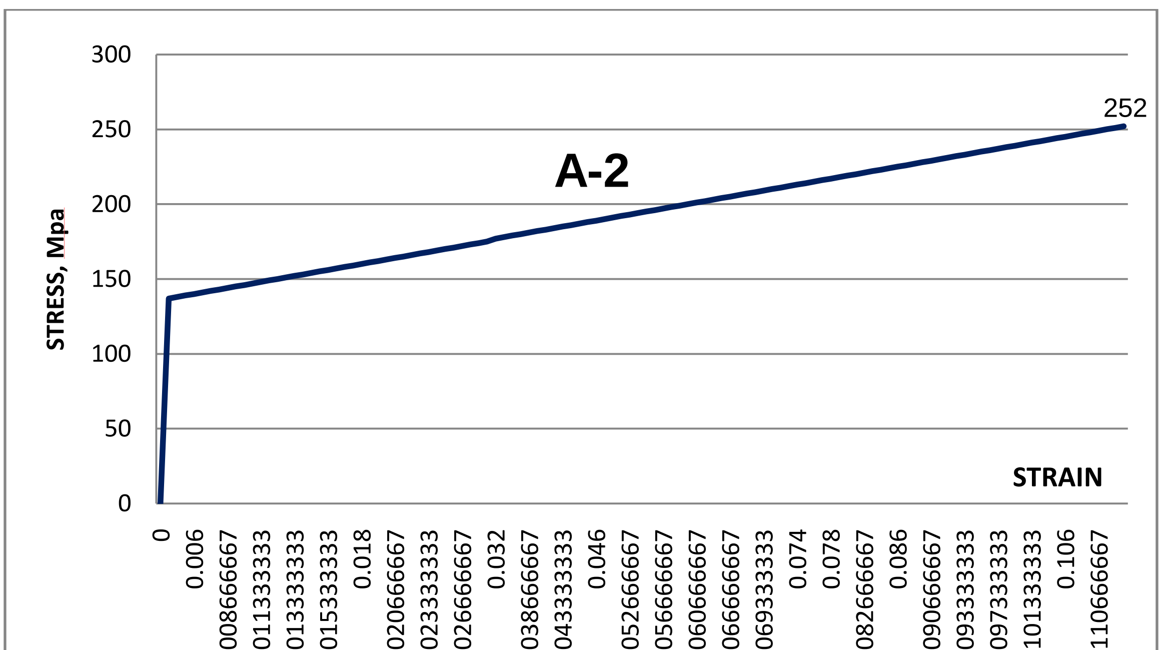


Fig. 5.15

5.5.3.3 Stress-vs.-Strain curves of sample A-3:-

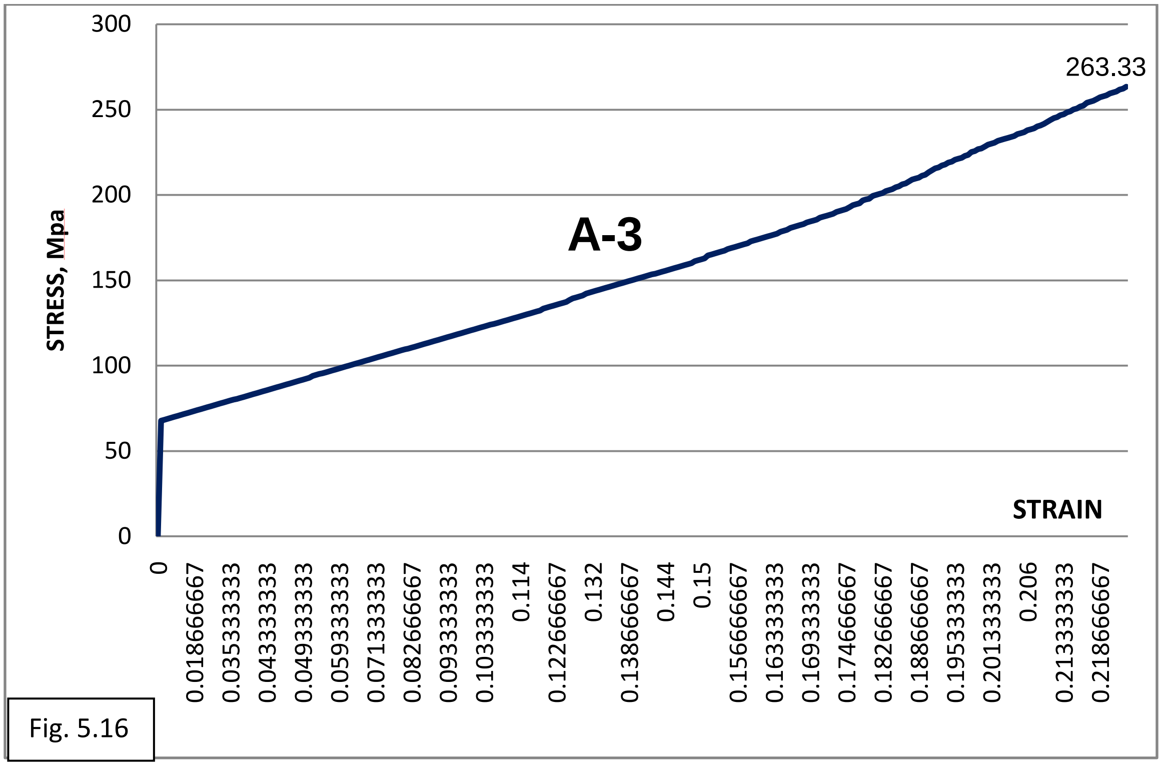


Fig. 5.16

5.5.3.4 Stress-vs.-Strain curves of sample A-4:-

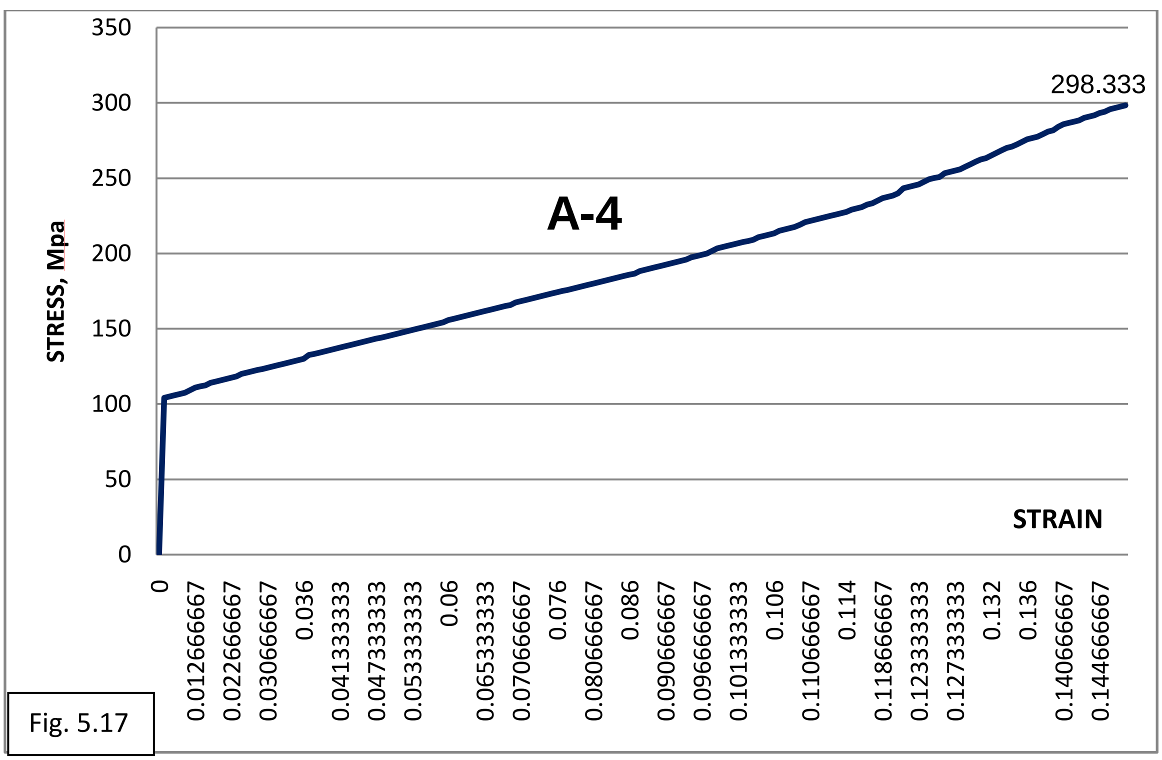


Fig. 5.17

5.5.3.5 Stress-vs.-Strain curves of sample A-5:-

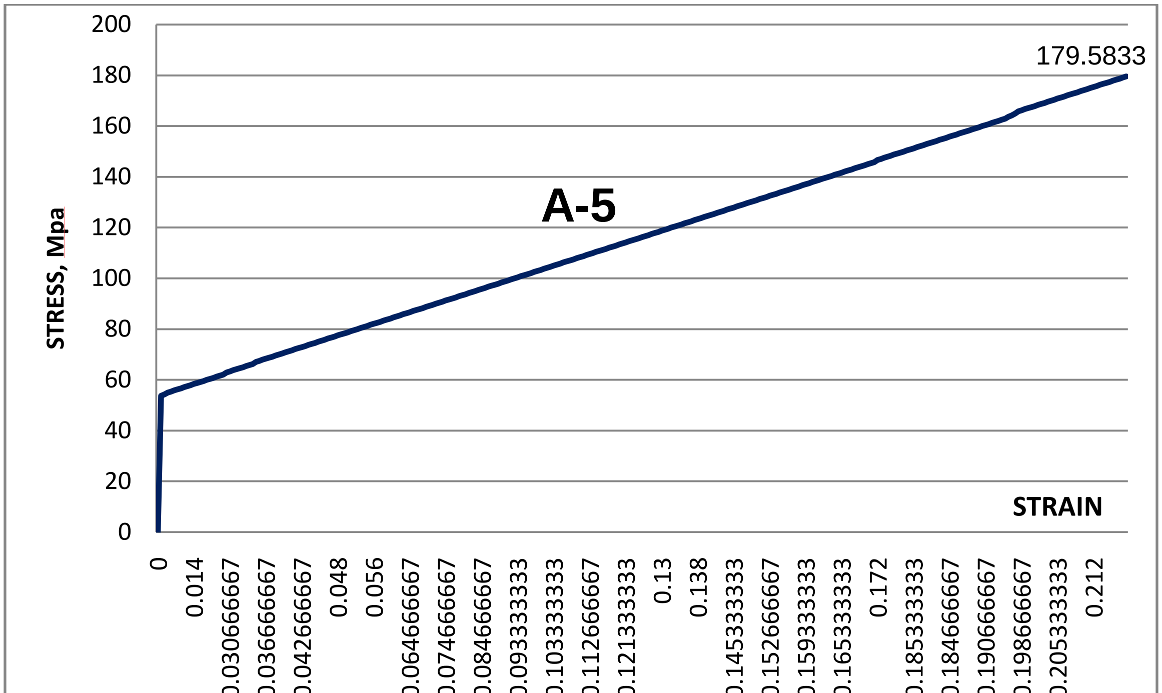


Fig. 5.18

5.5.3.6 Stress-vs.-Strain curves of sample A-6:-

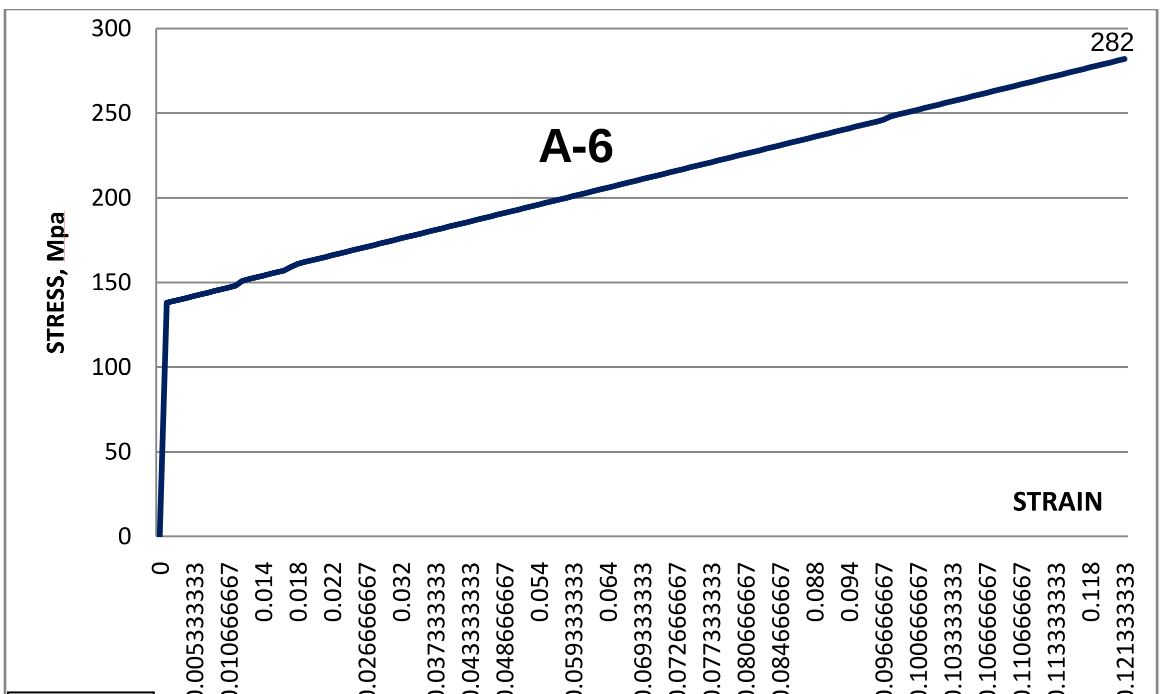


Fig. 5.19

5.5.4 Discussions

All the bamboo speciments shown brittle faliue at node, making node as the most critical section for faliure under tensile stresses.

A-1		**A-4**	
A-2		**A-5**	
A-3		**A-6**	

Fig. 5.20

The stress-vs.-strain curve of bamboo splint shows that bamboo is a visco elastic material(viscoelastic material have both viscous and elastic properties and exhibits time dependent strain, elasticity is the result of bond streching along the crystallographic planes in an ordered solid, viscosity is the result of diffusion of atoms or moecules inside an amorphous material.viscoelastic material have follwing properties-hysteresis is seen in stress strain curve, stress relaxation occurs, creep occurs). The modulus of elasticity of bamboo splints shows a wide range of values between 16.125Gpa(which is very less as compared to steel)-207Gpa(which is comparable to steel),the reason for this is that the specimens taken for the test were from diferent bamboo culms,and depending on the particular specie modulus of elasticity seems to vary. The ultimate tensile strent of bamboo splints is as high as 282Mpa which is comparable to the yield strength of structural steel i.e 250Mpa. Hence bamboo can take sufficient tensile loads in a concrete flexure element.

5.6 Durability Test on Bamboo Splints

5.6.1 Observation Table

Sample	Load at Failure (KN)	Displacement at Failure (mm)
W-1	21.80	33.6
W-2	36.6	35.0
W-3	39.6	40.4
S-1	20.9	10.6
S-2	27.2	27.8
S-3	47.7	51.3
C-1	22.4	20.2
C-2	31.5	26.4
C-3	35.9	32.6

Table-5.12

5.6.2 Mathematical Expressions used

$$\text{Stress}(\sigma) = \frac{\text{Load}(P)}{\text{crosssectioanl area}(A)}$$

$$\text{Strain}(\in) = \frac{\text{Displacement}(\Delta)}{\text{Gauge Length}(L)}$$

5.6.3 Results

5.6.3.1 Effects on Mechanical Properties of Bamboo Splints:-

Sample	Cross-section area (mm^2)	Strain	Ultimate tensile strength (MPa) f_t	Initial Ultimate tensile (MPa) f_i	Loss of tensile strength (MPa) f_i-f_t	% loss of tensile strength $((f_i-f_t)/f_i)x100$
Specimens kept in H_2O solution : Ph-7.0						
W-1	96.0	0.0473	227.083	282.000	054.917	19.47%
W-2	180	0.0470	203.333		078.667	27.89%
W-3	240	0.0541	165.000		117.000	41.48%
Average, % loss of tensile strength =						**29.61%**

Sample	Cross-section area (mm^2)	Strain	Ultimate tensile strength (MPa) f_t	Initial Ultimate tensile (MPa) f_i	Loss of tensile strength (MPa) f_i-f_t	% loss of tensile strength $((f_i-f_t)/f_i)x100$
Specimens kept in NaCl solution : Ph-7.5, Concentration-33.33gm/l						
S-1	88.0	0.0142	237.500	282.000	044.500	15.78%
S-2	152	0.0375	178.947		103.053	36.54%
S-3	220	0.0675	216.818		065.182	23.11%
Average, % loss of tensile strength =						**25.14%**

Sample	Cross-section area (mm^2)	Strain	Ultimate tensile strength (MPa) f_t	Initial Ultimate tensile (MPa) f_i	Loss of tensile strength (MPa) f_i-f_t	% loss of tensile strength $((f_i-f_t)/f_i)x100$
Specimens kept in $Ca(OH)_2$ solution : Ph-14, Concentration-33.33gm/l						
C-1	090.0	0.0282	248.888	282.000	033.112	11.74%
C-2	176.0	0.0356	179.545		102.455	36.33%
C-3	210.0	0.0442	170.952		111.048	39.36%
Average, % loss of tensile strength =						**29.14%**

Table-5.13

5.6.3.2 Chart comparing ultimate tensile strength:-

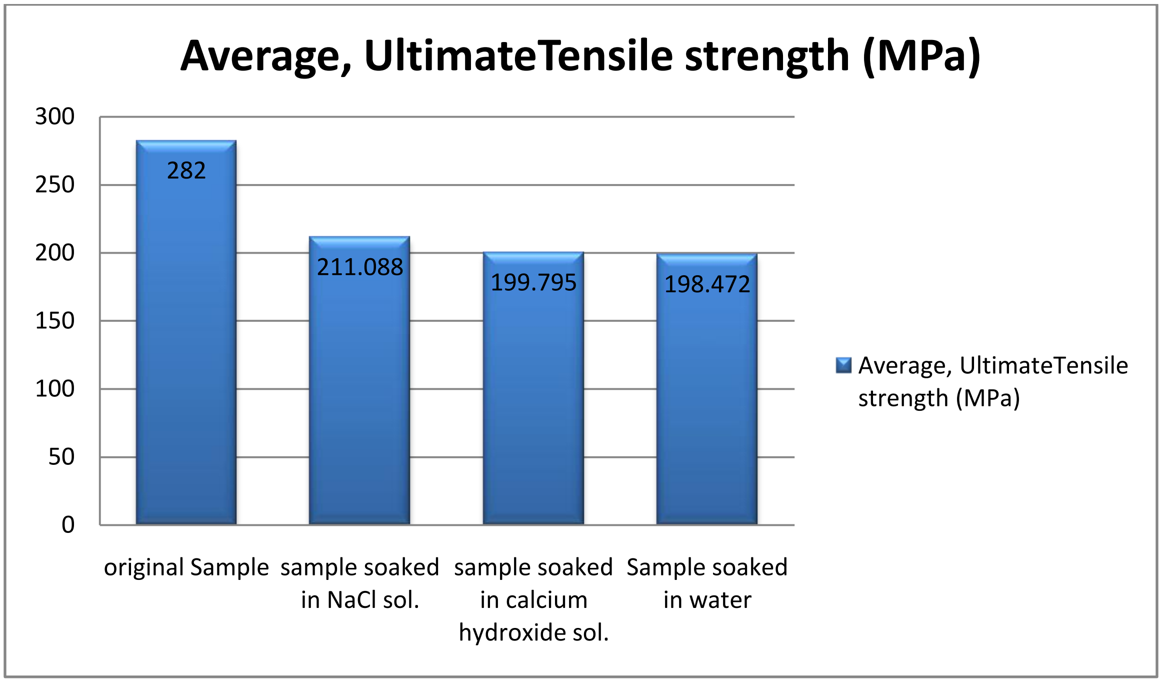


Fig. 5.21

5.6.3.3 Chart comparing %loss of ultimate tensile strength:-

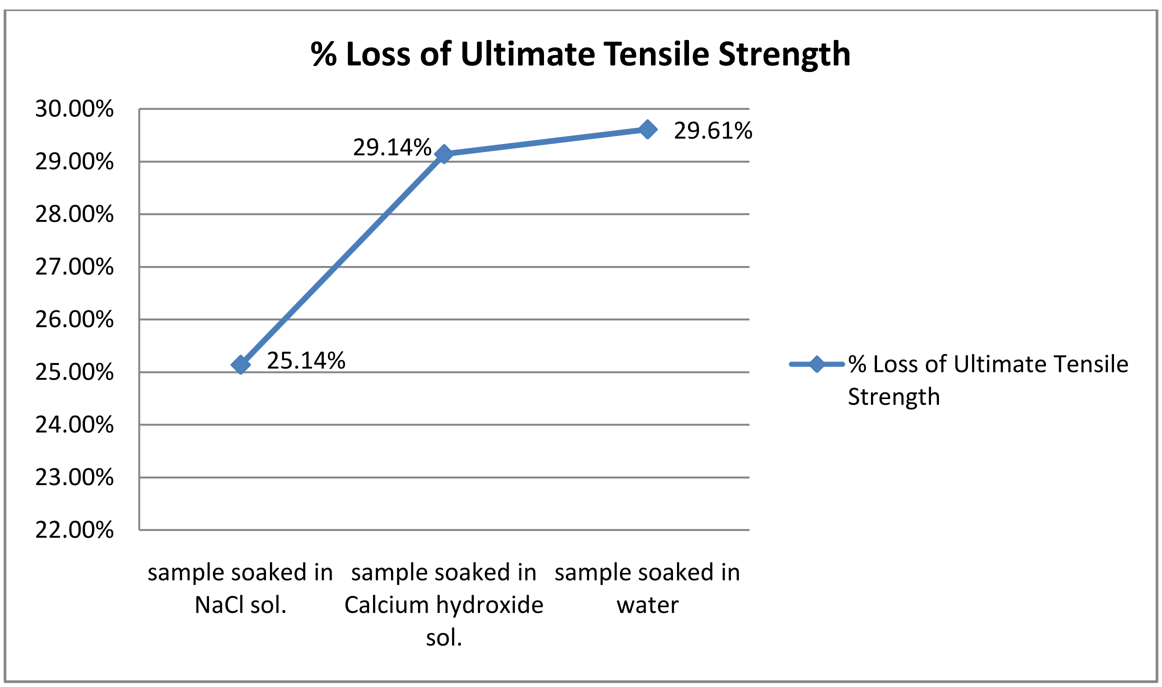


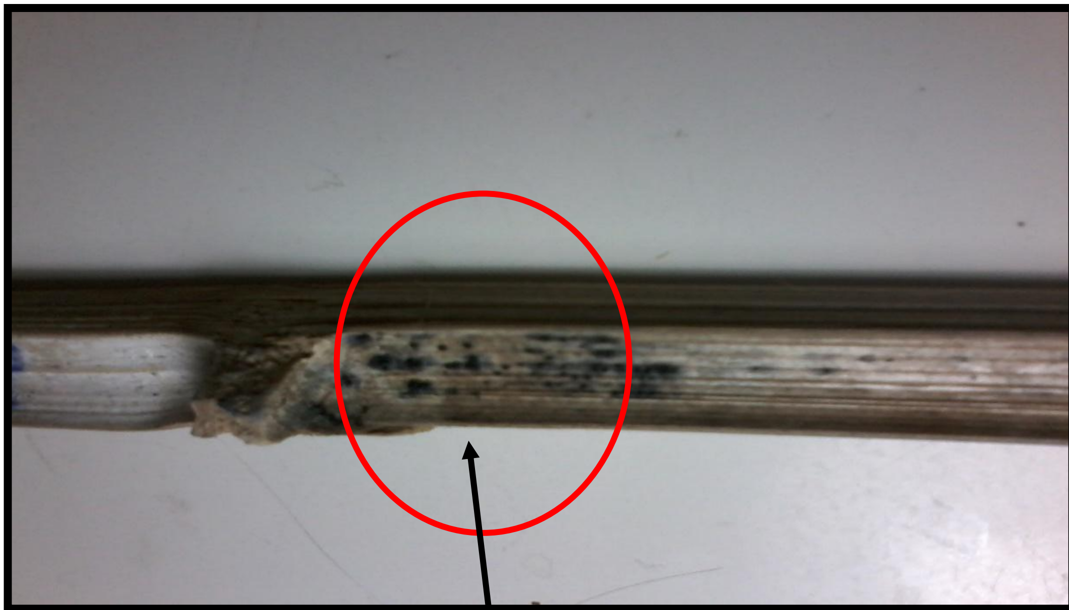
Fig. 5.22

5.6.3.4 Effects on Physical Properties of Bamboo Splints:-

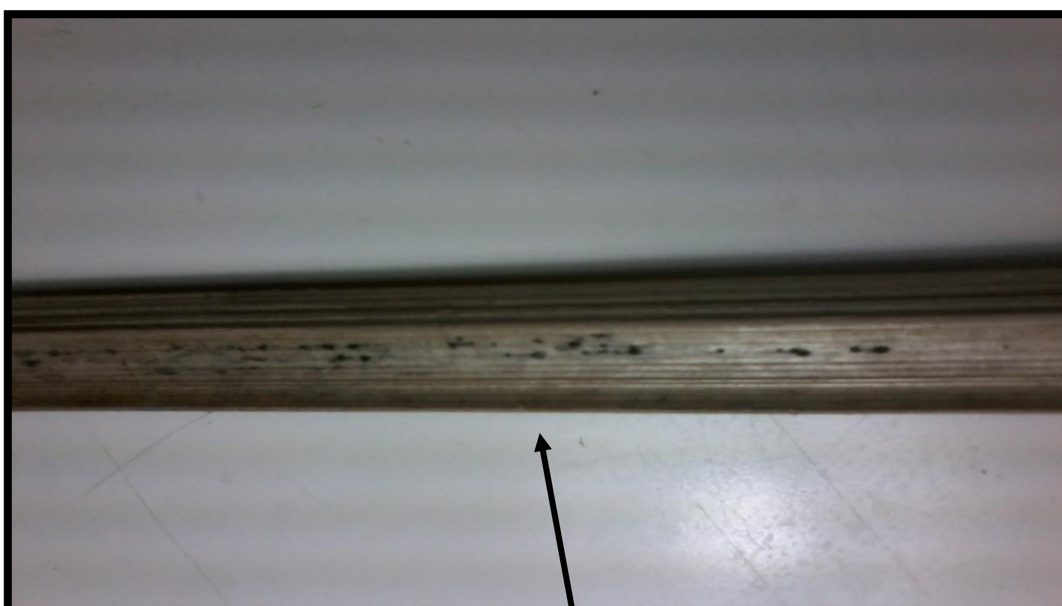
*Heavy fungal attack was observed on the surface of one of the bamboo splint (sample, W-1) wetted in **water**, causing rotting of bamboo and disintegration of fibers.*

Heavy Fungal Attack on surface and nodes

Disintegration of fibers



Fungal Attack on nodes, in sample W-2



Minute Fungal Attack on inner surface, in sample W-3

*Minor fungal attack was observed on the bamboo splints which were wetted in **calcium hydro-oxide solution,** at the nodes; the attack though did not caused any disintegration of fiber or rotting of bamboo. In addition to fungal attack deposition of calcium took place on the bamboo surface*

*No fungal attack was observed on the bamboo splints which were wetted in **sodium chloride solution,** neither at nodes nor at the inner surface.*

5.6.4 Discussions

25.14% of loss in ultimate tensile strength was observed in the samples wetted in NaCl solution. 29.14% of loss in ultimate tensile strength was observed in the samples wetted in $Ca(OH)_2$ solution & 29.61% of loss in ultimate tensile strength was observed in the samples wetted in tap water which was highest among the three, generally because of the rotting and disintegration of fibers.

The test results show that there is a significant loss in ultimate tensile strength of bamboo splints when they undergoes alternate swelling and shrinking in the presence of alkalis, chlorides and moisture - the environments they possibly would be exposed to when used as reinforcement in concrete elements, hence putting a question over the use of bamboo splints as reinforcement material in concrete elements?

To find out that whether this loss of tensile strength varies linearly or exponentially with the age of concrete or becomes constant after a specific age of concrete, the test need to be performed for longer duration and testing of samples should be done at successive intervals.

The swelling and shrinking of bamboo is attributed to its high water absorption and high water releasing properties due to its hygroscopic nature, hence this swelling and shrinking of bamboo can be controlled up to some extent by using a waterproof material like bitumen, coating over the surface of the bamboo splints before using them as a reinforcement material. The waterproofing material will not only prevent the swelling and shrinkage of bamboo but will also prevent the bamboo from coming in contact with alkalis and chlorides.

The samples wetted in water and $Ca(OH)_2$ shows a heavy fungal attack at nodes and at inner surface of the splints, leading to rotting of bamboo surface and disintegration of fibers. This necessitates the application of an anti fungal compound such as Boric Acid, over the bamboo splints before using them as a reinforcement material in concrete.

5.7 IS 516:1959 Third Point Loading Flexure Test on hardened Cement Concrete Flexure Elements Doubly Reinforced by Bamboo Splints, with Shear Links

5.7.1 Observation Table

Sample	Load at Failure (KN)	Displacement of Mid Section at Failure (mm)	Load at Yield (KN)	Displacement of Mid Section at Yield load (mm)
PCC-1	00.2	0.0	00.2	0.0
PCC-2	00.6	0.0	00.6	0.0
PCC-3	13.7	0.1	13.7	0.1
BRCC-1	12.3	6.7	07.7	0.1
BRCC-2	31.9	7.5	11.2	0.1
BRCC-3	32.0	9.9	22.5	0.1
MBRCC-1	29.8	1.9	19.6	0.1
MBRCC-2	34.9	5.4	27.5	0.1
MBRCC-3	40.7	6.6	30.3	0.1

Table-5.14

5.7.2 Mathematical Expressions used

Modulus of rupture of beam [13]

$$1)\quad f_b = \frac{3 \times p \times a}{b \times d^2}$$

Modulus of elasticity of beam [8], [13]

$$2)\quad E = \frac{23 \times W \times L^3}{648 \times \delta \times I}$$

f_b = Modulus of rupture, MPa

p = Maximum load, N

b = Width of beam, mm

d = Depth of beam, mm

a = Distance between line of fracture and nearest support.

W = Load at yield, N

L = Length of beam, mm

δ = Deflection of mid section at W load, mm

5.7.3 Results

5.7.3.1 Load-vs.-Deflection Curves after 7 days of Curing:-

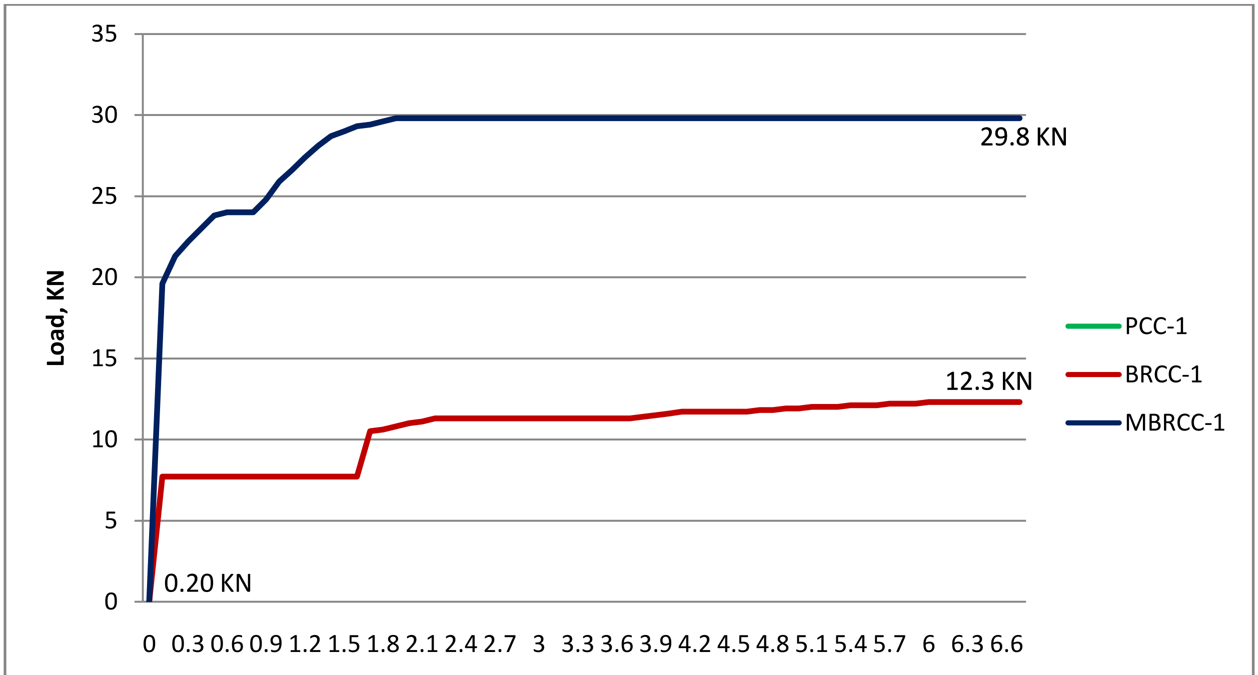


Fig. 5.23

5.7.3.2 Load-vs.-Deflection Curves after 14 days of Curing:-

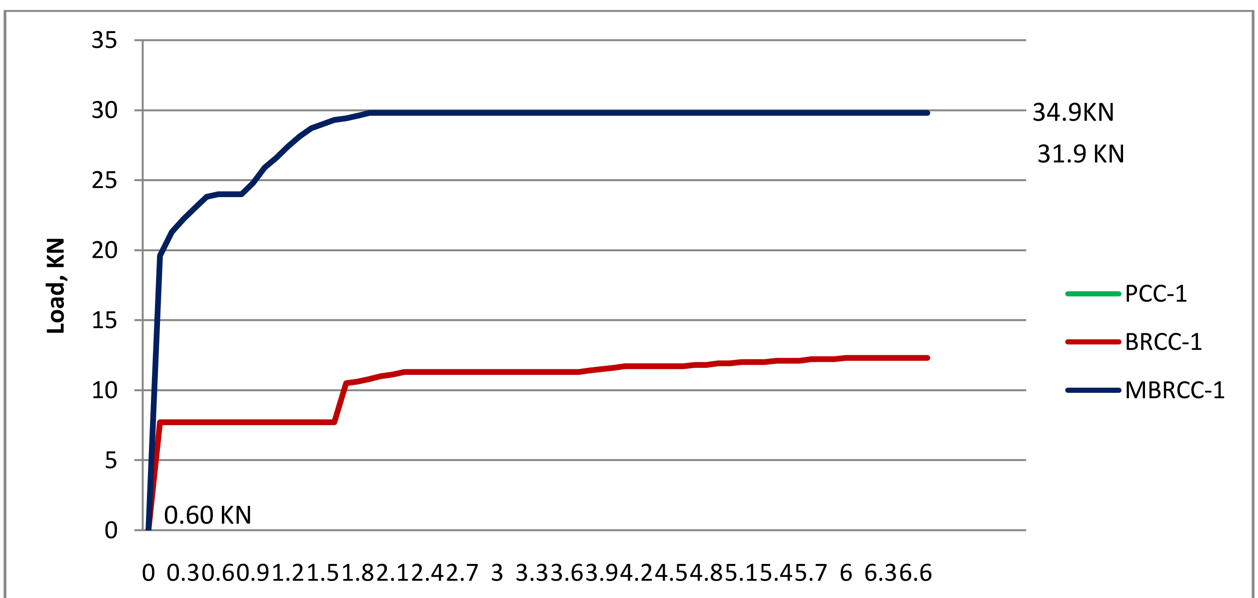


Fig. 5.24

5.7.3.3 Load-vs.-Deflection Curves after 28 days of Curing:-

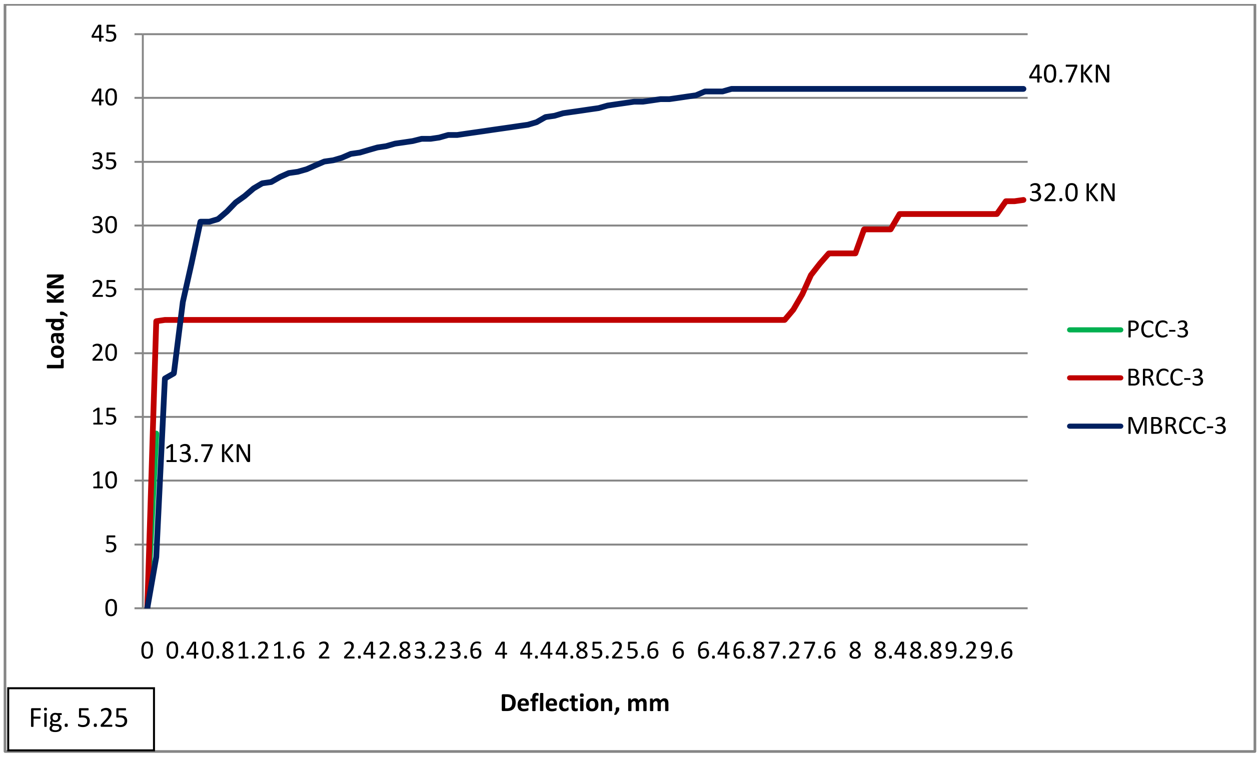


Fig. 5.25

5.7.3.4 Comparison of load at failure:-

Curing Period, Days	Specimens	Load at Failure, KN
7-Days	PCC-1	0.20
	BRCC-1	12.3
	MBRCC-1	29.8
14-Days	PCC-2	0.60
	BRCC-2	31.9
	MBRCC-2	34.9
28-Days	PCC-3	13.7
	BRCC-3	32.0
	MBRCC-3	40.7

Table-5.15

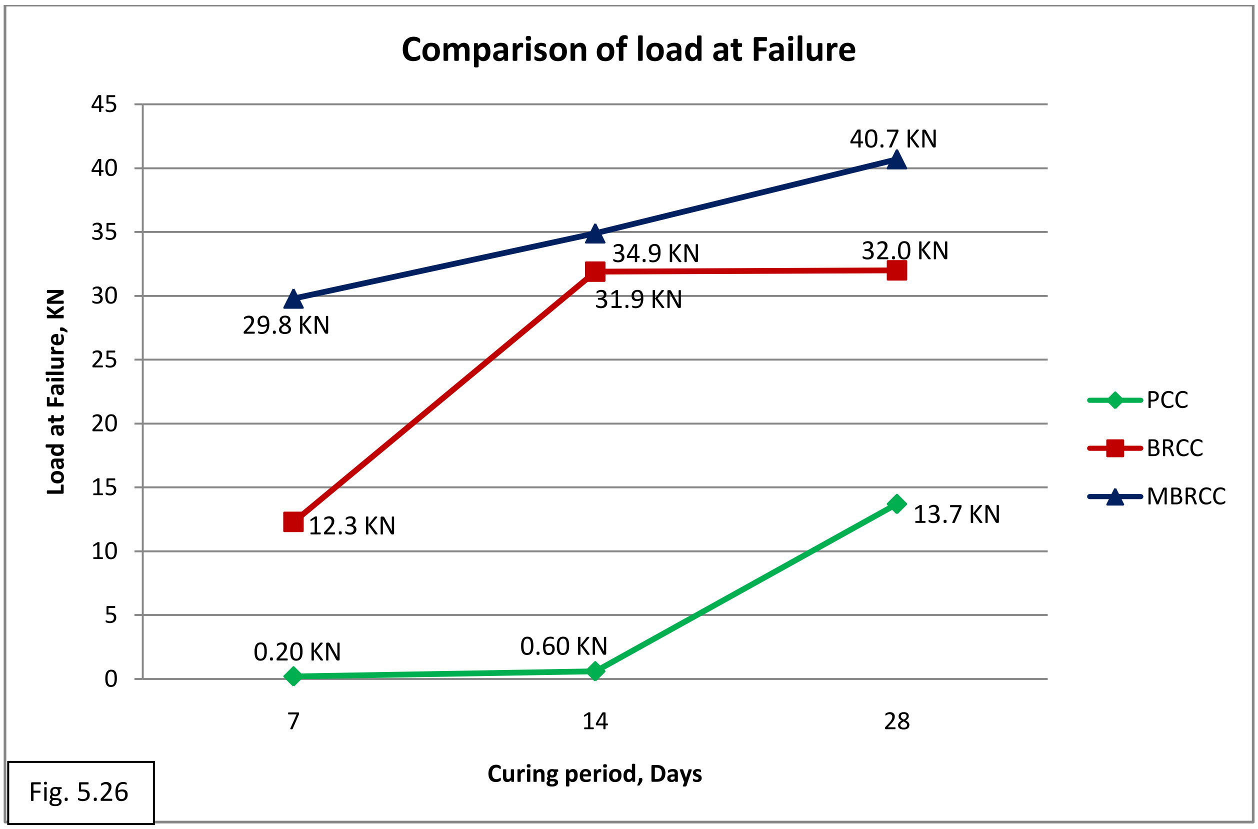


Fig. 5.26

5.7.3.5 Comparison of Deflection of mid section at failure:-

Curing Period, Days	Specimens	Max. deflection of mid section at failure, mm
7-Days	PCC-1	0.0
	BRCC-1	6.7
	MBRCC-1	1.9
14-Days	PCC-2	0.0
	BRCC-2	7.5
	MBRCC-2	5.4
28-Days	PCC-3	0.1
	BRCC-3	9.9
	MBRCC-3	6.6

Table-5.16

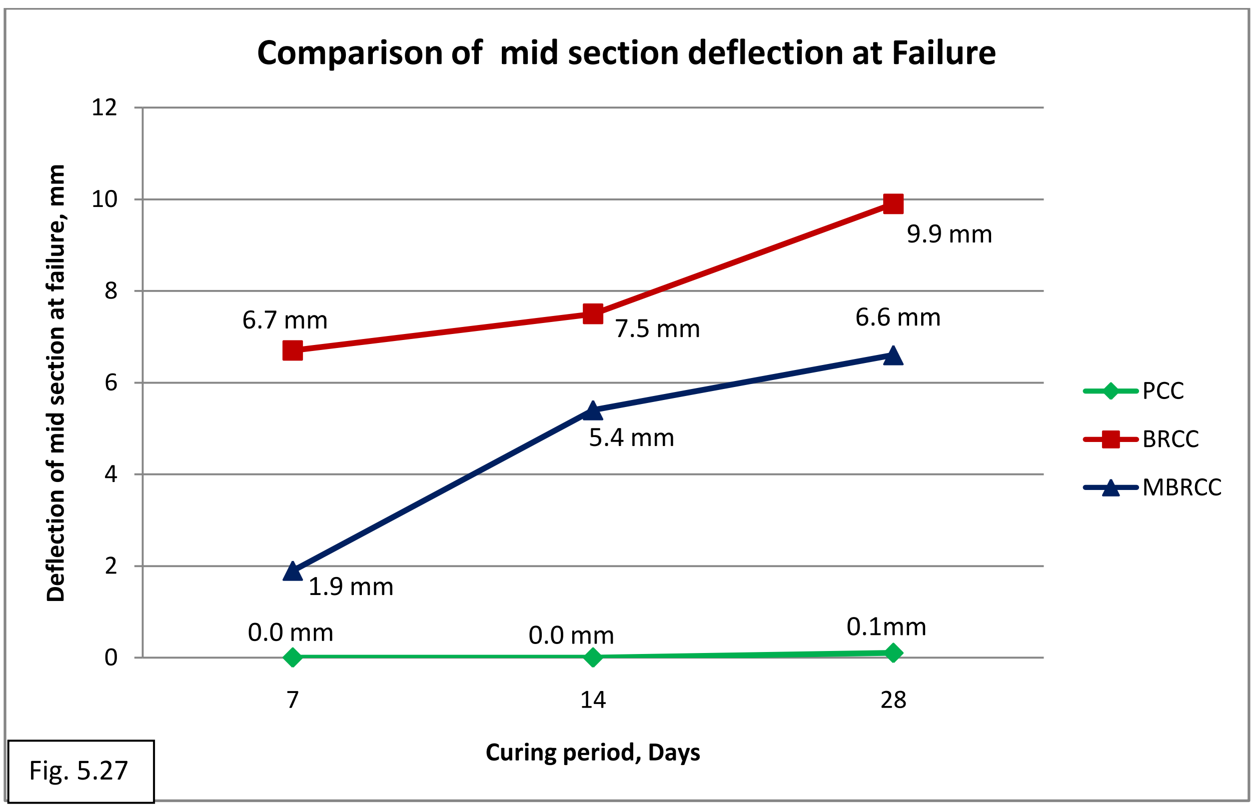


Fig. 5.27

5.7.3.6 Comparison of Modulus of Elasticity of Beams:-

Curing Period, Days	Specimens	Modulus of Elasticity, GPa
7-Days	PCC-1	-
	BRCC-1	040.99
	MBRCC-1	104.35
14-Days	PCC-2	-
	BRCC-2	059.63
	MBRCC-2	146.41
28-Days	PCC-3	072.94
	BRCC-3	119.79
	MBRCC-3	161.32

Table-5.17

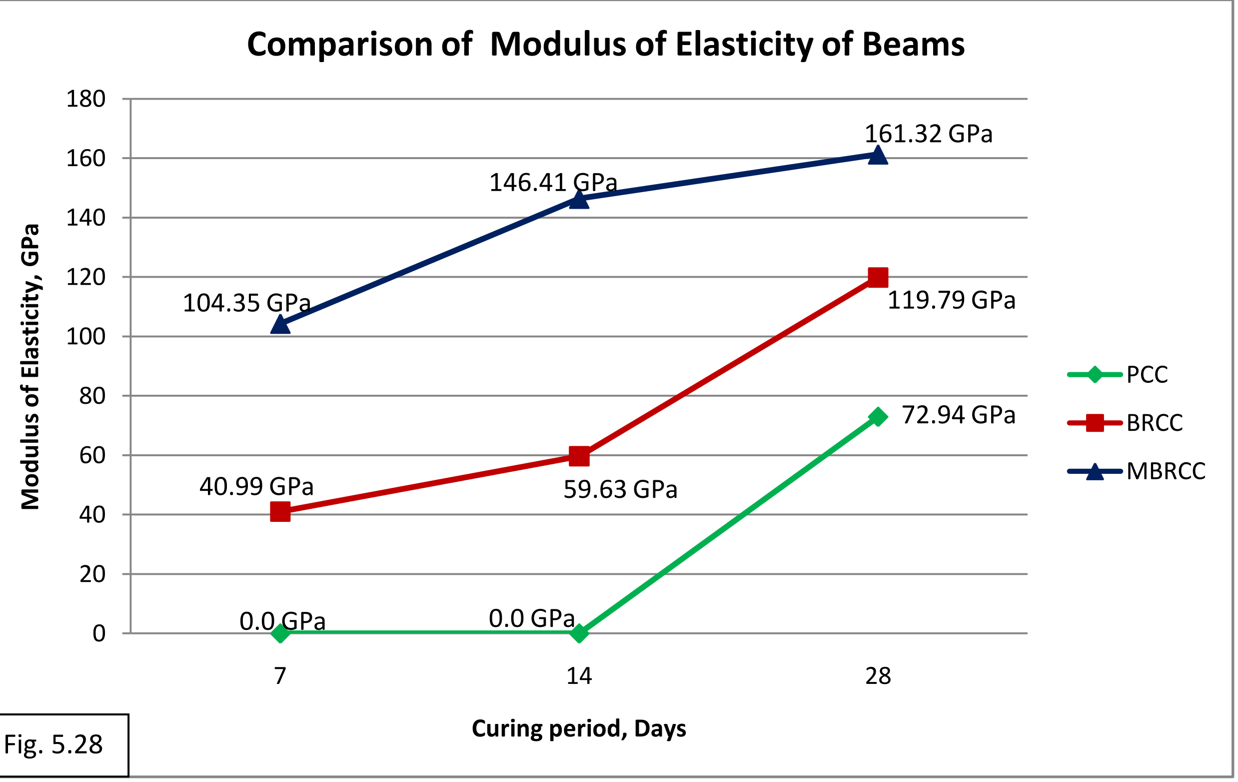


Fig. 5.28

5.7.3.7 Comparison of Modulus of Rupture of Beams:-

Curing Period, Days	Specimens	Modulus of Rupture, MPa
7-Days	PCC-1	00.90
	BRCC-1	03.32
	MBRCC-1	08.94
14-Days	PCC-2	00.18
	BRCC-2	09.57
	MBRCC-2	09.42
28-Days	PCC-3	04.93
	BRCC-3	11.52
	MBRCC-3	13.52

Table-5.18

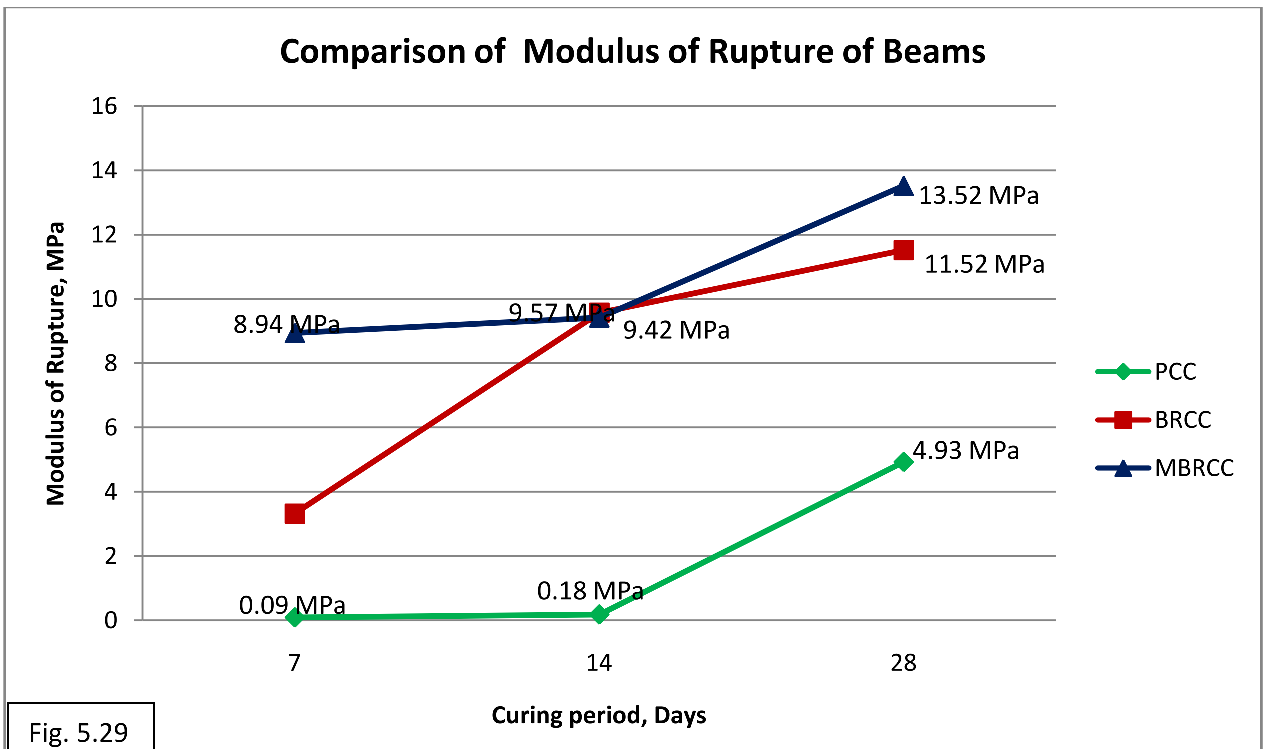
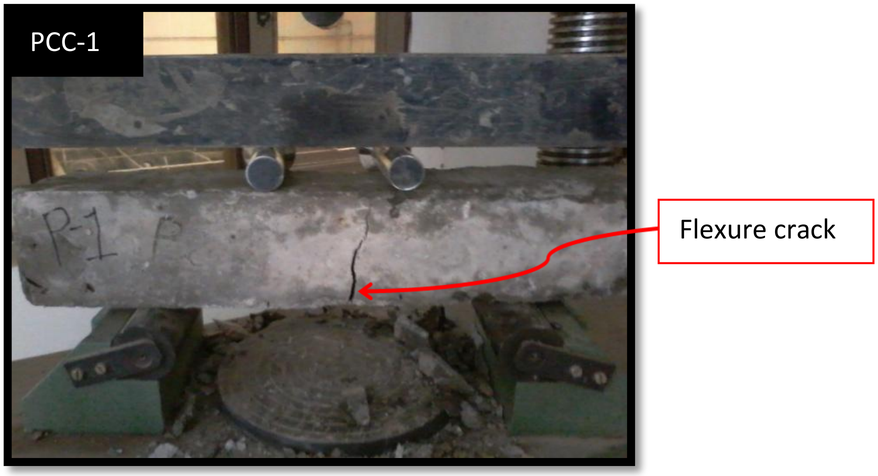


Fig. 5.29

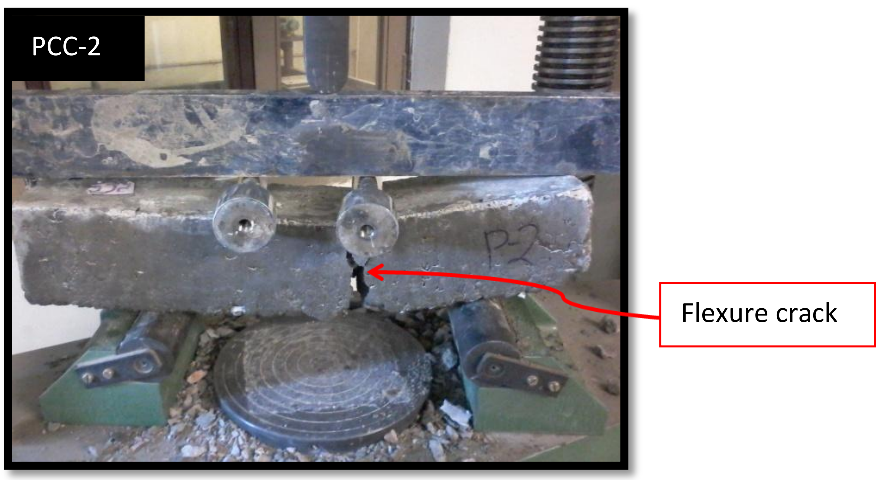
5.7.4 Discussions

5.7.4.1 Modes of failure of various beams:-



1) No deflection

2) Flexure crack develops as load increases



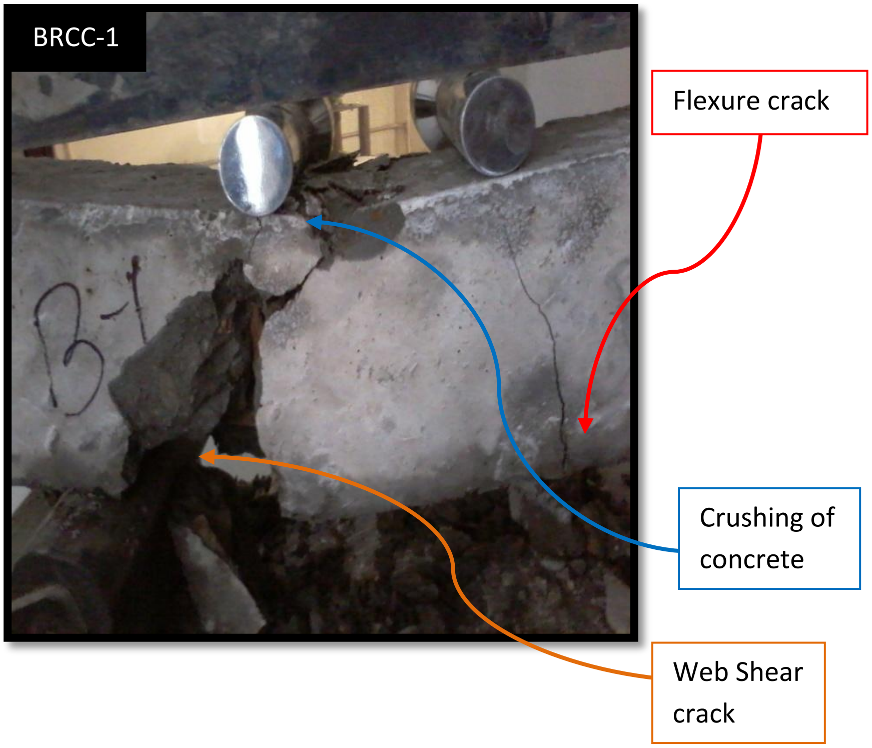
1) No deflection

2) Flexure crack develops as load increases

3) Crack widens as load increases.

1) No deflection

2) Flexure crack develops as load increases



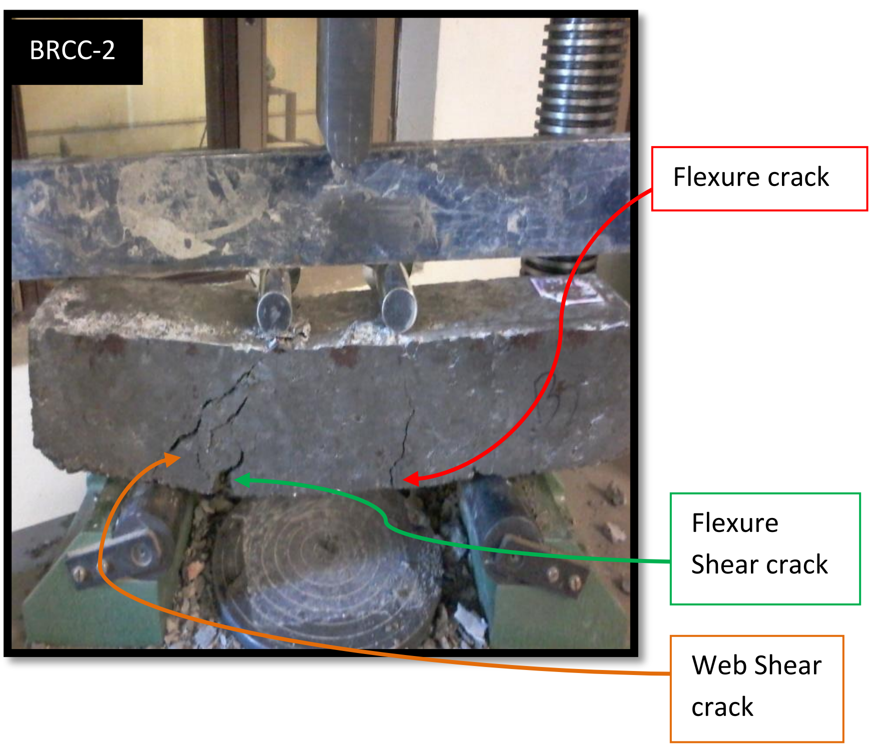
1) Deflection observed.

2) Firstly, flexure crack develops followed by shear cracks, as load increases.

3) Shear cracks widens up as load increases.

4) Crushing of concrete occurred at higher loads.

5) No yielding or splitting of bamboo was observed



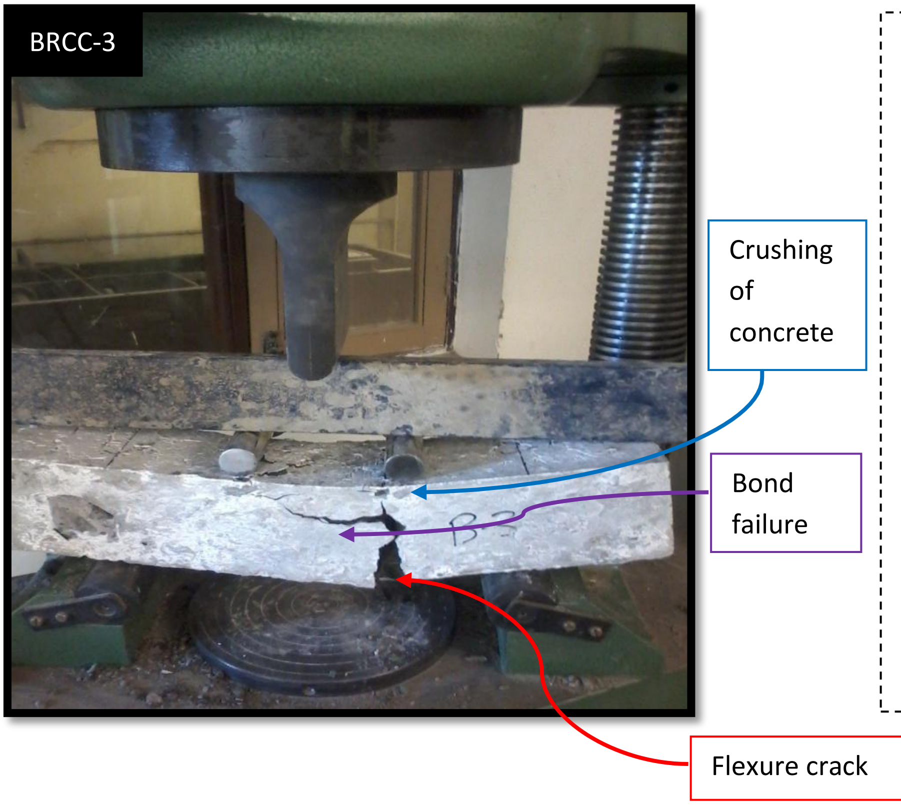
1) Deflection observed.

2) Firstly, flexure crack develops followed by shear cracks, as load increases.

3) No crushing of concrete was observed.

4) Splitting of bamboo fibers was observed.

5) Breakage of shear link at left support was observed.



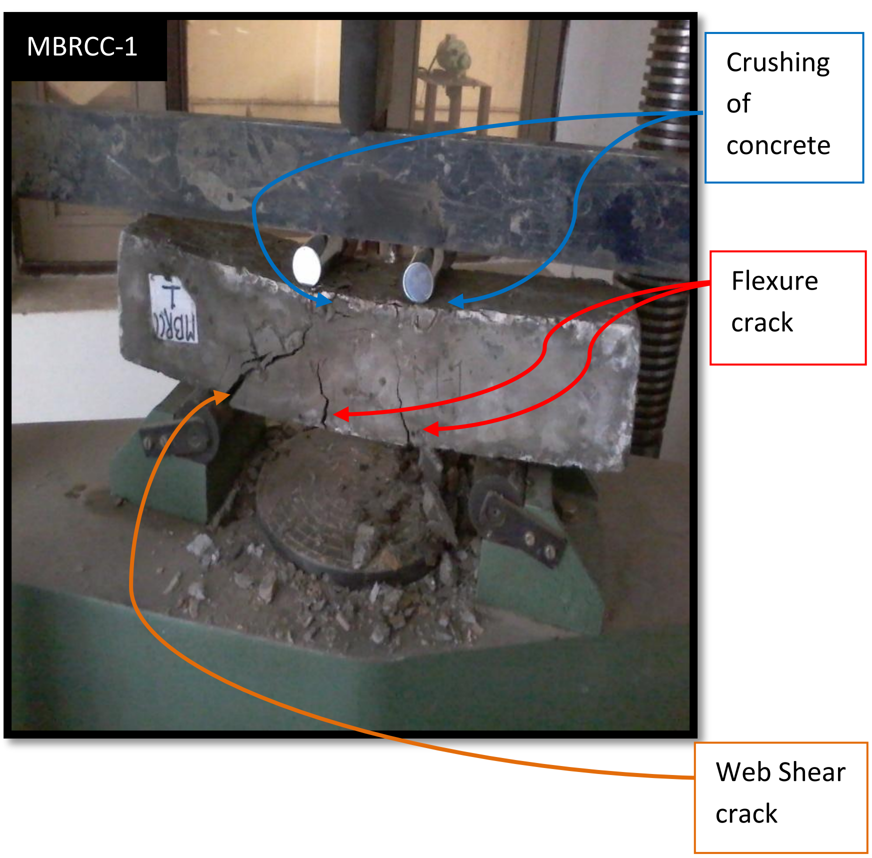
1) Deflection observed.

2) Flexure crack develops as load increases.

3) Flexure crack widens up as load increases.

4) Crushing of concrete occurred at higher loads.

5) Wide horizontal crack shows failure of bond between concrete & bamboo.



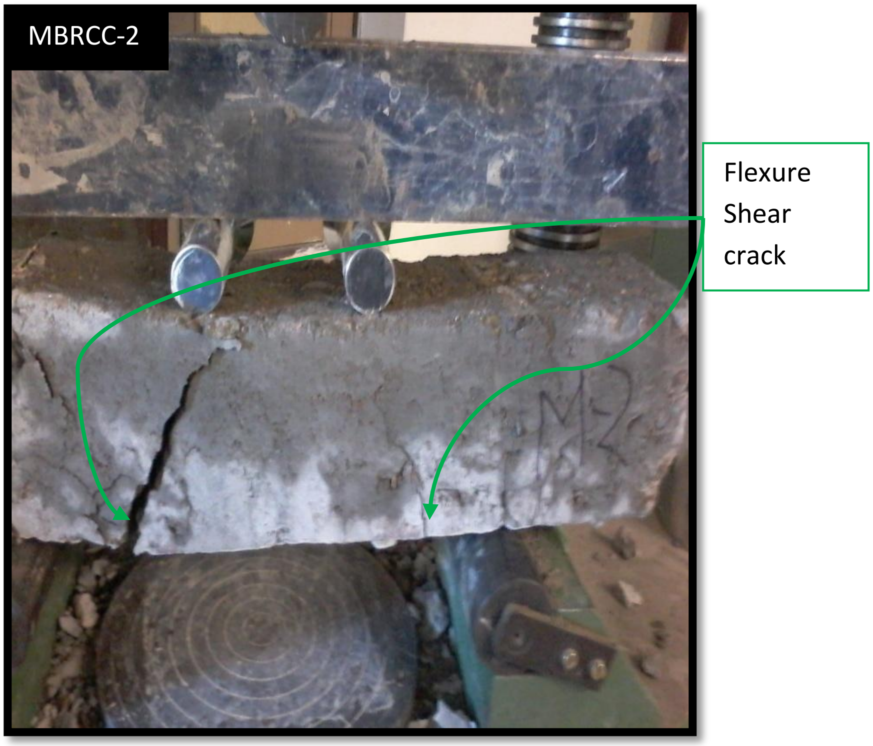
1) Deflection observed.

2) Firstly, flexure crack develops followed by shear cracks, as load increases.

3) Crushing of concrete occurred at higher loads.

4) No yielding of bamboo was observed

5) Breakage of shear link at left support was observed.

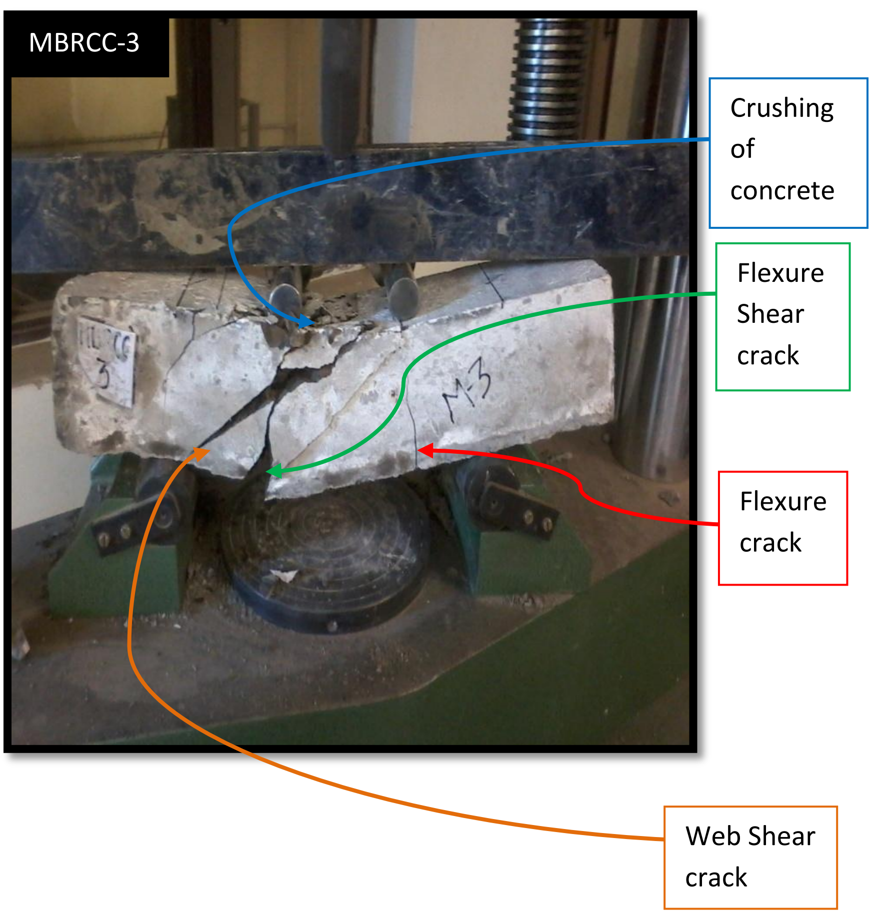


1) Deflection observed.

2) Flexure shear cracks develop which widens up as load was increased.

3) No yielding or splitting of bamboo was observed.

4) Breakage of shear link at supports was observed.



1) Deflection observed.

2) Flexure cracks develop followed by shear cracks as load was increased. Shear cracks widens up with increase in loading.

3) Crushing of concrete occurred at higher loads.

4) Splitting of bamboo fibers at mid section was observed.

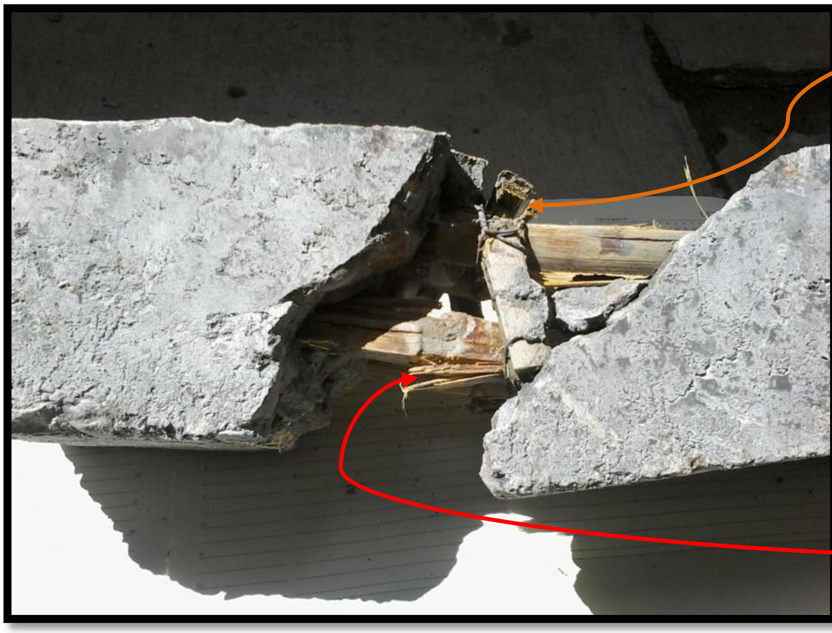
5) Breakage of shear link occurred at left support

Table-5.19

Beam	**Failure Mode**		**Number & types of cracks**
	Predicted	**Actual**	
PCC-1	Pure Flexure	Pure Flexure	1 Flexure crack
PCC-2	Pure Flexure	Pure Flexure	1 Flexure crack
PCC-3	Pure Flexure	Pure Flexure	1 Flexure crack
BRCC-1	Splitting of Bamboo	Diagonal tension failure, crushing of concrete	1 Flexure crack, 1 web shear crack, crushing of concrete.
BRCC-2	Splitting of Bamboo	Bamboo splitting , Breaking of shear link.	1 Flexure crack, 2 web shear crack, 1 flexure shear crack.
BRCC-3	Splitting of Bamboo	Pure flexure, crushing of concrete, Bond failure.	1 Flexure crack, crushing of concrete.
MBRCC-1	Splitting of Bamboo	Diagonal tension failure, crushing of concrete	2 Flexure cracks, 1 web shear crack, crushing of concrete.

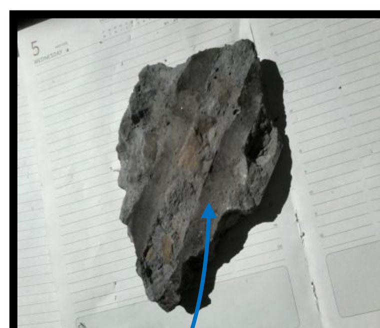
MBRCC-2	Splitting of Bamboo	Flexure shear, Breaking of shear link.	2 flexure shear cracks.
MBRCC-3	Splitting of Bamboo	Bamboo splitting, breaking of shear link.	1 Flexure crack, 1 web shear crack, c1 flexure shear crack, crushing of concrete.

5.7.4.2 Behavior of BRCC beams:-



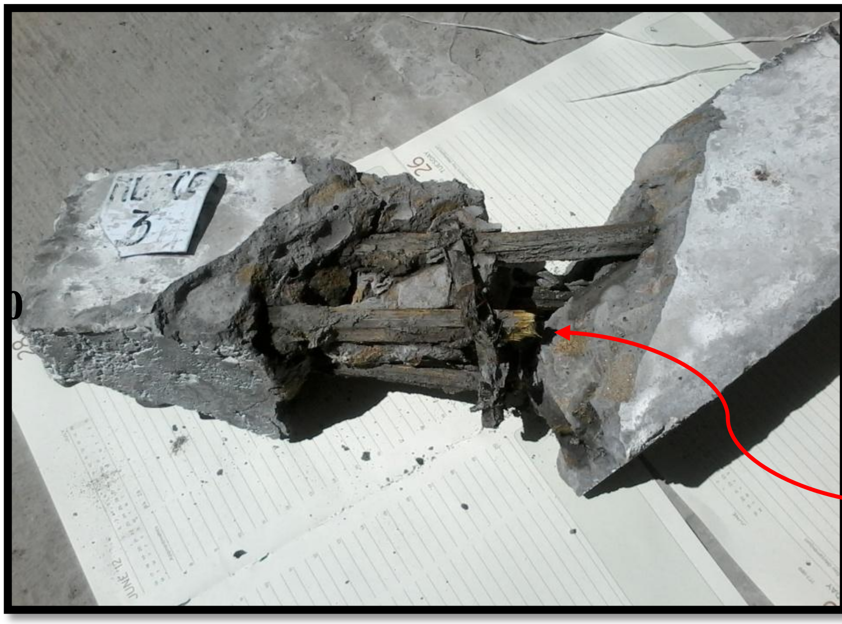
Breakage of Shear

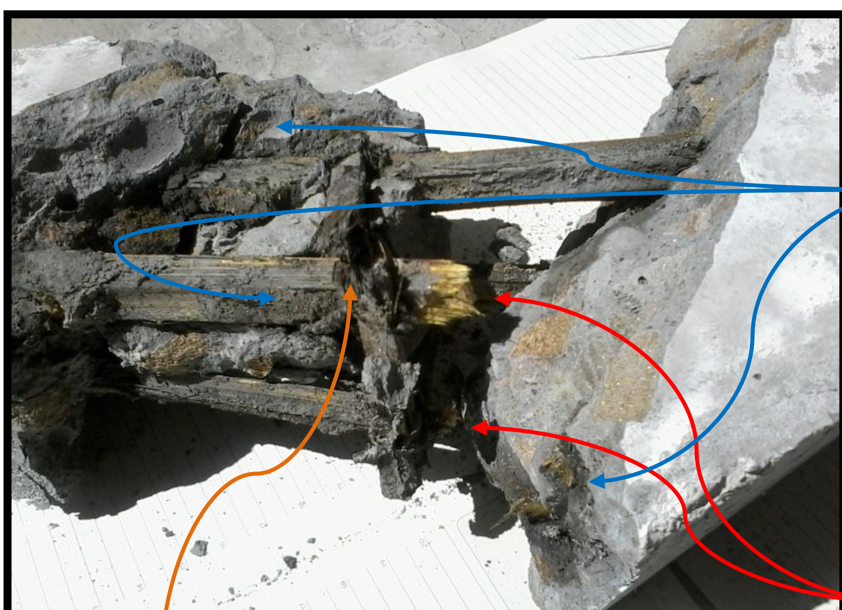
Splitting of tensile reinforcement at node, indicates ductile failure of beam



Smooth concrete surface indicating poor bond between reinforcement & concrete.

5.7.4.3 Behavior of MBRCC beams:-





5.7.4.4 General Discussions on Mechanical Properties of Beams:-

1) Load-vs.-Deflection Curves.

Load-vs.-deflection curves followed straight line variation until the appearance of first crack in concrete. Immediately following the first crack there was flattering of the deflection curve (may be due to local bond slippage), followed by another fairly straight line variation but with a decrease slope, until ultimate failure of member occurred.

2) Load at Failure

The load carrying capacity of beams increased by 61.5 times, 53.2 times, 2.3 times when reinforced with Non treated Bamboo splints, after 7 days of curing, 14 days of curing and 28 days of curing respectively.

The load carrying capacity of beams increased by 149 times, 58.2 times, 2.9 times when reinforced with Treated(Bitumen + sand mixture coated) bamboo splints, after 7 days of curing, 14 days of curing, 28 days of curing respectively.

3) Deflection of Mid-Section

No deflection of mid-section was observed in plane cement concrete beams at 7 days and 14 days of curing however there was a minute deflection of 0.1mm observed on testing at 28 days of curing, all the three beams failed with a sudden brittle failure.

Beams reinforced with Non-treated bamboo splints showed maximum deflection of mid-section among all the three types of beams, deflection ranging from 6.7mm to 9.9mm.

Beams reinforced with Treated (Bitumen + sand mixture coated) bamboo splints showed deflection in the range of 1.9mm to 6.6mm, which is smaller than that in Non-treated bamboo reinforced specimen, this shows that as the bond strength between the concrete and bamboo enhances it increases the Young's modulus of elasticity of the beam eventually reducing the plasticity of the beam of the beam.

Significant amount of deflections were observed in the beams reinforced with bamboo splints, before ultimate failure, hence reinforcing concrete beams with bamboo splints imparted sufficient ductility to the beams preventing sudden brittle failure at ultimate loads.

4) Modulus of Elasticity of Beams

Beams reinforced with Treated (Bitumen + sand mixture coated) bamboo splints showed highest Young's Modulus of elasticity among the three types of beams.

Improving the bond between reinforcement and concrete improved the homogeneity of the section, enhancing the strain compatibility between bamboo and concrete allowing better transfer of tensile stresses from concrete to bamboo.

Bamboo unlike steel is not a ductile material and do not yield, hence it can take large stresses without much elongation until the tensile stresses reached the ultimate tensile strength, as a result beam reinforced with bamboo splints was able to take large stresses at low strain which increased the modulus of elasticity of the beam.

The modulus of elasticity of beams reinforced with Treated (Bitumen + sand mixture coated) bamboo splints was found to be 2.5 times, 2.4 times, 1.3 times more than that of beams reinforced with Non Treated bamboo splints after 7 days, 14 days and 28 days respectively.

High modulus of elasticity of beams reinforced with (Bitumen + sand mixture coated) bamboo splints is the reason for low ductility of such beams.

5) Modulus of Rupture of Beams

Beams reinforced with Treated (Bitumen + sand mixture coated) bamboo splints shows highest Modulus of Rupture among the three types of specimens.

Improving the bond between reinforcement and concrete improved the homogeneity of the section enhancing the strain compatibility between bamboo and concrete allowing the bamboo to take the tensile stresses once the concrete below the neutral axis cracked, as a result the beam was able to take large stresses which increases the modulus of rupture of the beam

The modulus of rupture of the beam increases with an increase in the load carrying capacity of the beam.

The modulus of rupture of the beams reinforced with Treated (Bitumen + sand mixture coated) bamboo splints, was found to be 99 times, 52 times, 2.7 times more than that of plain cement concrete beams after 7 days of curing, 14 days of curing and 28 days of curing respectively.

The modulus of rupture of the beams reinforced with Non treated bamboo splints was fund to be 36.9 times, 53.3 times, 2.3 times more than that of plain cement concrete beams after 7 days of curing, 14 days of curing and 28 days of curing respectively.

6) Modes of failure of Beams

All the reinforced beams failed by the combination of one of the following modes of failure:-

- Longitudinal splitting of bamboo in tension.
- Flexure tension.
- Flexure shear.
- Web shear.
- Crushing of concrete.

Except beam MBRCC-2 which failed only in Flexure-Shear.

Out of the total 6 doubly reinforced beams tested only 2 of the beams failed by splitting of bamboo in tension, rest 4 beams failed either by shear failure, flexure shear failure or pure flexure failure because improper bonding between reinforcement and concrete did not allowed proper transfer of tensile stresses from concrete to bamboo splints.

5.8 IS 516:1959 Third Point Loading Flexure Test on hardened Cement Concrete Flexure Elements Singly Reinforced by Bamboo Splints, without Shear Links

5.8.1 Observation Table

Sample	Load at Failure (KN)	Displacement of Mid Section at Failure (mm)	Load at Yield (KN)	Displacement of Mid Section at Yield load (mm)
PCC	13.70	0.1	13.70	0.1
BSRCC	43.30	15.7	23.70	0.1
MBSRCC	52.20	7.90	22.80	0.1

Table-5.20

5.8.2 Mathematical Expressions used

Modulus of rupture of beam [13]

$$1)\quad f_b = \frac{3 \times p \times a}{b \times d^2}$$

Modulus of elasticity of beam [8], [13]

$$2)\quad E = \frac{23 \times W \times L^3}{648 \times \delta \times I}$$

f_b = Modulus of rupture, MPa

p = Maximum load, N

b = Width of beam, mm

d = Depth of beam, mm

a = Distance between line of fracture and nearest support.

W = Load at yield, N

L = Length of beam, mm

δ = Deflection of mid section at W load, mm

I = Moment of inertia, mm^4

5.8.3 Results

5.8.3.1 Load-vs.-Deflection Curves after 28 days of Curing:-

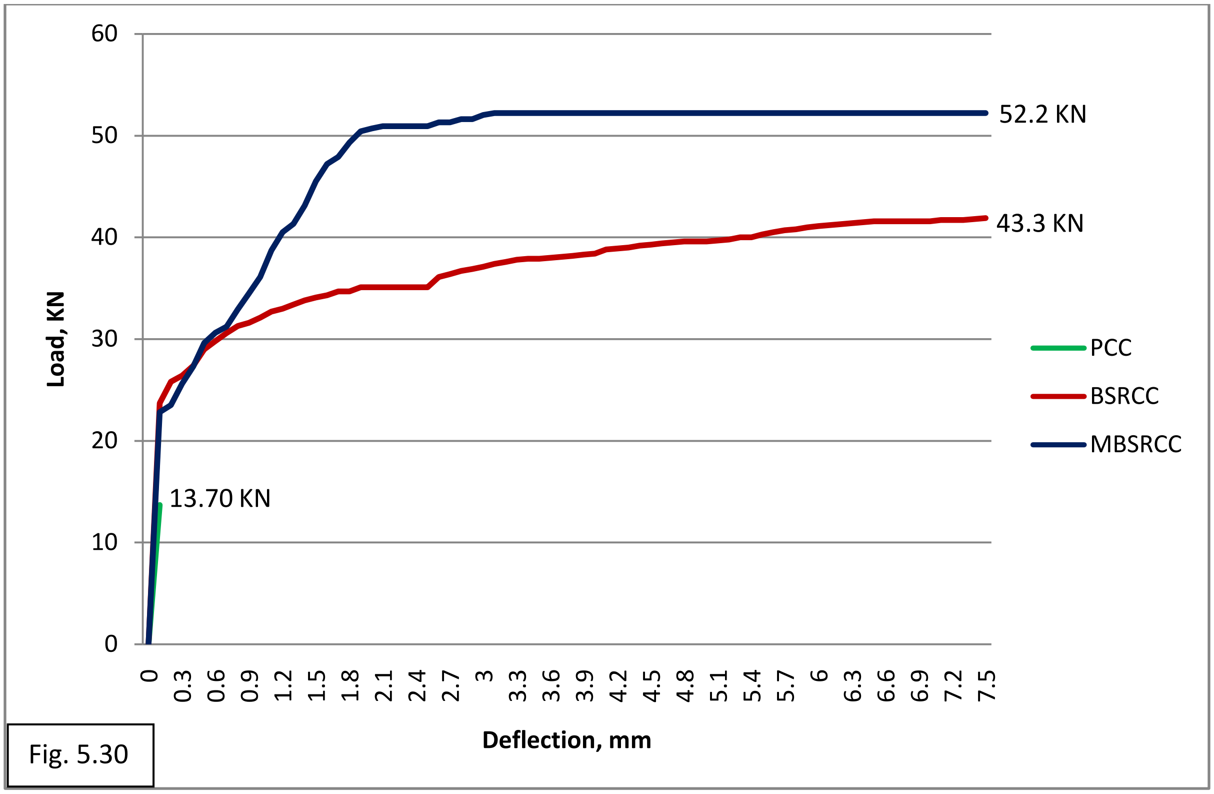


Fig. 5.30

5.8.3.2 Comparison of load at failure:-

Curing Period, Days	Specimens	Load at Failure (KN)
28-Days	PCC	13.70
	BSRCC	52.20
	MBSRCC	40.70

Table-5.21

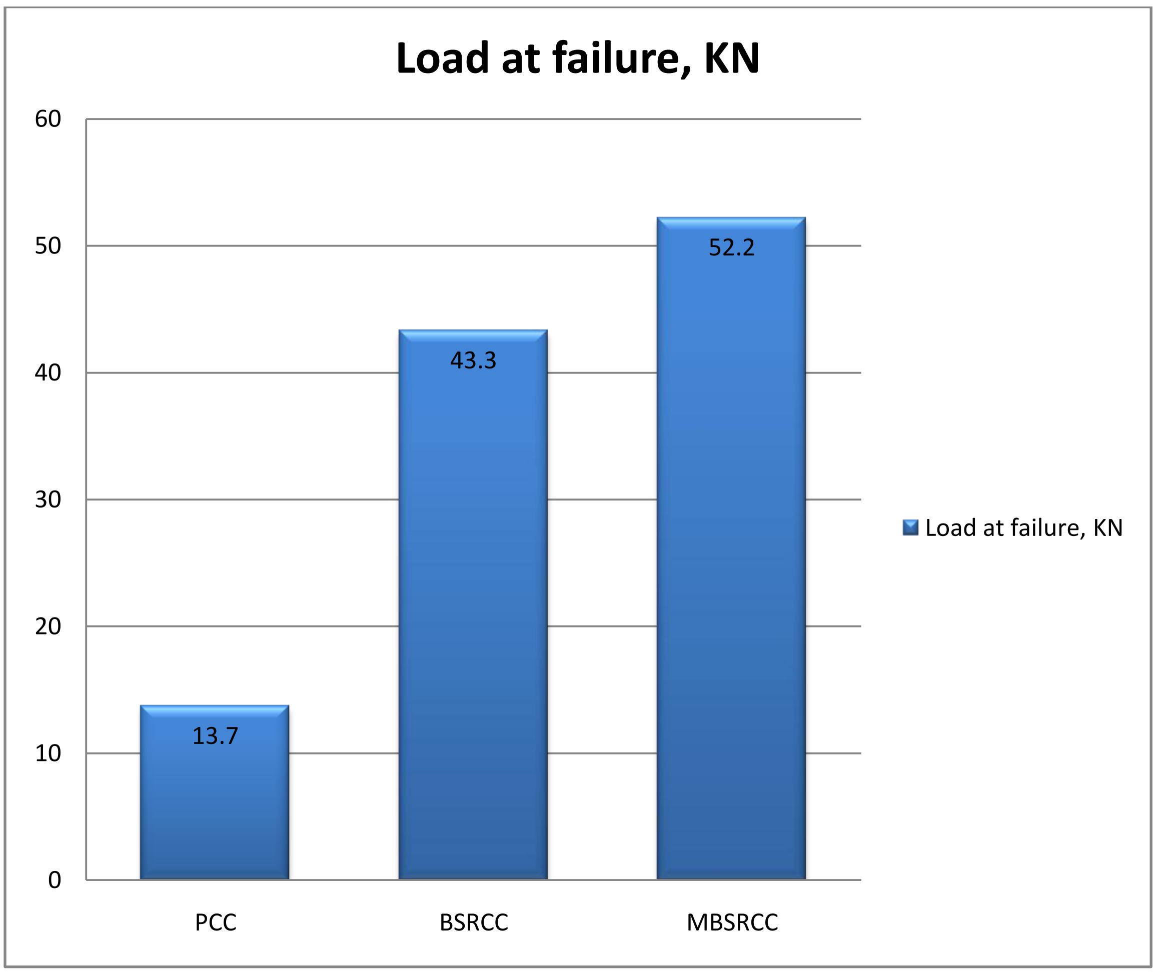


Fig. 5.31

5.8.3.3 Comparison of Deflection of mid section at failure:-

Curing Period, Days	Specimens	Max. deflection of mid section at failure, mm
28-Days	PCC	0.10
	BSRCC	15.7
	MBSRCC	07.9

Table-5.22

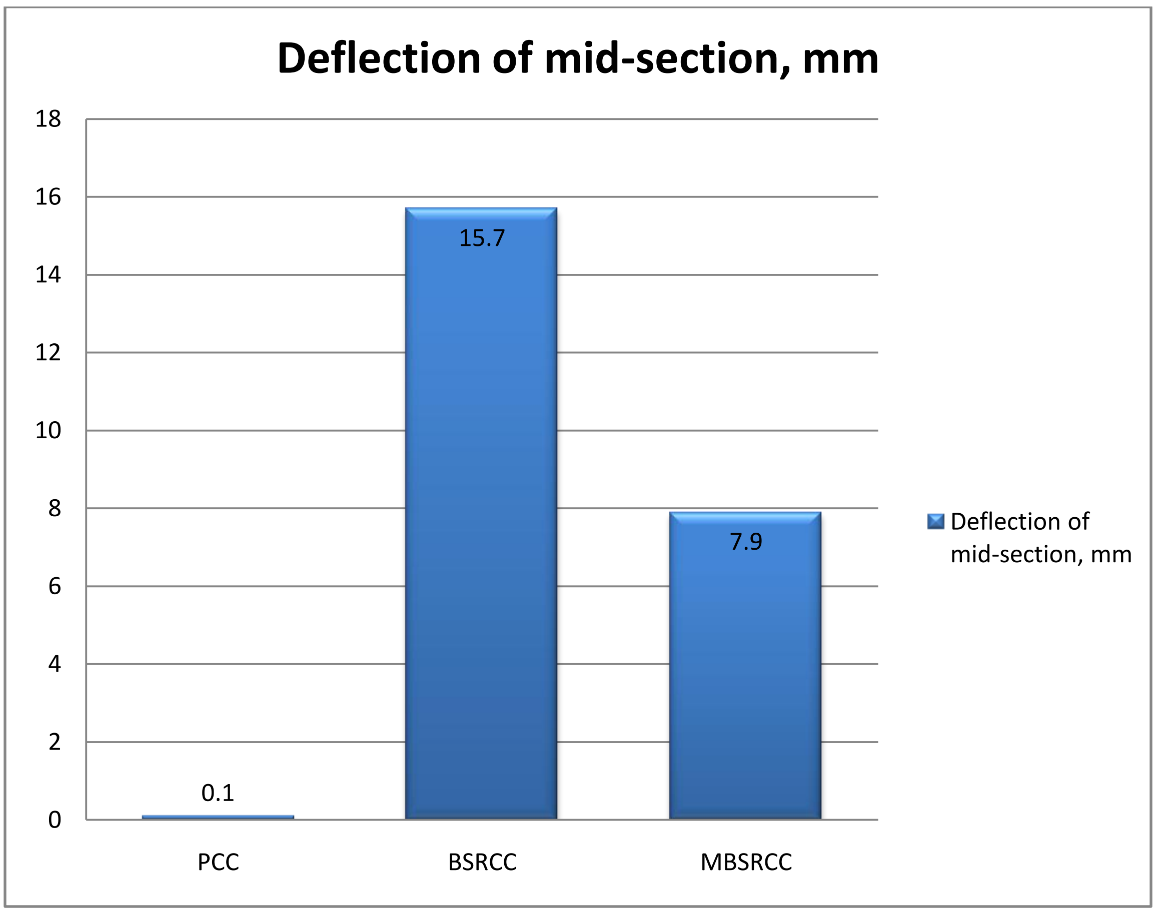


Fig. 5.32

5.8.3.4 Comparison of Modulus of Elasticity of Beams:-

Curing Period, Days	Specimens	Modulus of Elasticity, GPa
28-Days	PCC	072.940
	BSRCC	126.180
	MBSRCC	121.388

Table-5.23

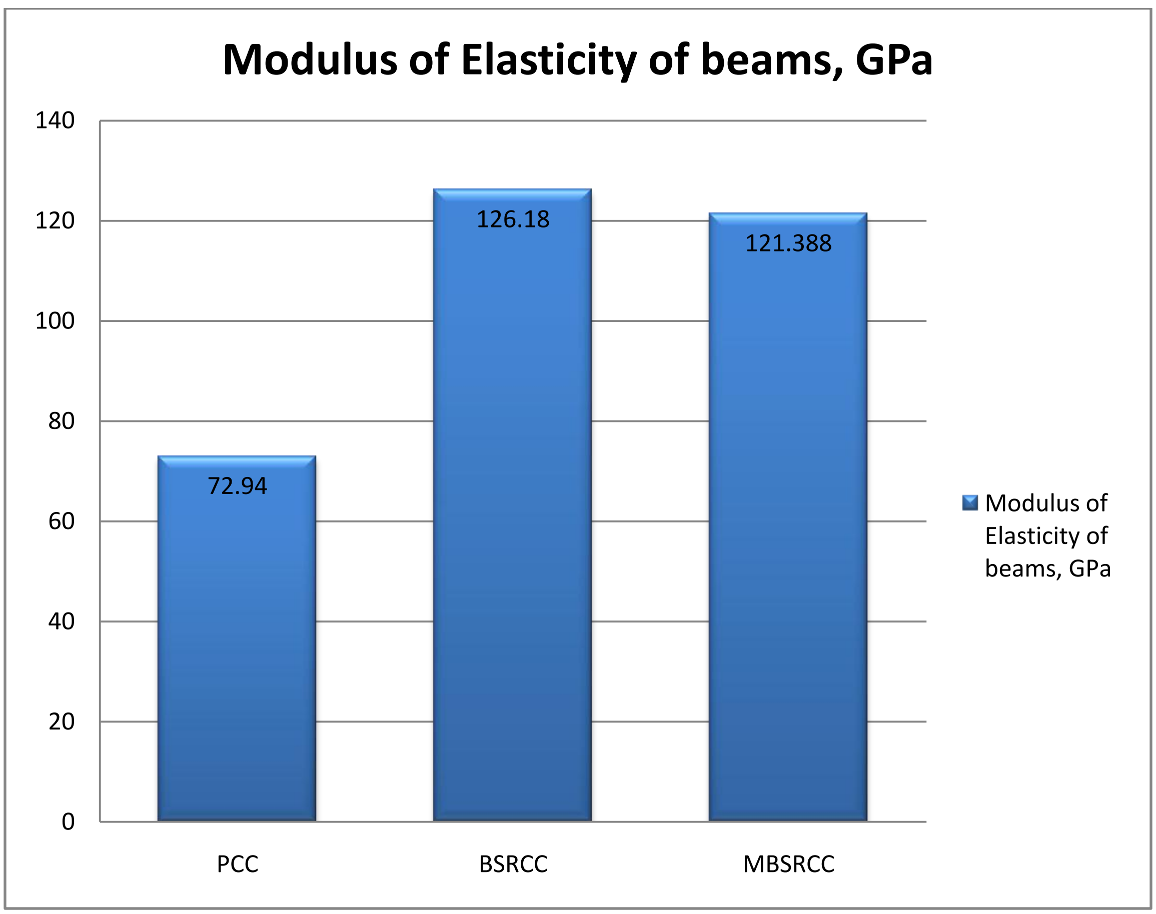


Fig. 5.33

5.8.3.5 Comparison of Modulus of Rupture of Beams:-

Curing Period, Days	Specimens	Modulus of Rupture, MPa
28-Days	PCC	04.930
	BSRCC	19.485
	MBSRCC	22.707

Table-5.24

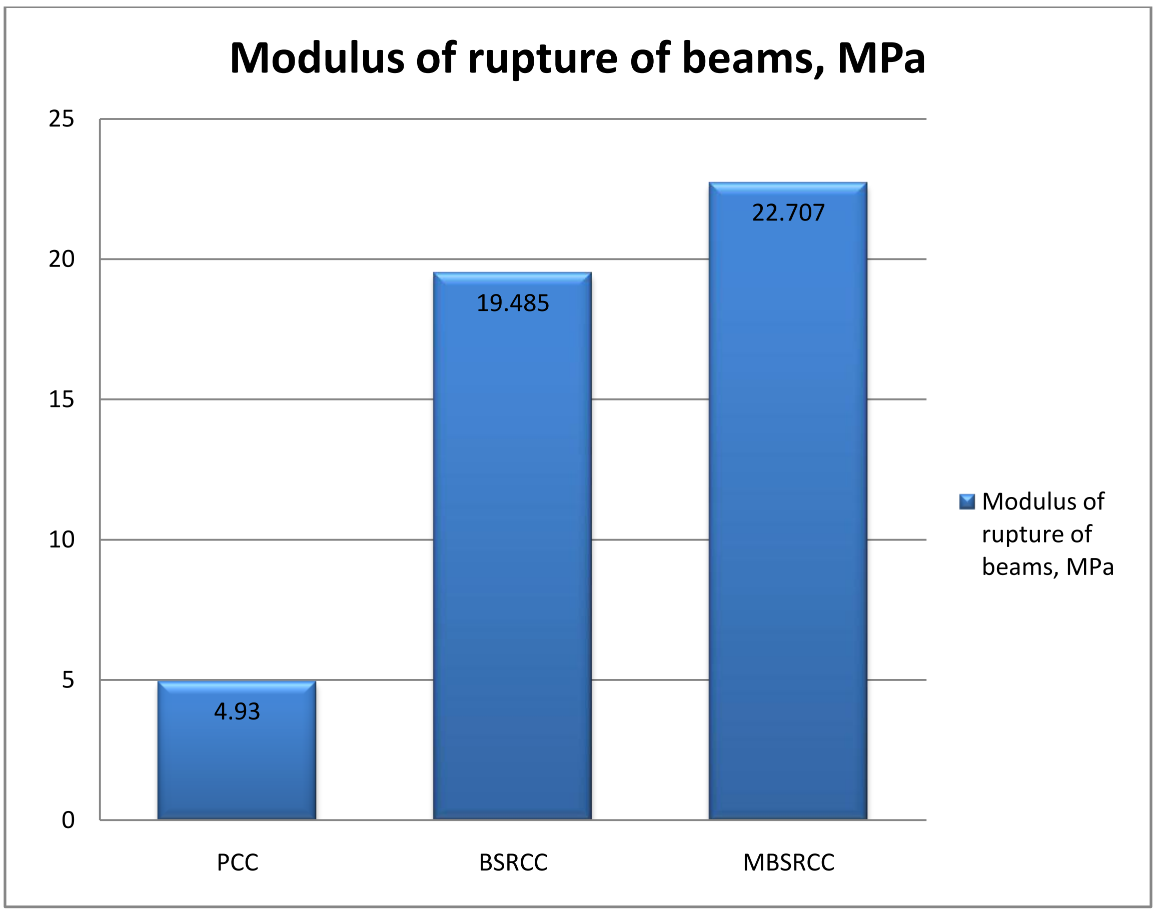


Fig. 5.34

5.8.4 Discussions

5.8.4.1 Modes of failure of various beams:-

1) No deflection

2) Flexure crack develops as load increases

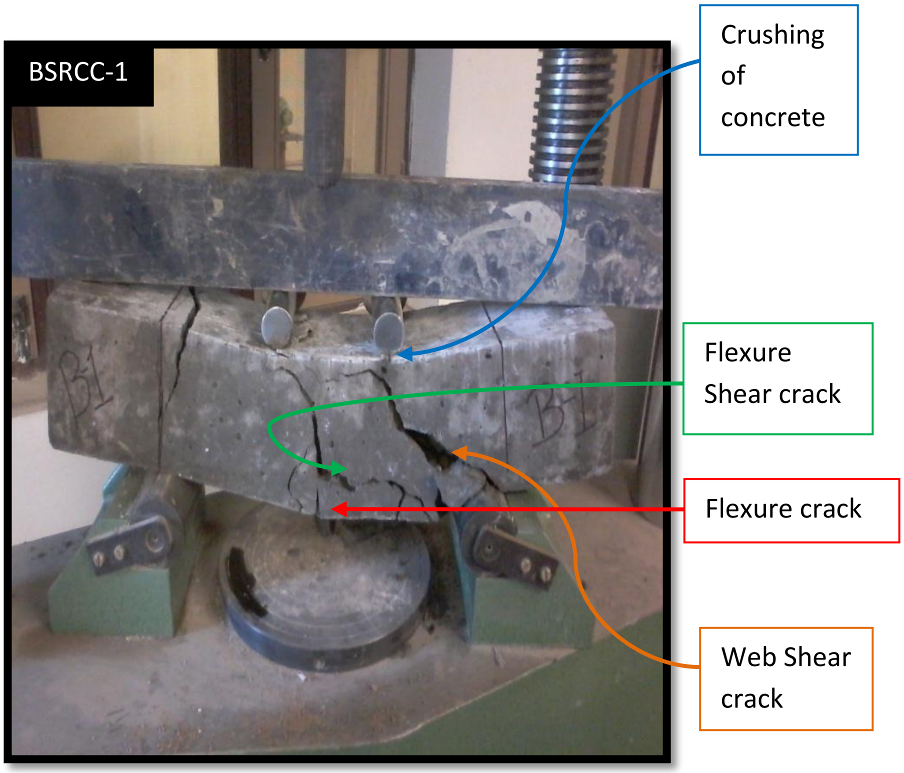
1) No deflection

2) Flexure crack develops as load increases

3) Crack widens as load increases.

1) No deflection

2) Flexure crack develops as load increases



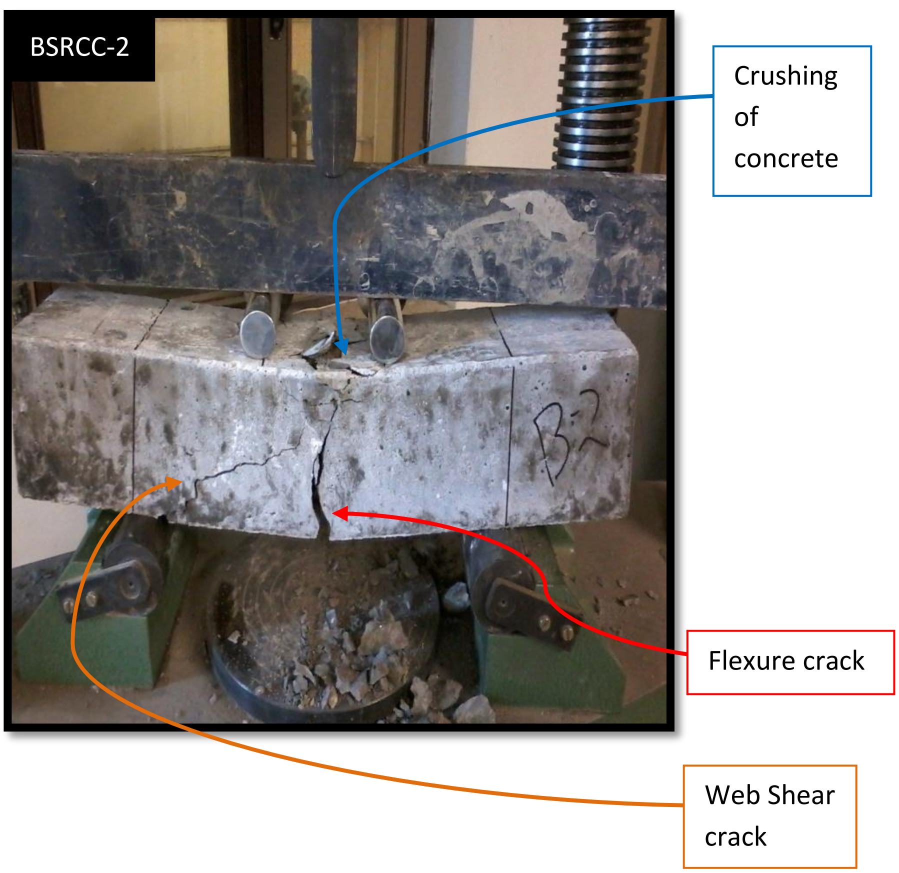
1) Deflection observed.

2) Flexure crack, Web shear cracks and flexure-shear cracks develop as load increases.

3) Cracks widens up with increase in loads.

4) Crushing of concrete occurred at higher loads.

5) No splitting of bamboo was observed.



1) Deflection observed.

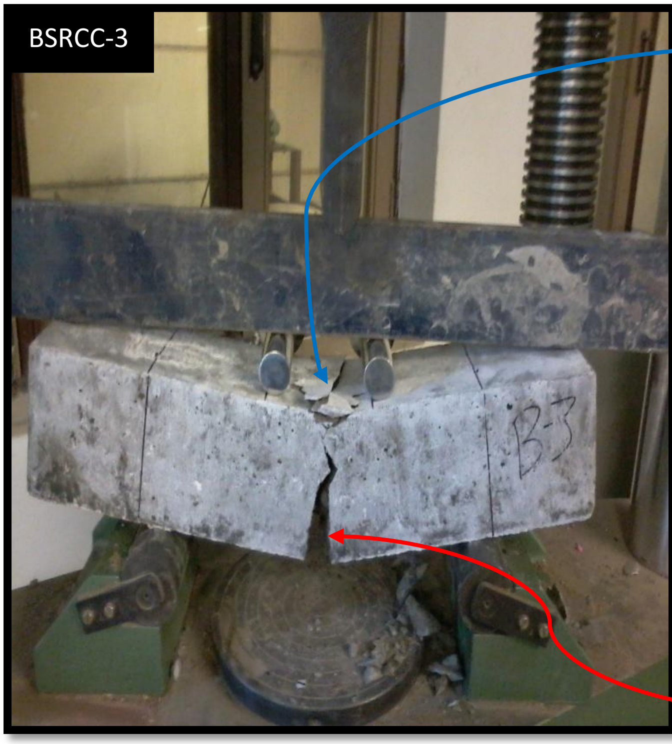
2) Flexure crack develops as load increases.

3) Flexure crack widens up as load increases.

4) As load is further increased web shear crack occurred at left support.

5) Crushing of concrete occurred at higher loads.

6) No splitting of bamboo was observed.



1) Deflection observed.

2) Flexure crack developed at the mid section as load increase.

3) Cracks widens up with increase in loads.

4) Crushing of concrete occurred at higher loads.

5) Splitting of bamboo at node at mid section of beam was observed.

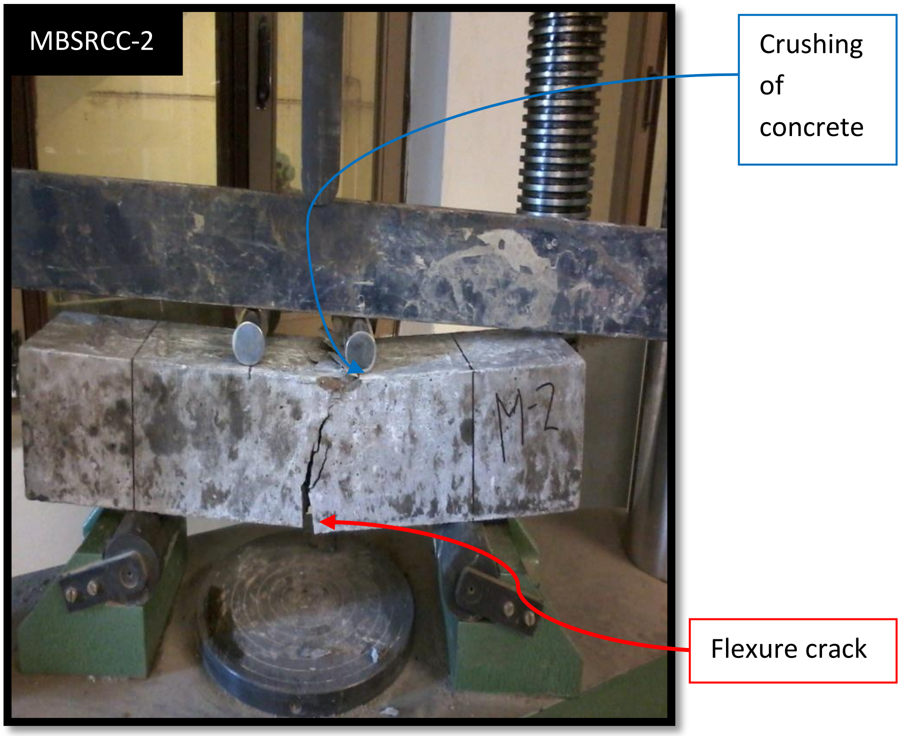
1) Deflection observed.

2) Web-shear crack and flexure –shear crack developed as load increases.

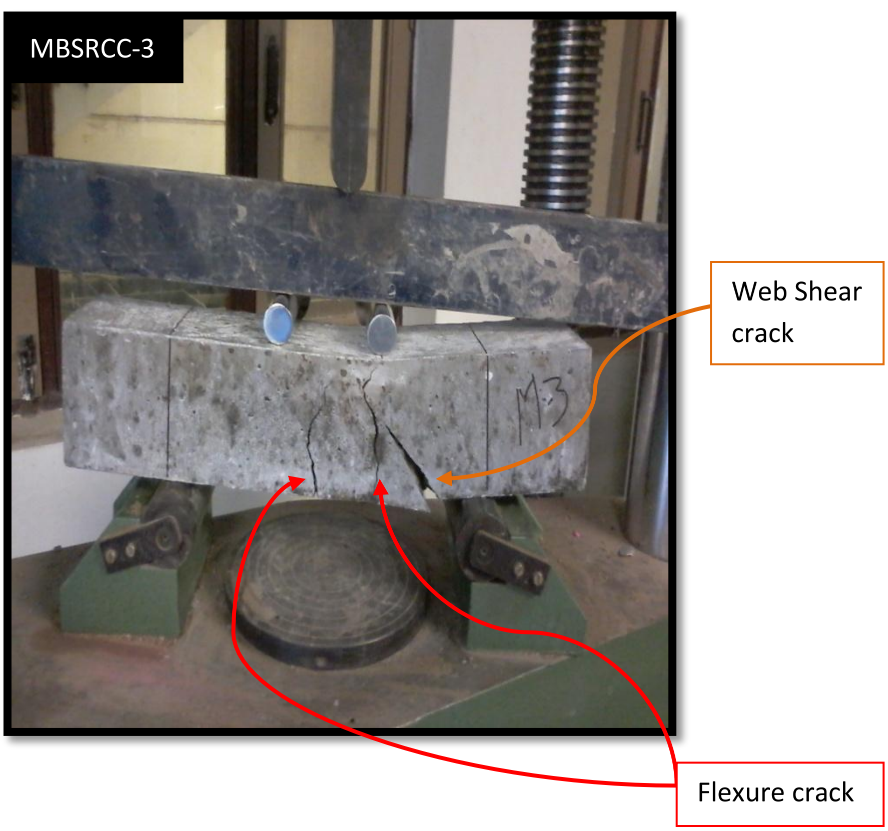
3) Web-shear crack widens up with increase in load.

3) Cracks widens up with increase in loads.

5) Splitting of bamboo was not observed.



1) Deflection observed.
2) Flexure crack developed at the mid section as load increase.
3) Cracks widens up with increase in loads.
4) Crushing of concrete occurred at higher loads.
5) Splitting of bamboo was not observed.



1) Deflection observed.
2) Flexure crack and web-shear crack developed as load increase.
3) Web-shear crack widens up with increase in loads.
5) Splitting of bamboo was not observed.

Table-5.25

Beam	**Failure Mode**		**Number & types of cracks**
	Predicted	**Actual**	
PCC-1	Pure Flexure	Pure Flexure	1 Flexure crack
PCC-2	Pure Flexure	Pure Flexure	1 Flexure crack
PCC-3	Pure Flexure	Pure Flexure	1 Flexure crack
BSRCC-1	Splitting of Bamboo	Diagonal tension failure, crushing of concrete	1 Flexure, 1 web shear, 1 Flexure shear crack, crushing of concrete.
BSRCC-2	Splitting of Bamboo	Pure flexure, crushing of concrete.	1 Flexure crack, 1 web shear crack, crushing of concrete.
BSRCC-3	Splitting of Bamboo	Pure flexure, crushing of concrete, Splitting of bamboo.	1 Flexure crack, crushing of concrete.
MBSRCC-1	Splitting of Bamboo	Diagonal tension failure.	1Flexure shear crack, 1 web shear crack.

MBSRCC-2	Splitting of Bamboo	Pure flexure, crushing of concrete.	1 Flexure crack, crushing of concrete.
MBSRCC-3	Splitting of Bamboo	Diagonal tension failure	2 Flexure cracks, 1 web shear crack. .

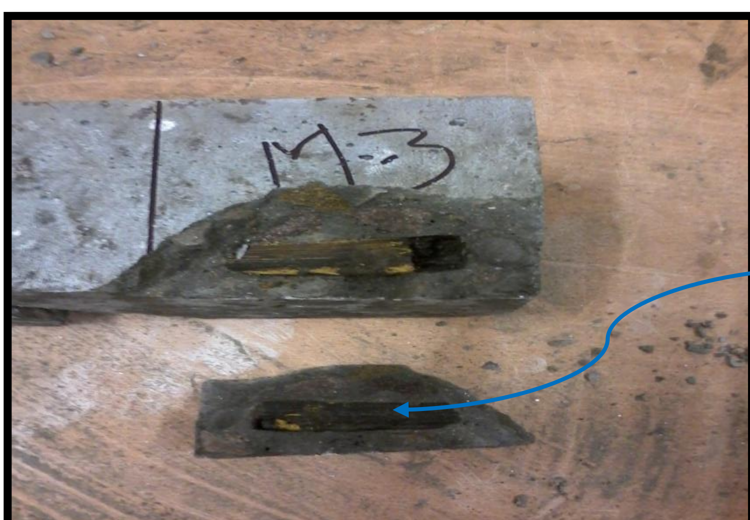
5.8.4.2 Behavior of BSRCC beams:-

Splitting of tensile reinforcement at node, indicates ductile failure of beam-BSRCC:3

Making grooves on the inner surface of bamboo splint helped in maintaining the structural integrity and enhanced the concrete-bamboo bond to a fair amount.

5.8.4.3 Behavior of MBSRCC beams:-

In case of MBRCC beams the grooves got filled up by bitumen+sand mixture making them ineffective in enhancing the concrete bamboo bond resulting in poor transfer of stresses between the two, because of this, splitting of bamboo did not occurred in any of the MBRCC beams.



Smooth surface indicating poor bonding

5.8.4.4 General Discussions on Mechanical Properties of Beams:-

1) Load-vs.-Deflection Curves.

Load-vs.-deflection curves followed straight line variation until the appearance of first crack in concrete. Immediately following the first crack there was flattering of the deflection curve (may be due to local bond slippage), followed by another fairly straight line variation but with a decrease slope, until ultimate failure of member occurred.

2) Load at Failure

The load carrying capacity of beams increased by 3.16 times when reinforced with Non treated Bamboo splints, after 28 days of curing.

The load carrying capacity of beams increased by 3.81 times when reinforced with Treated (Bitumen + sand mixture coated) bamboo splints, after 28 days of curing.

3) Deflection of Mid-Section

A minute deflection of 0.1mm was observed on testing plane cement concrete after 28 days of curing, the beams failed with a sudden brittle failure.

Beams reinforced with Non-treated bamboo splints showed maximum deflection of mid-section among all the three types of beams i.e. 15.70mm.

Beams reinforced with Treated (Bitumen + sand mixture coated) bamboo splints showed deflection of mid section up to 7.9mm which was smaller than that in Non-treated bamboo reinforced specimen.

Significant amount of deflections were observed in the beams reinforced with bamboo splints, before ultimate failure, hence reinforcing concrete beams with bamboo splints imparted sufficient ductility to the beams preventing sudden brittle failure at ultimate loads.

4) Modulus of Elasticity of Beams

Beams reinforced with Non-Treated bamboo splints showed highest Young's Modulus of elasticity among the three types of beams.

Effective utilization of grooves in case of beams reinforced with Non-Treated bamboo splints helped in improving the bond between reinforcement and concrete hence improving the homogeneity of the section, enhancing the strain compatibility between bamboo and concrete allowing better transfer of tensile stresses from concrete to bamboo.

Bamboo unlike steel is not a ductile material and do not yield, hence it can take large stresses without much elongation until the tensile stresses reached the ultimate tensile strength, as a result beam reinforced with bamboo splints was able to take large stresses at low strain which increased the modulus of elasticity of the beam.

The modulus of elasticity of the beams reinforced with Treated (Bitumen + sand mixture coated) bamboo splints, was found to be 1.66 times more than that of plain cement concrete beams after 28 days of curing.

The modulus of elasticity of the beams reinforced with Non treated bamboo splints was fund to be 1.73 times more than that of plain cement concrete beams after 28 days of curing.

5) Modulus of Rupture of Beams

Beams reinforced with Treated (Bitumen + sand mixture coated) bamboo splints shows highest Modulus of Rupture among the three types of specimens.

The modulus of rupture of the beam increases with an increase in the load carrying capacity of the beam.

The modulus of rupture of the beams reinforced with Treated (Bitumen + sand mixture coated) bamboo splints, was found to be 4.60 times more than that of plain cement concrete beams after 28 days of curing.

The modulus of rupture of the beams reinforced with Non treated bamboo splints was fund to be 3.95 times more than that of plain cement concrete beams after 28 days of curing.

6) Modes of failure of Beams

All the reinforced beams failed by the combination of one of the following modes of failure:-

- Longitudinal splitting of bamboo in tension.
- Flexure tension.
- Flexure shear.
- Web shear.
- Crushing of concrete.

Out of the total 6 singly reinforced beams tested only 1 of the beams failed by splitting of bamboo in tension, rest 5 beams failed either by shear failure, flexure shear failure or pure flexure failure because improper bonding between reinforcement and concrete did not allowed proper transfer of tensile stresses from concrete to bamboo splints.

In case of MBSRCC beams the grooves got filled up by Bitumen + Sand mixture making them ineffective in enhancing the concrete bamboo bond resulting in poor transfer of stresses between the two, because of this, splitting of bamboo did not occurred in any of the MBSRCC beams.

Most of the reinforced beams failed in diagonal tension (Web-Shear Cracks) near the supports which suggest that bamboo reinforced beams without proper design of shear reinforcement will not be safe for usage.

CHAPTER-6

6. CONCLUSIONS

6.1 The density of bamboo is very low lying in the range of 0.571-0.874 which makes it a very light material hence it can be transported and worked easily, rendering the use of cranes and other big machines unnecessary.

6.2 The initial moisture content decreases as we go along the height of bamboo Culm from bottom to top. Hence the specimen obtained from the bottom portion of bamboo should either be avoided for use as reinforcing material in concrete or if used, should be properly seasoned.

6.3 The water absorption capacity of non treated bamboo is as high as 60% by weight as seen aster 30 days of soaking in water, which necessitates the use of a water proofing compound, if bamboo has to be used as a reinforcing material in steel.

6.4 %increase in thickness after 30 days of soaking comes out to be as high as 40% in some of the non-treated bamboo samples which shows that there is a high possibility of swelling of the bamboo splints once they absorb water from the surroundings.

6.5 The water absorption capacity of bamboo increase with the increase in number of nodes hence the specimens containing large number of nodes should either be avoided for use as reinforcing material in concrete or if used, should be properly coated with an appropriate water proofing compound.

6.6 Bamboo in compression fails in two modes: Cracking of fiber and crushing. Most of specimens failed as a combination of both the modes.

6.7 Bamboo shows a high value of compressive strength (90.72Mpa) which is comparable or enen higher than steel and concrete.The compressive strength of bamboo specimen with internode has been found to be greater than that of specimens without and internode this could be because of additional crossectional area at nodes (as walls are thicker on both sides of the node) and due to the dense mass present at nodes.

6.8 Modulus of elasticity of a bamboo culm is as low as 56,7 Gpa because of this low value of modulus of elasticity of bamboo culm, it becomes unable to prevent tensile cracking in concrete. This is the main reason why a flexure element reinforced with a whole bamboo culm performs poorly than a flexure element reinforced with bamboo splints.

6.9 The stress-vs.-strain curve of bamboo splint in tension shows that bamboo is a visco elastic material having both viscous and elastic properties and exhibits time dependent strain elasticity.

6.10 The ultimate tensile strength of bamboo splints is as high as 282Mpa which is comparable to the yield strength of structural steel i.e 250Mpa. Hence bamboo splints can resist sufficient tensile loads in a concrete flexure element.

6.11 All the bamboo speciments shown brittle faliue at node, making node as the most critical section for faliure under tensile stresses. The reason behind the brittle nature of nose is that at node Firstly, there is a change of boundary,hence higher stress concentrations, Secondly, as compared to the internode part of bamboo where a very dense fibrous matrix is present along the length ,there is no fibers present at nodes, there are only fine granuals of wood present at the nodes ,on visual inspection it appears that nodes serves as the beginning and terminating point of fibers.

6.12 The samples wetted in water and $Ca(OH)_2$ shows a heavy fungal attack at nodes and at inner surface of the splints, leading to rotting of bamboo surface and disintegration of fibers. This necessitates the application of an anti fungal compound such as Boric Acid, over the bamboo splints before using them as a reinforcement material in concrete

6.13 25.14% of loss in ultimate tensile strength was observed in the samples wetted in NaCl solution. 29.14% of loss in ultimate tensile strength was observed in the samples wetted in $Ca(OH)_2$ solution & 29.61% of loss in ultimate tensile strength was observed in the samples wetted in tap water which was highest among the three, generally because of the rotting and disintegration of fibers.

6.14 The loss in ultimate tensile strength of bamboo splints due to swelling and shrinking of bamboo is attributed to its high water absorption and high water releasing properties due to its hygroscopic nature, hence this swelling and shrinking of bamboo can be controlled up to some extent by using a waterproof material like bitumen, coating over the surface of the bamboo splints before using them as a reinforcement material. The waterproofing material will not only prevent the swelling and shrinkage of bamboo but will also prevent the bamboo from coming in contact with alkalis and chlorides.

6.15 Load-vs.-deflection curves followed straight line variation until the appearance of first crack in concrete. Immediately following the first crack there was flattering of the deflection curve (may be due to local bond slippage), followed by another fairly straight line variation but with a decrease slope, until ultimate failure of member occurred.

6.16 The load carrying capacity of plain cement-concrete beams increased by 2.3 times when doubly reinforced with Non treated Bamboo splints and increased by 2.9 times when doubly reinforced with Treated (Bitumen + sand mixture coated) bamboo splints, after 28 days of curing respectively.

6.17 The load carrying capacity of plain cement-concrete beams increased by 3.16 times when singly reinforced with Non treated Bamboo splints and increased by 3.81 times when singly reinforced with Treated (Bitumen + sand mixture coated) bamboo splints, after 28 days of curing respectively.

6.18 Significant amount of deflections were observed in the beams reinforced with bamboo splints, before ultimate failure, hence reinforcing concrete beams with bamboo splints imparted sufficient ductility to the beams preventing sudden brittle failure at ultimate loads.

6.19 Beams reinforced with Treated (Bitumen + sand mixture coated) bamboo splints showed deflection smaller than that in Non-treated bamboo reinforced specimen, this could be because of the reduction in the reducing the plasticity of the beam due to high modulus of elasticity.

6.20 The modulus of elasticity of the plain cement-concrete beams increased by 2.21 times when doubly reinforced with Treated (Bitumen + sand mixture coated) bamboo splints, and increased by 1.64 times when doubly reinforced with Non treated bamboo splints after 28 days of curing respectively.

6.21 The modulus of elasticity of the plain cement-concrete beams increased by 1.66 times when singly reinforced with Treated (Bitumen + sand mixture coated) bamboo splints, and increased by 1.73 times when singly reinforced with Non treated bamboo splints after 28 days of curing respectively.

6.22 Beams reinforced with Treated (Bitumen + sand mixture coated) bamboo splints shows highest Modulus of Rupture among the three types of specimens in case of both singly and doubly reinforced beams because the modulus of rupture of the beam increases with an increase in the load carrying capacity of the beam.

6.23 The modulus of rupture of the plain cement-concrete beams increased by 2.74times when doubly reinforced with Treated (Bitumen + sand mixture coated) bamboo splints, and increased by 2.33 times when doubly reinforced with Non treated bamboo splints after 28 days of curing respectively.

6.24 The modulus of rupture of the plain cement-concrete beams increased by 4.60 times when singly reinforced with Treated (Bitumen + sand mixture coated) bamboo splints, and increased by 3.95 times when singly reinforced with Non treated bamboo splints after 28 days of curing respectively.

6.25 Out of the total 6 doubly reinforced beams tested only 2 of the beams failed by splitting of bamboo in tension, rest 4 beams failed either by shear failure, flexure shear failure or pure flexure failure, because in most of the beams improper bonding between reinforcement and concrete did not allowed proper transfer of tensile stresses from concrete to bamboo splints.

6.26 Out of the total 6 singly reinforced beams tested only 1 of the beams failed by splitting of bamboo in tension, rest 5 beams failed either by shear failure, flexure shear failure or pure flexure failure because in most of the beams improper bonding between reinforcement and concrete did not allowed proper transfer of tensile stresses from concrete to bamboo splints.

6.27 Most of the reinforced beams failed in diagonal tension (Web-Shear Cracks, breakage of shear link in case of doubly reinforced beams) near the supports which suggest that bamboo reinforced beams without proper design of shear reinforcement will not be safe for usage

CHAPTER-7

7. SCOPE FOR FURTHER STUDY

7.1 Though the water absorption capacity of bamboo get lowered to 25% from 60% on coating it with bitumen, but still there has been significant absorption of water in treated samples also which shows that bitumen is not a sucessful water coating material for bamboo because Firstly, of its high viscosity leading to improper coating over the bamboo surface and secondly, due to its stripping property in presence of water, hence to find out an appropriate waterproofing material for coating bamboo surface the water absorption test needs to be performed with more advanced and cheap water proofing materials in future.

7.2 The durability test results shows that there is a significant loss in ultimate tensile strength of bamboo splints when they undergoes alternate swelling and shrinking in the presence of alkalis, chlorides and moisture - the environments they possibly would be exposed to when used as reinforcement in concrete elements, hence putting a question over the use of bamboo splints as reinforcement material in concrete elements?

To find out that whether this loss of tensile strength varies linearly or exponentially with the age of concrete or becomes constant after a specific age of concrete, the test need to be performed for longer duration and testing to be done at successive intervals.

7.3 Though the doubly reinforced beams were adequately reinforced for shear by shear links made up of bamboo, but still in out of the 6 beams tested, breakage of shear link was observed in 3 of the beams, which shows that bamboo is not an adequate material for resisting the high shear force at supports hence the experiment need to be repeated with beams reinforced in shear with stirrups made up of different materials.

7.4 Coating bamboo splints with a mixture of sand and bitumen and making grooves on the inner surface of the bamboo splints improved the load carrying capacity, deflection of mid section, modulus of elasticity and modulus of rupture of the plain cement concrete beams (reinforced with bamboo splints) up to a fair extent, but still out of the 12 reinforced beams tested splitting of bamboo reinforcement was observed in only 3 of the beams rest all the 9 beams failed either by shear failure, flexure shear failure or pure flexure failure, because in most of the beams improper bonding between reinforcement and concrete did not allowed proper transfer of tensile stresses from concrete to bamboo splints, hence more advanced methods for improving the bamboo concrete bond needs to be worked out in future.

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APPENDICES

APPENDIX	DESCRIPTION
APPENDIX-1	Tension test: Load-vs. Displacement readings sample-A-1
APPENDIX-2	Tension test: Stress-vs.-Strain readings sample-A-1
APPENDIX-3	Tension test: Load-vs. Displacement readings sample-A-2
APPENDIX-4	Tension test: Stress-vs.-Strain readings sample-A-2
APPENDIX-5	Tension test: Load-vs. Displacement readings sample-A-3
APPENDIX-6	Tension test: Stress-vs.-Strain readings sample-A-4
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APPENDIX-18	Compression test: Stress-vs.-Strain readings sample-A-3
APPENDIX-19	Compression test: Load-vs. Displacement readings sample-B-1
APPENDIX-20	Compression test: Stress-vs.-Strain readings sample-B-1
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APPENDIX-22	Compression test: Stress-vs.-Strain readings sample-B-2
APPENDIX-23	Compression test: Load-vs. Displacement readings sample-B-3
APPENDIX-24	Compression test: Stress-vs.-Strain readings sample-B-3
APPENDIX-25	Flexure test on doubly reinforced beams: Load-vs.-Displacement

	readings after 7 days of curing
APPENDIX-26	Flexure test on doubly reinforced beams: Load-vs.-Displacement readings after 14 days of curing
APPENDIX-27	Flexure test on doubly reinforced beams: Load-vs.-Displacement readings after 28 days of curing
APPENDIX-28	Flexure test on singly reinforced beams: Load-vs.-Displacement readings after 28 days of curing

APPENDIX-1 TENSION TEST - UTM READINGS - SAMPLE-A-1

S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)
1	0	0	46	17700	8.8	91	22600	14.7	136	30200	23
2	12400	0.2	47	17800	8.9	92	22800	14.8	137	30300	23.1
3	12500	0.2	48	17900	9	93	22900	14.9	138	30400	23.2
4	12600	0.6	49	18000	9.1	94	23000	15	139	30500	23.4
5	13000	2.5	50	18100	9.2	95	23100	15.2	140	30600	23.5
6	13100	2.6	51	18200	9.4	96	23200	15.3	141	30800	23.6
7	13200	2.7	52	18300	9.5	97	23300	15.4	142	30900	23.7
8	13300	2.8	53	18400	9.6	98	23400	15.5	143	31100	23.9
9	13400	3	54	18500	9.7	99	23500	15.7	144	31200	24
10	13500	4	55	18600	9.8	100	23600	15.9	145	31400	24.2
11	13700	4.8	56	18700	9.9	101	23700	16.4	146	31500	24.3
12	13800	4.9	57	18800	10	102	23900	16.5	147	31600	24.4
13	13900	5	58	18900	10.1	103	24000	16.6	148	31700	24.4
14	14000	5.1	59	19000	10.3	104	24100	16.7	149	31800	24.6
15	14100	5.4	60	19100	10.4	105	24200	16.8	150	31900	24.7
16	14200	5.6	61	19200	10.5	106	24300	16.8	151	32000	24.8
17	14300	5.7	62	19300	10.6	107	24400	16.9	152	32100	24.9
18	14400	5.7	63	19400	10.7	108	24500	17	153	32300	25
19	14500	5.8	64	19500	10.8	109	24600	17.2	154	32500	25.2
20	14600	5.8	65	19700	11	110	24700	17.3	155	32600	25.3
21	14700	6	66	19800	11.2	111	24800	17.5	156	32700	25.4
22	14800	6	67	19900	11.3	112	24900	17.9	157	32900	25.5
23	14900	6.2	68	20000	11.4	113	25100	17.7	158	33000	25.6
24	15100	6.3	69	20100	11.5	114	25200	17.9	159	33200	25.7
25	15200	6.4	70	20200	11.8	115	25300	18	160	33300	25.8
26	15300	6.5	71	20300	11.9	116	25400	18.2	161	33400	25.9
27	15400	6.6	72	20400	12	117	25500	18.3	162	33600	26.2
28	15500	6.6	73	20500	12.1	118	25700	18.4	163	33900	26.3
29	15600	6.7	74	20600	12.2	119	25800	18.6	164	34000	26.5
30	15700	6.8	75	20700	12.3	120	28000	20.9	165	34100	26.6
31	15800	6.9	76	20800	12.4	121	28200	21	166	34300	26.7
32	15900	7	77	20900	12.6	122	28300	21.2	167	34500	26.8
33	16100	7.1	78	21000	12.6	123	28400	21.3	168	34600	26.9
34	16200	7.2	79	21100	12.8	124	28500	21.4	169	34800	27.2
35	16300	7.3	80	21200	12.9	125	28700	21.5	170	35000	27.3
36	16400	7.4	81	21300	13	126	28800	21.7	171	35100	27.4
37	16500	7.5	82	21400	13.1	127	28900	21.8	172	35600	27.8
38	16600	7.6	83	21500	13.3	128	29100	22	173	35800	27.9
39	16800	7.7	84	21600	13.4	129	29200	22.2	174	36000	28.1
40	17000	8.1	85	21700	13.6	130	29300	22.3	175	36100	28.2
41	17100	8.1	86	21800	13.6	131	29600	22.4	176	36300	28.3
42	17300	8.2	87	22100	13.9	132	29700	22.5	177	36500	28.5
43	17400	8.3	88	22200	14.1	133	29800	22.6	178	36700	28.6
44	17500	8.5	89	22300	14.2	134	29900	22.8	179	36800	28.8
45	17600	8.7	90	22500	14.5	135	30100	22.9	180	37000	28.9

TENSION TEST - UTM READINGS - SAMPLE-A-1											
S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)
181	37300	29.1									
182	37500	29.2									
183	37600	29.3									
184	38100	29.8									
185	38400	30.1									
186	38600	30.2									
187	38700	30.3									
188	38900	30.4									
189	39100	30.6									
190	39300	30.7									
191	39400	30.8									
192	39600	31									
193	40000	31.3									
194	40200	31.5									
195	40300	31.7									
196	40400	31.8									

APPENDIX-2			STRESS-VS-STRAIN READINGS : SAMPLE-A-1							E(Gpa)	38.75
S.NO.	σ Mpa	∈	S.NO.	σ Mpa	∈	S.NO.	σ Mpa	∈	S.NO.	σ Mpa	∈
1	0	0	46	73.75	0.0586667	91	94.167	0.098	136	125.833	0.15333333
2	51.6667	0.0013333	47	74.167	0.0593333	92	95	0.0986667	137	126.25	0.154
3	52.0833	0.0013333	48	74.583	0.06	93	95.417	0.0993333	138	126.667	0.15466667
4	52.5	0.004	49	75	0.0606667	94	95.833	0.1	139	127.083	0.156
5	54.1667	0.0166667	50	75.417	0.0613333	95	96.25	0.1013333	140	127.5	0.15666667
6	54.5833	0.0173333	51	75.833	0.0626667	96	96.667	0.102	141	128.333	0.15733333
7	55	0.018	52	76.25	0.0633333	97	97.083	0.1026667	142	128.75	0.158
8	55.4167	0.0186667	53	76.667	0.064	98	97.5	0.1033333	143	129.583	0.15933333
9	55.8333	0.02	54	77.083	0.0646667	99	97.917	0.1046667	144	130	0.16
10	56.25	0.0266667	55	77.5	0.0653333	100	98.333	0.106	145	130.833	0.16133333
11	57.0833	0.032	56	77.917	0.066	101	98.75	0.1093333	146	131.25	0.162
12	57.5	0.0326667	57	78.333	0.0666667	102	99.583	0.11	147	131.667	0.16266667
13	57.9167	0.0333333	58	78.75	0.0673333	103	100	0.1106667	148	132.083	0.16266667
14	58.3333	0.034	59	79.167	0.0686667	104	100.42	0.1113333	149	132.5	0.164
15	58.75	0.036	60	79.583	0.0693333	105	100.83	0.112	150	132.917	0.16466667
16	59.1667	0.0373333	61	80	0.07	106	101.25	0.112	151	133.333	0.16533333
17	59.5833	0.038	62	80.417	0.0706667	107	101.67	0.1126667	152	133.75	0.166
18	60	0.038	63	80.833	0.0713333	108	102.08	0.1133333	153	134.583	0.16666667
19	60.4167	0.0386667	64	81.25	0.072	109	102.5	0.1146667	154	135.417	0.168
20	60.8333	0.0386667	65	82.083	0.0733333	110	102.92	0.1153333	155	135.833	0.16866667
21	61.25	0.04	66	82.5	0.0746667	111	103.33	0.1166667	156	136.25	0.16933333
22	61.6667	0.04	67	82.917	0.0753333	112	103.75	0.1193333	157	137.083	0.17
23	62.0833	0.0413333	68	83.333	0.076	113	104.58	0.118	158	137.5	0.17066667
24	62.9167	0.042	69	83.75	0.0766667	114	105	0.1193333	159	138.333	0.17133333
25	63.3333	0.0426667	70	84.167	0.0786667	115	105.42	0.12	160	138.75	0.172
26	63.75	0.0433333	71	84.583	0.0793333	116	105.83	0.1213333	161	139.167	0.17266667
27	64.1667	0.044	72	85	0.08	117	106.25	0.122	162	140	0.17466667
28	64.5833	0.044	73	85.417	0.0806667	118	107.08	0.1226667	163	141.25	0.17533333
29	65	0.0446667	74	85.833	0.0813333	119	107.5	0.124	164	141.667	0.17666667
30	65.4167	0.0453333	75	86.25	0.082	120	116.67	0.1393333	165	142.083	0.17733333
31	65.8333	0.046	76	86.667	0.0826667	121	117.5	0.14	166	142.917	0.178
32	66.25	0.0466667	77	87.083	0.084	122	117.92	0.1413333	167	143.75	0.17866667
33	67.0833	0.0473333	78	87.5	0.084	123	118.33	0.142	168	144.167	0.17933333
34	67.5	0.048	79	87.917	0.0853333	124	118.75	0.1426667	169	145	0.18133333
35	67.9167	0.0486667	80	88.333	0.086	125	119.58	0.1433333	170	145.833	0.182
36	68.3333	0.0493333	81	88.75	0.0866667	126	120	0.1446667	171	146.25	0.18266667
37	68.75	0.05	82	89.167	0.0873333	127	120.42	0.1453333	172	148.333	0.18533333
38	69.1667	0.0506667	83	89.583	0.0886667	128	121.25	0.1466667	173	149.167	0.186
39	70	0.0513333	84	90	0.0893333	129	121.67	0.148	174	150	0.18733333
40	70.8333	0.054	85	90.417	0.0906667	130	122.08	0.1486667	175	150.417	0.188
41	71.25	0.054	86	90.833	0.0906667	131	123.33	0.1493333	176	151.25	0.18866667
42	72.0833	0.0546667	87	92.083	0.0926667	132	123.75	0.15	177	152.083	0.19
43	72.5	0.0553333	88	92.5	0.094	133	124.17	0.1506667	178	152.917	0.19066667
44	72.9167	0.0566667	89	92.917	0.0946667	134	124.58	0.152	179	153.333	0.192
45	73.3333	0.058	90	93.75	0.0966667	135	125.42	0.1526667	180	154.167	0.19266667

STRESS-VS-STRAIN READINGS - SAMPLE-A-1											
S.NO.	σ Mpa	$\in$	S.NO.			S.NO.			S.NO.		
181	155.417	0.194									
182	156.25	0.1946667									
183	156.667	0.1953333									
184	158.75	0.1986667									
185	160	0.2006667									
186	160.833	0.2013333									
187	161.25	0.202									
188	162.083	0.2026667									
189	162.917	0.204									
190	163.75	0.2046667									
191	164.167	0.2053333									
192	165	0.2066667									
193	166.667	0.2086667									
194	167.5	0.21									
195	167.917	0.2113333									
196	168.333	0.212									

APPENDIX-3					TENSION TEST - UTM READINGS - SAMPLE-A-2						
S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)
1	0	0	46	18200	5.9	91	22700	13.2			
2	13700	0.1	47	18300	6	92	22800	13.5			
3	13800	0.2	48	18400	6.1	93	22900	13.6			
4	13900	0.5	49	18500	6.5	94	23000	13.7			
5	14000	0.9	50	18600	6.6	95	23100	13.8			
6	14100	1	51	18700	6.7	96	23200	13.9			
7	14200	1.1	52	18800	6.8	97	23300	14			
8	14300	1.2	53	18900	6.9	98	23400	14.4			
9	14400	1.3	54	19000	7.3	99	23500	14.5			
10	14500	1.5	55	19100	7.7	100	23600	14.5			
11	14600	1.5	56	19200	7.8	101	23700	14.6			
12	14700	1.6	57	19300	7.9	102	23800	14.7			
13	14800	1.7	58	19400	7.9	103	23900	15			
14	14900	1.7	59	19500	8	104	24000	15.1			
15	15000	1.7	60	19600	8.1	105	24100	15.2			
16	15100	1.8	61	19700	8.5	106	24200	15.3			
17	15200	2	62	19800	8.7	107	24300	15.4			
18	15300	2.1	63	19900	9	108	24400	15.9			
19	15400	2.1	64	20000	9.1	109	24500	15.9			
20	15500	2.2	65	20100	9.1	110	24600	16			
21	15600	2.3	66	20200	9.6	111	24700	16.3			
22	15700	2.4	67	20300	9.6	112	24800	16.5			
23	15800	2.5	68	20400	9.7	113	24900	16.6			
24	15900	2.6	69	20500	10	114	25000	16.7			
25	16000	2.7	70	20600	10.1	115	25100	16.8			
26	16100	2.8	71	20700	10.2	116	25200	16.9			
27	16200	2.9	72	20800	10.3						
28	16300	3	73	20900	10.4						
29	16400	3.1	74	21000	10.8						
30	16500	3.2	75	21100	10.9						
31	16600	3.3	76	21200	11						
32	16700	3.4	77	21300	11.1						
33	16800	3.5	78	21400	11.4						
34	16900	3.7	79	21500	11.5						
35	17000	3.8	80	21600	11.6						
36	17100	3.9	81	21700	11.7						
37	17200	4	82	21800	11.8						
38	17300	4.1	83	21900	11.9						
39	17400	4.6	84	22000	12.3						
40	17500	4.7	85	22100	12.4						
41	17700	4.8	86	22200	12.5						
42	17800	5	87	22300	12.6						
43	17900	5.1	88	22400	12.8						
44	18000	5.2	89	22500	12.9						
45	18100	5.8	90	22600	13.1						

APPENDIX-4			STRESS-VS-STRAIN READINGS - SAMPLE-A-2							E(Gpa)	205.5
S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$
1	0	0	46	182	0.039333	91	227	0.088			
2	137	0.000667	47	183	0.04	92	228	0.09			
3	138	0.001333	48	184	0.040667	93	229	0.090667			
4	139	0.003333	49	185	0.043333	94	230	0.091333			
5	140	0.006	50	186	0.044	95	231	0.092			
6	141	0.006667	51	187	0.044667	96	232	0.092667			
7	142	0.007333	52	188	0.045333	97	233	0.093333			
8	143	0.008	53	189	0.046	98	234	0.096			
9	144	0.008667	54	190	0.048667	99	235	0.096667			
10	145	0.01	55	191	0.051333	100	236	0.096667			
11	146	0.01	56	192	0.052	101	237	0.097333			
12	147	0.010667	57	193	0.052667	102	238	0.098			
13	148	0.011333	58	194	0.052667	103	239	0.1			
14	149	0.011333	59	195	0.053333	104	240	0.100667			
15	150	0.011333	60	196	0.054	105	241	0.101333			
16	151	0.012	61	197	0.056667	106	242	0.102			
17	152	0.013333	62	198	0.058	107	243	0.102667			
18	153	0.014	63	199	0.06	108	244	0.106			
19	154	0.014	64	200	0.060667	109	245	0.106			
20	155	0.014667	65	201	0.060667	110	246	0.106667			
21	156	0.015333	66	202	0.064	111	247	0.108667			
22	157	0.016	67	203	0.064	112	248	0.11			
23	158	0.016667	68	204	0.064667	113	249	0.110667			
24	159	0.017333	69	205	0.066667	114	250	0.111333			
25	160	0.018	70	206	0.067333	115	251	0.112			
26	161	0.018667	71	207	0.068	116	252	0.112667			
27	162	0.019333	72	208	0.068667						
28	163	0.02	73	209	0.069333						
29	164	0.020667	74	210	0.072						
30	165	0.021333	75	211	0.072667						
31	166	0.022	76	212	0.073333						
32	167	0.022667	77	213	0.074						
33	168	0.023333	78	214	0.076						
34	169	0.024667	79	215	0.076667						
35	170	0.025333	80	216	0.077333						
36	171	0.026	81	217	0.078						
37	172	0.026667	82	218	0.078667						
38	173	0.027333	83	219	0.079333						
39	174	0.030667	84	220	0.082						
40	175	0.031333	85	221	0.082667						
41	177	0.032	86	222	0.083333						
42	178	0.033333	87	223	0.084						
43	179	0.034	88	224	0.085333						
44	180	0.034667	89	225	0.086						
45	181	0.038667	90	226	0.087333						

APPENDIX-5 TENSION TEST - UTM READINGS - SAMPLE-A-3

S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)
1	0	0	46	16600	7.5	91	21200	14.4	136	26100	20
2	12200	0.1	47	16700	7.6	92	21300	14.5	137	26200	20.1
3	12300	1.1	48	16900	7.9	93	21400	14.6	138	26300	20.1
4	12400	1.9	49	17000	8	94	21500	14.7	139	26400	20.3
5	12500	2.1	50	17100	8.2	95	21600	14.9	140	26500	20.4
6	12600	2.3	51	17200	8.3	96	21700	15	141	26600	20.5
7	12700	2.4	52	17300	8.4	97	21800	15.1	142	26700	20.6
8	12800	2.5	53	17400	8.5	98	21900	15.3	143	26800	20.7
9	12900	2.6	54	17500	8.7	99	22000	15.4	144	26900	20.8
10	13000	2.7	55	17600	8.8	100	22100	15.5	145	27000	20.8
11	13100	2.8	56	17700	8.9	101	22200	15.8	146	27100	20.8
12	13200	2.8	57	17800	9.1	102	22300	16	147	27200	20.9
13	13300	2.9	58	17900	9.2	103	22400	16.2	148	27300	21
14	13400	3	59	18000	9.3	104	22500	16.3	149	27400	21.2
15	13500	3.1	60	18100	9.6	105	22600	16.4	150	27500	21.3
16	13600	3.1	61	18200	9.7	106	22700	16.6	151	27600	21.3
17	13700	3.2	62	18300	9.8	107	22800	16.7	152	27700	21.4
18	13800	3.3	63	18400	10	108	22900	16.8	153	27800	21.4
19	13900	3.5	64	18500	10.2	109	23000	16.9	154	27900	21.5
20	14000	3.7	65	18600	10.4	110	23100	17	155	28000	21.6
21	14100	5.1	66	18700	10.6	111	23200	17.1	156	28100	21.7
22	14200	5.2	67	18800	10.7	112	23300	17.3	157	28200	21.8
23	14300	5.3	68	18900	10.8	113	23400	17.4	158	28300	21.8
24	14400	5.6	69	19000	10.9	114	23500	17.5	159	28400	21.9
25	14500	5.6	70	19100	11.2	115	23600	17.6	160	28500	22
26	14600	5.7	71	19200	11.3	116	23700	17.8	161	28600	22
27	14700	5.8	72	19300	11.5	117	23800	18	162	28700	22.2
28	14800	5.9	73	19400	11.7	118	24000	18.1	163	28800	22.3
29	14900	6	74	19500	11.9	119	24100	18.2	164	29000	22.3
30	15000	6.1	75	19600	12	120	24200	18.2	165	29100	22.4
31	15100	6.2	76	19700	12.1	121	24300	18.3	166	29200	22.5
32	15200	6.3	77	19800	12.3	122	24400	18.4	167	29300	22.5
33	15300	6.4	78	19900	12.4	123	24500	18.5	168	29600	22.8
34	15400	6.5	79	20000	12.7	124	24600	18.9	169	29700	22.9
35	15500	6.5	80	20100	12.8	125	24700	19	170	29800	23
36	15600	6.6	81	20200	12.9	126	24900	19.1	171	29900	23
37	15700	6.7	82	20300	13	127	25100	19.2	172	30000	23.1
38	15800	6.8	83	20400	13.1	128	25200	19.3	173	30100	23.2
39	15900	6.9	84	20500	13.2	129	25300	19.4	174	30300	23.3
40	16000	7	85	20600	13.5	130	25400	19.5	175	30400	23.4
41	16100	7.1	86	20700	13.7	131	25600	19.6	176	30500	23.5
42	16200	7.2	87	20800	13.8	132	25700	19.7	177	30600	23.5
43	16300	7.2	88	20900	13.9	133	25800	19.8	178	30700	23.6
44	16400	7.3	89	21000	14	134	25900	19.9	179	30800	23.7
45	16500	7.4	90	21100	14.2	135	26000	19.9	180	30900	23.8

TENSION TEST - UTM READINGS - SAMPLE-A-3											
S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)
181	31100	23.9	226	36900	27.7	271	43700	31.4			
182	31200	24	227	37100	27.8	272	43900	31.5			
183	31300	24.1	228	37200	27.9	273	44100	31.6			
184	31400	24.1	229	37400	28	274	44200	31.7			
185	31500	24.2	230	37600	28.1	275	44400	31.8			
186	31600	24.2	231	37700	28.1	276	44500	32			
187	31700	24.3	232	37800	28.3	277	44700	32.1			
188	31800	24.5	233	38000	28.4	278	44800	32.1			
189	31900	24.5	234	38100	28.4	279	45000	32.2			
190	32100	24.6	235	38400	28.6	280	45100	32.3			
191	32200	24.8	236	38600	28.7	281	45300	32.3			
192	32300	24.8	237	38800	28.8	282	45400	32.4			
193	32500	24.9	238	38900	28.9	283	45700	32.5			
194	32600	25	239	39100	28.9	284	45800	32.6			
195	32700	25.1	240	39200	29.1	285	45900	32.7			
196	32800	25.2	241	39400	29.1	286	46100	32.8			
197	32900	25.3	242	39500	29.2	287	46300	32.8			
198	33100	25.4	243	39700	29.3	288	46400	32.9			
199	33200	25.4	244	39800	29.4	289	46500	32.9			
200	33300	25.5	245	39900	29.4	290	46700	33			
201	33400	25.6	246	40100	29.5	291	46800	33.1			
202	33600	25.7	247	40200	29.6	292	46900	33.2			
203	33700	25.7	248	40500	29.7	293	47100	33.3			
204	33800	25.8	249	40600	29.8	294	47200	33.3			
205	33900	25.9	250	40800	29.9	295	47400	33.4			
206	34000	26	251	40900	30						
207	34200	26.1	252	41100	30						
208	34300	26.2	253	41300	30.1						
209	34400	26.2	254	41400	30.2						
210	34500	26.2	255	41500	30.3						
211	34700	26.5	256	41700	30.3						
212	34900	26.6	257	41800	30.4						
213	35000	26.7	258	41900	30.4						
214	35100	26.8	259	42000	30.5						
215	35400	26.9	260	42100	30.6						
216	35500	27	261	42200	30.6						
217	35600	27.2	262	42400	30.7						
218	35900	27.2	263	42500	30.7						
219	36000	27.2	264	42600	30.8						
220	36100	27.3	265	42800	30.9						
221	36200	27.4	266	42900	31						
222	36400	27.4	267	43000	31						
223	36500	27.5	268	43200	31.1						
224	36600	27.6	269	43300	31.2						
225	36800	27.7	270	43500	31.3						

APPENDIX-6				STRESS-VS-STRAIN READINGS - SAMPLE-A-3						E(Gpa)	101.66667
S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$
1	0	0	46	92.22222	0.05	91	117.7778	0.096	136	145	0.1333333
2	67.77778	0.0006667	47	92.77778	0.0506667	92	118.3333	0.096667	137	145.5556	0.134
3	68.33333	0.0073333	48	93.88889	0.0526667	93	118.8889	0.097333	138	146.1111	0.134
4	68.88889	0.0126667	49	94.44444	0.0533333	94	119.4444	0.098	139	146.6667	0.1353333
5	69.44444	0.014	50	95	0.0546667	95	120	0.099333	140	147.2222	0.136
6	70	0.0153333	51	95.55556	0.0553333	96	120.5556	0.1	141	147.7778	0.1366667
7	70.55556	0.016	52	96.11111	0.056	97	121.1111	0.100667	142	148.3333	0.1373333
8	71.11111	0.0166667	53	96.66667	0.0566667	98	121.6667	0.102	143	148.8889	0.138
9	71.66667	0.0173333	54	97.22222	0.058	99	122.2222	0.102667	144	149.4444	0.1386667
10	72.22222	0.018	55	97.77778	0.0586667	100	122.7778	0.103333	145	150	0.1386667
11	72.77778	0.0186667	56	98.33333	0.0593333	101	123.3333	0.105333	146	150.5556	0.1386667
12	73.33333	0.0186667	57	98.88889	0.0606667	102	123.8889	0.106667	147	151.1111	0.1393333
13	73.88889	0.0193333	58	99.44444	0.0613333	103	124.4444	0.108	148	151.6667	0.14
14	74.44444	0.02	59	100	0.062	104	125	0.108667	149	152.2222	0.1413333
15	75	0.0206667	60	100.5556	0.064	105	125.5556	0.109333	150	152.7778	0.142
16	75.55556	0.0206667	61	101.1111	0.0646667	106	126.1111	0.110667	151	153.3333	0.142
17	76.11111	0.0213333	62	101.6667	0.0653333	107	126.6667	0.111333	152	153.8889	0.1426667
18	76.66667	0.022	63	102.2222	0.0666667	108	127.2222	0.112	153	154.4444	0.1426667
19	77.22222	0.0233333	64	102.7778	0.068	109	127.7778	0.112667	154	155	0.1433333
20	77.77778	0.0246667	65	103.3333	0.0693333	110	128.3333	0.113333	155	155.5556	0.144
21	78.33333	0.034	66	103.8889	0.0706667	111	128.8889	0.114	156	156.1111	0.1446667
22	78.88889	0.0346667	67	104.4444	0.0713333	112	129.4444	0.115333	157	156.6667	0.1453333
23	79.44444	0.0353333	68	105	0.072	113	130	0.116	158	157.2222	0.1453333
24	80	0.0373333	69	105.5556	0.0726667	114	130.5556	0.116667	159	157.7778	0.146
25	80.55556	0.0373333	70	106.1111	0.0746667	115	131.1111	0.117333	160	158.3333	0.1466667
26	81.11111	0.038	71	106.6667	0.0753333	116	131.6667	0.118667	161	158.8889	0.1466667
27	81.66667	0.0386667	72	107.2222	0.0766667	117	132.2222	0.12	162	159.4444	0.148
28	82.22222	0.0393333	73	107.7778	0.078	118	133.3333	0.120667	163	160	0.1486667
29	82.77778	0.04	74	108.3333	0.0793333	119	133.8889	0.121333	164	161.1111	0.1486667
30	83.33333	0.0406667	75	108.8889	0.08	120	134.4444	0.121333	165	161.6667	0.1493333
31	83.88889	0.0413333	76	109.4444	0.0806667	121	135	0.122	166	162.2222	0.15
32	84.44444	0.042	77	110	0.082	122	135.5556	0.122667	167	162.7778	0.15
33	85	0.0426667	78	110.5556	0.0826667	123	136.1111	0.123333	168	164.4444	0.152
34	85.55556	0.0433333	79	111.1111	0.0846667	124	136.6667	0.126	169	165	0.1526667
35	86.11111	0.0433333	80	111.6667	0.0853333	125	137.2222	0.126667	170	165.5556	0.1533333
36	86.66667	0.044	81	112.2222	0.086	126	138.3333	0.127333	171	166.1111	0.1533333
37	87.22222	0.0446667	82	112.7778	0.0866667	127	139.4444	0.128	172	166.6667	0.154
38	87.77778	0.0453333	83	113.3333	0.0873333	128	140	0.128667	173	167.2222	0.1546667
39	88.33333	0.046	84	113.8889	0.088	129	140.5556	0.129333	174	168.3333	0.1553333
40	88.88889	0.0466667	85	114.4444	0.09	130	141.1111	0.13	175	168.8889	0.156
41	89.44444	0.0473333	86	115	0.0913333	131	142.2222	0.130667	176	169.4444	0.1566667
42	90	0.048	87	115.5556	0.092	132	142.7778	0.131333	177	170	0.1566667
43	90.55556	0.048	88	116.1111	0.0926667	133	143.3333	0.132	178	170.5556	0.1573333
44	91.11111	0.0486667	89	116.6667	0.0933333	134	143.8889	0.132667	179	171.1111	0.158
45	91.66667	0.0493333	90	117.2222	0.0946667	135	144.4444	0.132667	180	171.6667	0.1586667

STRESS-VS-STRAIN READINGS - SAMPLE-A-3											
S.NO.	σ Mpa	∈	S.NO.	σ Mpa	∈	S.NO.	σ Mpa	∈	S.NO.	σ Mpa	∈
181	172.7778	0.1593333	226	205	0.1846667	271	242.7778	0.209333			
182	173.3333	0.16	227	206.1111	0.1853333	272	243.8889	0.21			
183	173.8889	0.1606667	228	206.6667	0.186	273	245	0.210667			
184	174.4444	0.1606667	229	207.7778	0.1866667	274	245.5556	0.211333			
185	175	0.1613333	230	208.8889	0.1873333	275	246.6667	0.212			
186	175.5556	0.1613333	231	209.4444	0.1873333	276	247.2222	0.213333			
187	176.1111	0.162	232	210	0.1886667	277	248.3333	0.214			
188	176.6667	0.1633333	233	211.1111	0.1893333	278	248.8889	0.214			
189	177.2222	0.1633333	234	211.6667	0.1893333	279	250	0.214667			
190	178.3333	0.164	235	213.3333	0.1906667	280	250.5556	0.215333			
191	178.8889	0.1653333	236	214.4444	0.1913333	281	251.6667	0.215333			
192	179.4444	0.1653333	237	215.5556	0.192	282	252.2222	0.216			
193	180.5556	0.166	238	216.1111	0.1926667	283	253.8889	0.216667			
194	181.1111	0.1666667	239	217.2222	0.1926667	284	254.4444	0.217333			
195	181.6667	0.1673333	240	217.7778	0.194	285	255	0.218			
196	182.2222	0.168	241	218.8889	0.194	286	256.1111	0.218667			
197	182.7778	0.1686667	242	219.4444	0.1946667	287	257.2222	0.218667			
198	183.8889	0.1693333	243	220.5556	0.1953333	288	257.7778	0.219333			
199	184.4444	0.1693333	244	221.1111	0.196	289	258.3333	0.219333			
200	185	0.17	245	221.6667	0.196	290	259.4444	0.22			
201	185.5556	0.1706667	246	222.7778	0.1966667	291	260	0.220667			
202	186.6667	0.1713333	247	223.3333	0.1973333	292	260.5556	0.221333			
203	187.2222	0.1713333	248	225	0.198	293	261.6667	0.222			
204	187.7778	0.172	249	225.5556	0.1986667	294	262.2222	0.222			
205	188.3333	0.1726667	250	226.6667	0.1993333	295	263.3333	0.222667			
206	188.8889	0.1733333	251	227.2222	0.2						
207	190	0.174	252	228.3333	0.2						
208	190.5556	0.1746667	253	229.4444	0.2006667						
209	191.1111	0.1746667	254	230	0.2013333						
210	191.6667	0.1746667	255	230.5556	0.202						
211	192.7778	0.1766667	256	231.6667	0.202						
212	193.8889	0.1773333	257	232.2222	0.2026667						
213	194.4444	0.178	258	232.7778	0.2026667						
214	195	0.1786667	259	233.3333	0.2033333						
215	196.6667	0.1793333	260	233.8889	0.204						
216	197.2222	0.18	261	234.4444	0.204						
217	197.7778	0.1813333	262	235.5556	0.2046667						
218	199.4444	0.1813333	263	236.1111	0.2046667						
219	200	0.1813333	264	236.6667	0.2053333						
220	200.5556	0.182	265	237.7778	0.206						
221	201.1111	0.1826667	266	238.3333	0.2066667						
222	202.2222	0.1826667	267	238.8889	0.2066667						
223	202.7778	0.1833333	268	240	0.2073333						
224	203.3333	0.184	269	240.5556	0.208						
225	204.4444	0.1846667	270	241.6667	0.2086667						

APPENDIX-7						TENSION TEST - UTM READINGS - SAMPLE-A-4					
S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)
1	0	0	46	17500	7.4	91	22200	12.8	136	27600	17.3
2	12500	0.1	47	17600	7.6	92	22300	12.9	137	27700	17.4
3	12600	0.1	48	17700	7.8	93	22400	13	138	27900	17.5
4	12700	0.2	49	17800	7.9	94	22600	13.1	139	28000	17.5
5	12800	0.7	50	17900	8	95	22700	13.2	140	28200	17.6
6	12900	0.8	51	18000	8	96	22800	13.3	141	28400	17.8
7	13100	1.9	52	18100	8.4	97	22900	13.4	142	28500	17.8
8	13300	1.9	53	18200	8.4	98	23000	13.5	143	28600	17.9
9	13400	2.1	54	18300	8.5	99	23100	13.6	144	28800	18
10	13500	2.2	55	18400	8.6	100	23200	13.7	145	29200	18.2
11	13700	2.3	56	18500	8.8	101	23300	13.8	146	29300	18.3
12	13800	2.4	57	18700	9	102	23400	13.9	147	29400	18.4
13	13900	2.5	58	18800	9.1	103	23500	14	148	29500	18.5
14	14000	2.6	59	18900	9.2	104	23700	14.2	149	29700	18.6
15	14100	3.4	60	19000	9.5	105	23800	14.2	150	29900	18.7
16	14200	3.5	61	19100	9.6	106	23900	14.5	151	30000	18.8
17	14400	3.6	62	19200	9.6	107	24000	14.8	152	30100	18.8
18	14500	4	63	19300	9.7	108	24200	14.9	153	30400	18.9
19	14600	4.1	64	19400	9.8	109	24400	14.9	154	30500	19
20	14700	4.2	65	19500	9.9	110	24500	15	155	30600	19.1
21	14800	4.5	66	19600	10	111	24600	15.1	156	30700	19.2
22	14900	4.6	67	19700	10.2	112	24700	15.1	157	30900	19.3
23	15000	4.7	68	19800	10.3	113	24800	15.2	158	31100	19.4
24	15100	4.8	69	19900	10.4	114	24900	15.3	159	31300	19.5
25	15200	4.9	70	20100	10.5	115	25000	15.4	160	31500	19.6
26	15300	5.1	71	20200	10.6	116	25100	15.5	161	31600	19.7
27	15400	5.2	72	20300	10.9	117	25300	15.6	162	31800	19.8
28	15500	5.3	73	20400	11	118	25400	15.7	163	32000	19.9
29	15600	5.4	74	20500	11.1	119	25500	15.8	164	32200	20
30	15900	5.5	75	20600	11.2	120	25600	15.9	165	32400	20.1
31	16000	5.6	76	20700	11.2	121	25800	16	166	32500	20.1
32	16100	5.7	77	20800	11.3	122	25900	16.1	167	32700	20.3
33	16200	5.9	78	20900	11.4	123	26000	16.2	168	32900	20.4
34	16300	6	79	21000	11.5	124	26100	16.3	169	33100	20.4
35	16400	6.1	80	21100	11.6	125	26300	16.4	170	33200	20.5
36	16500	6.2	81	21200	11.8	126	26500	16.5	171	33300	20.6
37	16600	6.3	82	21300	11.9	127	26600	16.6	172	33500	20.7
38	16700	6.5	83	21400	12	128	26700	16.7	173	33700	20.8
39	16800	6.6	84	21500	12.1	129	26800	16.7	174	33800	20.9
40	16900	6.7	85	21600	12.1	130	26900	16.8	175	34100	21
41	17000	6.9	86	21700	12.3	131	27000	16.9	176	34300	21.1
42	17100	7	87	21800	12.4	132	27100	17	177	34400	21.2
43	17200	7.1	88	21900	12.5	133	27200	17	178	34500	21.3
44	17300	7.2	89	22000	12.6	134	27300	17.1	179	34600	21.4
45	17400	7.3	90	22100	12.7	135	27500	17.2	180	34800	21.4

TENSION TEST - UTM READINGS - SAMPLE-A-4											
S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)
181	34900	21.5									
182	35000	21.6									
183	35200	21.7									
184	35300	21.8									
185	35500	21.9									
186	35600	22									
187	35700	22									
188	35800	22.4									

APPENDIX-8	STRESS-VS-STRAIN READINGS - SAMPLE-A-4									E(Gpa)	156.25
S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$
1	0	0	46	145.8333	0.0493333	91	185	0.0853333	136	230	0.1153333
2	104.1667	0.0006667	47	146.6667	0.0506667	92	185.8333	0.086	137	230.8333	0.116
3	105	0.0006667	48	147.5	0.052	93	186.6667	0.0866667	138	232.5	0.1166667
4	105.8333	0.0013333	49	148.3333	0.0526667	94	188.3333	0.0873333	139	233.3333	0.1166667
5	106.6667	0.0046667	50	149.1667	0.0533333	95	189.1667	0.088	140	235	0.1173333
6	107.5	0.0053333	51	150	0.0533333	96	190	0.0886667	141	236.6667	0.1186667
7	109.1667	0.0126667	52	150.8333	0.056	97	190.8333	0.0893333	142	237.5	0.1186667
8	110.8333	0.0126667	53	151.6667	0.056	98	191.6667	0.09	143	238.3333	0.1193333
9	111.6667	0.014	54	152.5	0.0566667	99	192.5	0.0906667	144	240	0.12
10	112.5	0.0146667	55	153.3333	0.0573333	100	193.3333	0.0913333	145	243.3333	0.1213333
11	114.1667	0.0153333	56	154.1667	0.0586667	101	194.1667	0.092	146	244.1667	0.122
12	115	0.016	57	155.8333	0.06	102	195	0.0926667	147	245	0.1226667
13	115.8333	0.0166667	58	156.6667	0.0606667	103	195.8333	0.0933333	148	245.8333	0.1233333
14	116.6667	0.0173333	59	157.5	0.0613333	104	197.5	0.0946667	149	247.5	0.124
15	117.5	0.0226667	60	158.3333	0.0633333	105	198.3333	0.0946667	150	249.1667	0.1246667
16	118.3333	0.0233333	61	159.1667	0.064	106	199.1667	0.0966667	151	250	0.1253333
17	120	0.024	62	160	0.064	107	200	0.0986667	152	250.8333	0.1253333
18	120.8333	0.0266667	63	160.8333	0.0646667	108	201.6667	0.0993333	153	253.3333	0.126
19	121.6667	0.0273333	64	161.6667	0.0653333	109	203.3333	0.0993333	154	254.1667	0.1266667
20	122.5	0.028	65	162.5	0.066	110	204.1667	0.1	155	255	0.1273333
21	123.3333	0.03	66	163.3333	0.0666667	111	205	0.1006667	156	255.8333	0.128
22	124.1667	0.0306667	67	164.1667	0.068	112	205.8333	0.1006667	157	257.5	0.1286667
23	125	0.0313333	68	165	0.0686667	113	206.6667	0.1013333	158	259.1667	0.1293333
24	125.8333	0.032	69	165.8333	0.0693333	114	207.5	0.102	159	260.8333	0.13
25	126.6667	0.0326667	70	167.5	0.07	115	208.3333	0.1026667	160	262.5	0.1306667
26	127.5	0.034	71	168.3333	0.0706667	116	209.1667	0.1033333	161	263.3333	0.1313333
27	128.3333	0.0346667	72	169.1667	0.0726667	117	210.8333	0.104	162	265	0.132
28	129.1667	0.0353333	73	170	0.0733333	118	211.6667	0.1046667	163	266.6667	0.1326667
29	130	0.036	74	170.8333	0.074	119	212.5	0.1053333	164	268.3333	0.1333333
30	132.5	0.0366667	75	171.6667	0.0746667	120	213.3333	0.106	165	270	0.134
31	133.3333	0.0373333	76	172.5	0.0746667	121	215	0.1066667	166	270.8333	0.134
32	134.1667	0.038	77	173.3333	0.0753333	122	215.8333	0.1073333	167	272.5	0.1353333
33	135	0.0393333	78	174.1667	0.076	123	216.6667	0.108	168	274.1667	0.136
34	135.8333	0.04	79	175	0.0766667	124	217.5	0.1086667	169	275.8333	0.136
35	136.6667	0.0406667	80	175.8333	0.0773333	125	219.1667	0.1093333	170	276.6667	0.1366667
36	137.5	0.0413333	81	176.6667	0.0786667	126	220.8333	0.11	171	277.5	0.1373333
37	138.3333	0.042	82	177.5	0.0793333	127	221.6667	0.1106667	172	279.1667	0.138
38	139.1667	0.0433333	83	178.3333	0.08	128	222.5	0.1113333	173	280.8333	0.1386667
39	140	0.044	84	179.1667	0.0806667	129	223.3333	0.1113333	174	281.6667	0.1393333
40	140.8333	0.0446667	85	180	0.0806667	130	224.1667	0.112	175	284.1667	0.14
41	141.6667	0.046	86	180.8333	0.082	131	225	0.1126667	176	285.8333	0.1406667
42	142.5	0.0466667	87	181.6667	0.0826667	132	225.8333	0.1133333	177	286.6667	0.1413333
43	143.3333	0.0473333	88	182.5	0.0833333	133	226.6667	0.1133333	178	287.5	0.142
44	144.1667	0.048	89	183.3333	0.084	134	227.5	0.114	179	288.3333	0.1426667
45	145	0.0486667	90	184.1667	0.0846667	135	229.1667	0.1146667	180	290	0.1426667

TENSION TEST - STRESS-VS-STRAIN READINGS - SAMPLE-A-4											
S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$
181	290.8333	0.1433333									
182	291.6667	0.144									
183	293.3333	0.1446667									
184	294.1667	0.1453333									
185	295.8333	0.146									
186	296.6667	0.1466667									
187	297.5	0.1466667									
188	298.3333	0.1493333									

APPENDIX-9							TENSION TEST - UTM READINGS - SAMPLE-A-5				
S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)
1	0	0	46	17600	6.5	91	22100	11.4	136	26600	17.2
2	12900	0.5	47	17700	6.5	92	22200	11.6	137	26700	17.3
3	13000	1.4	48	17800	6.6	93	22300	11.7	138	26800	17.4
4	13200	1.5	49	17900	6.7	94	22400	11.8	139	26900	17.5
5	13300	1.6	50	18000	6.7	95	22500	12	140	27000	17.6
6	13400	1.7	51	18100	6.8	96	22600	12.1	141	27100	17.7
7	13500	1.7	52	18200	6.9	97	22700	12.3	142	27200	17.9
8	13600	1.8	53	18300	7	98	22800	12.5	143	27300	18
9	13700	1.9	54	18400	7.1	99	22900	12.6	144	27400	18.2
10	13800	1.9	55	18500	7.2	100	23000	12.7	145	27500	18.3
11	13900	2	56	18600	7.2	101	23100	12.8	146	27600	18.3
12	14000	2.1	57	18700	7.4	102	23200	12.9	147	27700	18.5
13	14100	2.2	58	18800	7.5	103	23300	13.1	148	27800	18.6
14	14200	2.3	59	18900	7.6	104	23400	13.2	149	27900	18.7
15	14300	3	60	19000	7.7	105	23500	13.2	150	28000	18.8
16	14400	4.2	61	19100	7.8	106	23600	13.4	151	28100	19.1
17	14500	4.3	62	19200	7.9	107	23700	13.5	152	28200	19.2
18	14600	4.4	63	19300	7.9	108	23800	13.6	153	28300	19.3
19	14700	4.4	64	19400	8	109	23900	13.8	154	28400	19.4
20	14800	4.5	65	19500	8.1	110	24000	13.9	155	28500	19.5
21	14900	4.5	66	19600	8.2	111	24100	14	156	28600	19.6
22	15100	4.6	67	19700	8.4	112	24200	14.4	157	28700	19.8
23	15200	4.6	68	19800	8.5	113	24300	14.6	158	28800	19.9
24	15300	4.7	69	19900	8.5	114	24400	14.7	159	28900	20
25	15400	4.8	70	20000	8.7	115	24500	14.8	160	29000	20.1
26	15500	4.8	71	20100	8.9	116	24600	14.8	161	29100	20.3
27	15600	4.9	72	20200	9	117	24700	14.9	162	29200	20.4
28	15700	5	73	20300	9.1	118	24800	15	163	29300	20.5
29	15800	5.1	74	20400	9.2	119	24900	15.1	164	29400	20.5
30	15900	5.2	75	20500	9.4	120	25000	15.2	165	29500	20.6
31	16100	5.3	76	20600	9.5	121	25100	15.4	166	29600	20.7
32	16200	5.4	77	20700	9.6	122	25200	15.5	167	29700	20.8
33	16300	5.4	78	20800	9.7	123	25300	15.6	168	29800	20.9
34	16400	5.5	79	20900	9.8	124	25400	15.7	169	29900	21.1
35	16500	5.6	80	21000	10	125	25500	15.8	170	30000	21.2
36	16600	5.7	81	21100	10.1	126	25600	16	171	30100	21.3
37	16700	5.8	82	21200	10.2	127	25700	16.1	172	30200	21.4
38	16800	5.9	83	21300	10.4	128	25800	16.3	173	30300	21.5
39	16900	5.9	84	21400	10.5	129	25900	16.5	174	30400	21.6
40	17000	6	85	21500	10.6	130	26000	16.6	175	30500	21.7
41	17100	6.1	86	21600	10.7	131	26100	16.6	176	30600	21.8
42	17200	6.2	87	21700	10.9	132	26200	16.8	177	30700	21.8
43	17300	6.3	88	21800	11	133	26300	16.9	178	30800	21.9
44	17400	6.3	89	21900	11.2	134	26400	17	179	30900	22
45	17500	6.4	90	22000	11.3	135	26500	17.1	180	31000	22.2

TENSION TEST - UTM READINGS - SAMPLE-A-5											
S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)
181	31100	22.2	226	35700	26.3	271	40500	30.4			
182	31200	22.3	227	35800	26.4	272	40600	30.5			
183	31300	22.4	228	35900	26.5	273	40700	30.6			
184	31400	22.5	229	36000	26.5	274	40800	30.6			
185	31500	22.6	230	36100	26.6	275	40900	30.7			
186	31600	22.7	231	36200	26.7	276	41000	30.8			
187	31700	22.8	232	36300	27.8	277	41100	30.9			
188	31800	22.9	233	36400	26.9	278	41200	30.9			
189	31900	22.9	234	36500	26.9	279	41300	31			
190	32000	23.1	235	36600	27	280	41400	31			
191	32100	23.2	236	36700	27.1	281	41500	31.1			
192	32200	23.3	237	36800	27.2	282	41600	31.2			
193	32300	23.3	238	36900	27.3	283	41700	31.3			
194	32400	23.4	239	37000	27.4	284	41800	31.5			
195	32500	23.5	240	37100	27.5	285	41900	31.6			
196	32600	23.6	241	37200	27.5	286	42000	31.7			
197	32700	23.7	242	37300	27.6	287	42100	31.8			
198	32800	23.8	243	37400	27.7	288	42200	31.8			
199	32900	23.9	244	37500	27.8	289	42300	32			
200	33000	24	245	37600	27.8	290	42400	32			
201	33100	24.1	246	37700	27.9	291	42500	32.1			
202	33200	24.1	247	37800	28	292	42600	32.2			
203	33300	24.3	248	37900	28.1	293	42700	32.3			
204	33400	24.3	249	38000	28.2	294	42800	32.4			
205	33500	24.4	250	38100	28.2	295	42900	32.5			
206	33600	24.5	251	38200	28.3	296	43000	32.6			
207	33700	24.6	252	38300	28.4	297	43100	32.6			
208	33800	24.6	253	38400	28.5						
209	33900	24.7	254	38500	28.6						
210	34000	24.8	255	38600	28.7						
211	34100	24.9	256	38700	28.8						
212	34200	25	257	38800	28.9						
213	34300	25.1	258	38900	29						
214	34400	25.2	259	39000	29.1						
215	34500	25.2	260	39100	29.2						
216	34600	25.3	261	39300	29.4						
217	34700	25.4	262	39400	29.5						
218	34800	25.5	263	39600	29.6						
219	34900	25.6	264	39800	29.7						
220	35000	25.7	265	39900	29.8						
221	35200	25.8	266	40000	29.9						
222	35300	25.9	267	40100	30						
223	35400	26	268	40200	30.1						
224	35500	26.1	269	40300	30.2						
225	35600	26.2	270	40400	30.3						

APPENDIX10				STRESS-VS-STRAIN READINGS - SAMPLE-A-5						E(Gpa)	16.125
S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$
1	0	0	46	73.33333	0.0433333	91	92.08333	0.076	136	110.8333	0.114666667
2	53.75	0.003333	47	73.75	0.0433333	92	92.5	0.0773333	137	111.25	0.115333333
3	54.16667	0.009333	48	74.16667	0.044	93	92.91667	0.078	138	111.6667	0.116
4	55	0.01	49	74.58333	0.0446667	94	93.33333	0.0786667	139	112.0833	0.116666667
5	55.41667	0.010667	50	75	0.0446667	95	93.75	0.08	140	112.5	0.117333333
6	55.83333	0.011333	51	75.41667	0.0453333	96	94.16667	0.0806667	141	112.9167	0.118
7	56.25	0.011333	52	75.83333	0.046	97	94.58333	0.082	142	113.3333	0.119333333
8	56.66667	0.012	53	76.25	0.0466667	98	95	0.0833333	143	113.75	0.12
9	57.08333	0.012667	54	76.66667	0.0473333	99	95.41667	0.084	144	114.1667	0.121333333
10	57.5	0.012667	55	77.08333	0.048	100	95.83333	0.0846667	145	114.5833	0.122
11	57.91667	0.013333	56	77.5	0.048	101	96.25	0.0853333	146	115	0.122
12	58.33333	0.014	57	77.91667	0.0493333	102	96.66667	0.086	147	115.4167	0.123333333
13	58.75	0.014667	58	78.33333	0.05	103	97.08333	0.0873333	148	115.8333	0.124
14	59.16667	0.015333	59	78.75	0.0506667	104	97.5	0.088	149	116.25	0.124666667
15	59.58333	0.02	60	79.16667	0.0513333	105	97.91667	0.088	150	116.6667	0.125333333
16	60	0.028	61	79.58333	0.052	106	98.33333	0.0893333	151	117.0833	0.127333333
17	60.41667	0.028667	62	80	0.0526667	107	98.75	0.09	152	117.5	0.128
18	60.83333	0.029333	63	80.41667	0.0526667	108	99.16667	0.0906667	153	117.9167	0.128666667
19	61.25	0.029333	64	80.83333	0.0533333	109	99.58333	0.092	154	118.3333	0.129333333
20	61.66667	0.03	65	81.25	0.054	110	100	0.0926667	155	118.75	0.13
21	62.08333	0.03	66	81.66667	0.0546667	111	100.4167	0.0933333	156	119.1667	0.130666667
22	62.91667	0.030667	67	82.08333	0.056	112	100.8333	0.096	157	119.5833	0.132
23	63.33333	0.030667	68	82.5	0.0566667	113	101.25	0.0973333	158	120	0.132666667
24	63.75	0.031333	69	82.91667	0.0566667	114	101.6667	0.098	159	120.4167	0.133333333
25	64.16667	0.032	70	83.33333	0.058	115	102.0833	0.0986667	160	120.8333	0.134
26	64.58333	0.032	71	83.75	0.0593333	116	102.5	0.0986667	161	121.25	0.135333333
27	65	0.032667	72	84.16667	0.06	117	102.9167	0.0993333	162	121.6667	0.136
28	65.41667	0.033333	73	84.58333	0.0606667	118	103.3333	0.1	163	122.0833	0.136666667
29	65.83333	0.034	74	85	0.0613333	119	103.75	0.1006667	164	122.5	0.136666667
30	66.25	0.034667	75	85.41667	0.0626667	120	104.1667	0.1013333	165	122.9167	0.137333333
31	67.08333	0.035333	76	85.83333	0.0633333	121	104.5833	0.1026667	166	123.3333	0.138
32	67.5	0.036	77	86.25	0.064	122	105	0.1033333	167	123.75	0.138666667
33	67.91667	0.036	78	86.66667	0.0646667	123	105.4167	0.104	168	124.1667	0.139333333
34	68.33333	0.036667	79	87.08333	0.0653333	124	105.8333	0.1046667	169	124.5833	0.140666667
35	68.75	0.037333	80	87.5	0.0666667	125	106.25	0.1053333	170	125	0.141333333
36	69.16667	0.038	81	87.91667	0.0673333	126	106.6667	0.1066667	171	125.4167	0.142
37	69.58333	0.038667	82	88.33333	0.068	127	107.0833	0.1073333	172	125.8333	0.142666667
38	70	0.039333	83	88.75	0.0693333	128	107.5	0.1086667	173	126.25	0.143333333
39	70.41667	0.039333	84	89.16667	0.07	129	107.9167	0.11	174	126.6667	0.144
40	70.83333	0.04	85	89.58333	0.0706667	130	108.3333	0.1106667	175	127.0833	0.144666667
41	71.25	0.040667	86	90	0.0713333	131	108.75	0.1106667	176	127.5	0.145333333
42	71.66667	0.041333	87	90.41667	0.0726667	132	109.1667	0.112	177	127.9167	0.145333333
43	72.08333	0.042	88	90.83333	0.0733333	133	109.5833	0.1126667	178	128.3333	0.146
44	72.5	0.042	89	91.25	0.0746667	134	110	0.1133333	179	128.75	0.146666667
45	72.91667	0.042667	90	91.66667	0.0753333	135	110.4167	0.114	180	129.1667	0.148

STRESS-VS-STRAIN READINGS - SAMPLE-A-5											
S.NO.	σ Mpa	∈	S.NO.	σ Mpa	∈	S.NO.	σ Mpa	∈	S.NO.	σ Mpa	∈
181	129.5833	0.148	226	148.75	0.1753333	271	168.75	0.2026667			
182	130	0.148667	227	149.1667	0.176	272	169.1667	0.2033333			
183	130.4167	0.149333	228	149.5833	0.1766667	273	169.5833	0.204			
184	130.8333	0.15	229	150	0.1766667	274	170	0.204			
185	131.25	0.150667	230	150.4167	0.1773333	275	170.4167	0.2046667			
186	131.6667	0.151333	231	150.8333	0.178	276	170.8333	0.2053333			
187	132.0833	0.152	232	151.25	0.1853333	277	171.25	0.206			
188	132.5	0.152667	233	151.6667	0.1793333	278	171.6667	0.206			
189	132.9167	0.152667	234	152.0833	0.1793333	279	172.0833	0.2066667			
190	133.3333	0.154	235	152.5	0.18	280	172.5	0.2066667			
191	133.75	0.154667	236	152.9167	0.1806667	281	172.9167	0.2073333			
192	134.1667	0.155333	237	153.3333	0.1813333	282	173.3333	0.208			
193	134.5833	0.155333	238	153.75	0.182	283	173.75	0.2086667			
194	135	0.156	239	154.1667	0.1826667	284	174.1667	0.21			
195	135.4167	0.156667	240	154.5833	0.1833333	285	174.5833	0.2106667			
196	135.8333	0.157333	241	155	0.1833333	286	175	0.2113333			
197	136.25	0.158	242	155.4167	0.184	287	175.4167	0.212			
198	136.6667	0.158667	243	155.8333	0.1846667	288	175.8333	0.212			
199	137.0833	0.159333	244	156.25	0.1853333	289	176.25	0.2133333			
200	137.5	0.16	245	156.6667	0.1853333	290	176.6667	0.2133333			
201	137.9167	0.160667	246	157.0833	0.186	291	177.0833	0.214			
202	138.3333	0.160667	247	157.5	0.1866667	292	177.5	0.2146667			
203	138.75	0.162	248	157.9167	0.1873333	293	177.9167	0.2153333			
204	139.1667	0.162	249	158.3333	0.188	294	178.3333	0.216			
205	139.5833	0.162667	250	158.75	0.188	295	178.75	0.2166667			
206	140	0.163333	251	159.1667	0.1886667	296	179.1667	0.2173333			
207	140.4167	0.164	252	159.5833	0.1893333	297	179.5833	0.2173333			
208	140.8333	0.164	253	160	0.19						
209	141.25	0.164667	254	160.4167	0.1906667						
210	141.6667	0.165333	255	160.8333	0.1913333						
211	142.0833	0.166	256	161.25	0.192						
212	142.5	0.166667	257	161.6667	0.1926667						
213	142.9167	0.167333	258	162.0833	0.1933333						
214	143.3333	0.168	259	162.5	0.194						
215	143.75	0.168	260	162.9167	0.1946667						
216	144.1667	0.168667	261	163.75	0.196						
217	144.5833	0.169333	262	164.1667	0.1966667						
218	145	0.17	263	165	0.1973333						
219	145.4167	0.170667	264	165.8333	0.198						
220	145.8333	0.171333	265	166.25	0.1986667						
221	146.6667	0.172	266	166.6667	0.1993333						
222	147.0833	0.172667	267	167.0833	0.2						
223	147.5	0.173333	268	167.5	0.2006667						
224	147.9167	0.174	269	167.9167	0.2013333						
225	148.3333	0.174667	270	168.3333	0.202						

APPENDIX-11						TENSION TEST - UTM READINGS - SAMPLE-A-6					
S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)	S.NO.	Load(N)	Disp.(mm)
1	0	0	46	18600	6.5	91	23100	12.7	136	27700	17.7
2	13800	0.1	47	18700	6.6	92	23200	12.8	137	27800	17.8
3	13900	0.4	48	18800	6.8	93	23300	12.9	138	27900	17.8
4	14000	0.6	49	18900	6.9	94	23400	13	139	28000	17.9
5	14100	0.7	50	19000	7.1	95	23500	13.1	140	28100	18
6	14200	0.8	51	19100	7.3	96	23600	13.2	141	28200	18.2
7	14300	0.9	52	19200	7.5	97	23700	13.3			
8	14400	1.1	53	19300	7.6	98	23800	13.4			
9	14500	1.3	54	19400	7.7	99	23900	13.6			
10	14600	1.5	55	19500	8	100	24000	14			
11	14700	1.6	56	19600	8.1	101	24100	14.1			
12	14800	1.6	57	19700	8.3	102	24200	14.2			
13	15100	1.7	58	19800	8.5	103	24300	14.2			
14	15200	1.8	59	19900	8.6	104	24400	14.3			
15	15300	1.9	60	20000	8.8	105	24500	14.4			
16	15400	2.1	61	20100	8.9	106	24600	14.5			
17	15500	2.2	62	20200	9.1	107	24800	14.6			
18	15600	2.3	63	20300	9.2	108	24900	14.7			
19	15700	2.5	64	20400	9.3	109	25000	14.8			
20	15900	2.6	65	20500	9.5	110	25100	15			
21	16100	2.7	66	20600	9.6	111	25200	15.1			
22	16200	2.8	67	20700	9.7	112	25300	15.1			
23	16300	3.1	68	20800	9.9	113	25400	15.2			
24	16400	3.2	69	20900	10	114	25500	15.3			
25	16500	3.3	70	21000	10.3	115	25600	15.4			
26	16600	3.3	71	21100	10.4	116	25700	15.5			
27	16700	3.4	72	21200	10.4	117	25800	15.7			
28	16800	3.7	73	21300	10.5	118	25900	15.7			
29	16900	3.8	74	21400	10.6	119	26000	15.8			
30	17000	3.9	75	21500	10.7	120	26100	15.9			
31	17100	4	76	21600	10.9	121	26200	16			
32	17200	4.1	77	21700	11.1	122	26300	16.2			
33	17300	4.3	78	21800	11.1	123	26400	16.3			
34	17400	4.4	79	21900	11.2	124	26500	16.4			
35	17500	4.7	80	22000	11.5	125	26600	16.5			
36	17600	4.8	81	22100	11.6	126	26700	16.6			
37	17700	5	82	22200	11.6	127	26800	16.7			
38	17800	5.1	83	22300	11.7	128	26900	16.8			
39	17900	5.2	84	22400	11.8	129	27000	16.9			
40	18000	5.3	85	22500	12	130	27100	16.9			
41	18100	5.6	86	22600	12.1	131	27200	17			
42	18200	5.7	87	22700	12.2	132	27300	17.2			
43	18300	5.9	88	22800	12.3	133	27400	17.3			
44	18400	6.2	89	22900	12.5	134	27500	17.4			
45	18500	6.3	90	23000	12.6	135	27600	17.5			

APPENDIX-12				STRESS-VS-STRAIN READINGS - SAMPLE-A-6						E(Gpa)	207
S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$	S.NO.	σ Mpa	$\in$
1	0	0	46	186	0.0433333	91	231	0.0846667	136	277	0.118
2	138	0.0006667	47	187	0.044	92	232	0.0853333	137	278	0.118667
3	139	0.0026667	48	188	0.0453333	93	233	0.086	138	279	0.118667
4	140	0.004	49	189	0.046	94	234	0.0866667	139	280	0.119333
5	141	0.0046667	50	190	0.0473333	95	235	0.0873333	140	281	0.12
6	142	0.0053333	51	191	0.0486667	96	236	0.088	141	282	0.121333
7	143	0.006	52	192	0.05	97	237	0.0886667			
8	144	0.0073333	53	193	0.0506667	98	238	0.0893333			
9	145	0.0086667	54	194	0.0513333	99	239	0.0906667			
10	146	0.01	55	195	0.0533333	100	240	0.0933333			
11	147	0.0106667	56	196	0.054	101	241	0.094			
12	148	0.0106667	57	197	0.0553333	102	242	0.0946667			
13	151	0.0113333	58	198	0.0566667	103	243	0.0946667			
14	152	0.012	59	199	0.0573333	104	244	0.0953333			
15	153	0.0126667	60	200	0.0586667	105	245	0.096			
16	154	0.014	61	201	0.0593333	106	246	0.0966667			
17	155	0.0146667	62	202	0.0606667	107	248	0.0973333			
18	156	0.0153333	63	203	0.0613333	108	249	0.098			
19	157	0.0166667	64	204	0.062	109	250	0.0986667			
20	159	0.0173333	65	205	0.0633333	110	251	0.1			
21	161	0.018	66	206	0.064	111	252	0.1006667			
22	162	0.0186667	67	207	0.0646667	112	253	0.1006667			
23	163	0.0206667	68	208	0.066	113	254	0.1013333			
24	164	0.0213333	69	209	0.0666667	114	255	0.102			
25	165	0.022	70	210	0.0686667	115	256	0.1026667			
26	166	0.022	71	211	0.0693333	116	257	0.1033333			
27	167	0.0226667	72	212	0.0693333	117	258	0.1046667			
28	168	0.0246667	73	213	0.07	118	259	0.1046667			
29	169	0.0253333	74	214	0.0706667	119	260	0.1053333			
30	170	0.026	75	215	0.0713333	120	261	0.106			
31	171	0.0266667	76	216	0.0726667	121	262	0.1066667			
32	172	0.0273333	77	217	0.074	122	263	0.108			
33	173	0.0286667	78	218	0.074	123	264	0.1086667			
34	174	0.0293333	79	219	0.0746667	124	265	0.1093333			
35	175	0.0313333	80	220	0.0766667	125	266	0.11			
36	176	0.032	81	221	0.0773333	126	267	0.1106667			
37	177	0.0333333	82	222	0.0773333	127	268	0.1113333			
38	178	0.034	83	223	0.078	128	269	0.112			
39	179	0.0346667	84	224	0.0786667	129	270	0.1126667			
40	180	0.0353333	85	225	0.08	130	271	0.1126667			
41	181	0.0373333	86	226	0.0806667	131	272	0.1133333			
42	182	0.038	87	227	0.0813333	132	273	0.1146667			
43	183	0.0393333	88	228	0.082	133	274	0.1153333			
44	184	0.0413333	89	229	0.0833333	134	275	0.116			
45	185	0.042	90	230	0.084	135	276	0.1166667			

APPENDIX-13	Compression test-UTM readings Sample-A-1	
S.NO.	Load (N)	Displacement (mm)
1	0	0
2	37100	0.1
3	38600	0.2
4	41600	0.3
5	42300	0.4
6	42600	0.5
7	43400	0.6
8	44100	0.7
9	44400	0.8
10	44600	0.9
11	44800	1

APPENDIX-14	stress-vs.strain readings Sample-A-1	
S.NO.	Stress (MPa)	Strain
1	0	0
2	48	0.00069
3	49.94	0.00137
4	53.83	0.00207
5	54.73	0.00276
6	55.12	0.00345
7	56.16	0.00414
8	57.06	0.00483
9	57.45	0.00552
10	57.7	0.00621
11	57.97	0.00689

APPENDIX-15	Compression test-UTM readings Sample-A-2	
S.NO.	Load (N)	Displacement (mm)
1	0	0
2	46300	0.1
3	49000	0.2
4	52000	0.3
5	60800	0.6
6	68400	0.7
7	71700	0.8
8	73500	0.9
9	74100	1
10	74400	1.1

APPENDIX-16	stress-vs.strain readings Sample-A-2	
S.NO.	Stress (MPa)	Strain
1	0	0
2	52.63	0.0007
3	55.7	0.0014
4	59.11	0.00211
5	69.12	0.00422
6	77.76	0.00493
7	81.51	0.00563
8	83.56	0.00634
9	84.24	0.00704
10	84.58	0.00775

APPENDIX-17	Compression test-UTM readings Sample-A-3	
S.NO.	Load (N)	Displacement (mm)
1	0	0
2	23400	0.1
3	32300	0.2
4	38200	0.3
5	50600	0.4
6	60900	0.5
7	66900	0.6
8	72300	0.7
9	75700	0.8
10	78200	0.9
11	79700	1

APPENDIX-18	stress-vs.strain readings Sample-A-3	
S.NO.	Stress (MPa)	Strain
1	0	0
2	21.91	0.00085
3	30.24	0.00171
4	35.76	0.00256
5	47.37	0.00342
6	57.01	0.00427
7	62.63	0.00513
8	67.68	0.00598
9	70.87	0.00684
10	73.21	0.00769
11	74.61	0.00855

APPENDIX-19	Compression test-UTM readings Sample-B-1	
S.NO.	Load (N)	Displacement (mm)
1	0	0
2	40100	0.1
3	43900	0.2
4	46500	0.4
5	47300	0.5
6	47500	0.6

APPENDIX-20	stress-vs.strain readings Sample-B-1	
S.NO.	Stress (MPa)	Strain
1	0	0
2	60.78	0.00067
3	66.54	0.00135
4	70.48	0.0027
5	71.69	0.00337
6	71.99	0.00405

APPENDIX-21	Compression test-UTM readings Sample-B-2	
S.NO.	Load (N)	Displacement (mm)
1	0	0
2	66600	0.1
3	68000	0.2
4	72900	0.3
5	76900	0.5
6	78900	0.6
7	79700	0.7
8	79800	0.8

APPENDIX-22	stress-vs.strain readings Sample-B-2	
S.NO.	Stress (MPa)	Strain
1	0	0
2	75.71	0.00068
3	77.3	0.00137
4	82.87	0.00205
5	87.42	0.00342
6	89.69	0.00411
6	90.6	0.00479
6	90.71	0.00548

APPENDIX-23	Compression test-UTM readings Sample-B-3	
S.NO.	Load (N)	Displacement (mm)
1	0	0
2	68600	0.1
3	76500	0.2
4	80900	0.3
5	83900	0.4
6	86300	0.5
7	87600	0.6

APPENDIX-24	stress-vs.strain readings Sample-B-3	
S.NO.	Stress (MPa)	Strain
1	0	0
2	69.32	0.00069
3	77.3	0.00139
4	81.75	0.00209
5	84.78	0.00279
6	87.21	0.00349
7	88.52	0.00419

APPENDIX-25	Flexure test on doubly reinforced beams, load-vs.-displacement data after 7 days of curing						
	PCC-1	BRCC-1	MBRCC-1		PCC-1	BRCC-1	MBRCC-1
Displacement (mm)	Load (KN)			Displacement (mm)	Load (KN)		
0	0.2	0	0	4.1	-	11.7	29.8
0.1	-	7.7	19.6	4.2	-	11.7	29.8
0.2	-	7.7	21.3	4.3	-	11.7	29.8
0.3	-	7.7	22.2	4.4	-	11.7	29.8
0.4	-	7.7	23	4.5	-	11.7	29.8
0.5	-	7.7	23.8	4.6	-	11.7	29.8
0.6	-	7.7	24	4.7	-	11.8	29.8
0.7	-	7.7	24	4.8	-	11.8	29.8
0.8	-	7.7	24	4.9	-	11.9	29.8
0.9	-	7.7	24.8	5	-	11.9	29.8
1	-	7.7	25.9	5.1	-	12	29.8
1.1	-	7.7	26.6	5.2	-	12	29.8
1.2	-	7.7	27.4	5.3	-	12	29.8
1.3	-	7.7	28.1	5.4	-	12.1	29.8
1.4	-	7.7	28.7	5.5	-	12.1	29.8
1.5	-	7.7	29	5.6	-	12.1	29.8
1.6	-	7.7	29.3	5.7	-	12.2	29.8
1.7	-	10.5	29.4	5.8	-	12.2	29.8
1.8	-	10.6	29.6	5.9	-	12.2	29.8
1.9	-	10.8	29.8	6	-	12.3	29.8
2	-	11	29.8	6.1	-	12.3	29.8
2.1	-	11.1	29.8	6.2	-	12.3	29.8
2.2	-	11.3	29.8	6.3	-	12.3	29.8
2.3	-	11.3	29.8	6.4	-	12.3	29.8
2.4	-	11.3	29.8	6.5	-	12.3	29.8
2.5	-	11.3	29.8	6.6	-	12.3	29.8
2.6	-	11.3	29.8	6.7	-	12.3	29.8
2.7	-	11.3	29.8				
2.8	-	11.3	29.8				
2.9	-	11.3	29.8				
3	-	11.3	29.8				
3.1	-	11.3	29.8				
3.2	-	11.3	29.8				
3.3	-	11.3	29.8				
3.4	-	11.3	29.8				
3.5	-	11.3	29.8				
3.6	-	11.3	29.8				
3.7	-	11.3	29.8				
3.8	-	11.4	29.8				
3.9	-	11.5	29.8				
4	-	11.6	29.8				

APPENDIX-26	Flexure test on doubly reinforced beams, load-vs.-displacement data after 14 days of curing						
	PCC-2	BRCC-2	MBRCC-2		PCC-2	BRCC-2	MBRCC-2
Displacement (mm)	Load (KN)			Displacement (mm)	Load (KN)		
0	0.2	0	0	4.2	-	11.7	29.8
0.1	-	7.7	19.6	4.3	-	11.7	29.8
0.2	-	7.7	21.3	4.4	-	11.7	29.8
0.3	-	7.7	22.2	4.5	-	11.7	29.8
0.4	-	7.7	23	4.6	-	11.7	29.8
0.5	-	7.7	23.8	4.7	-	11.8	29.8
0.6	-	7.7	24	4.8	-	11.8	29.8
0.7	-	7.7	24	4.9	-	11.9	29.8
0.8	-	7.7	24	5	-	11.9	29.8
0.9	-	7.7	24.8	5.1	-	12	29.8
1	-	7.7	25.9	5.2	-	12	29.8
1.1	-	7.7	26.6	5.3	-	12	29.8
1.2	-	7.7	27.4	5.4	-	12.1	29.8
1.3	-	7.7	28.1	5.5	-	12.1	29.8
1.4	-	7.7	28.7	5.6	-	12.1	29.8
1.5	-	7.7	29	5.7	-	12.2	29.8
1.6	-	7.7	29.3	5.8	-	12.2	29.8
1.7	-	10.5	29.4	5.9	-	12.2	29.8
1.8	-	10.6	29.6	6	-	12.3	29.8
1.9	-	10.8	29.8	6.1	-	12.3	29.8
2	-	11	29.8	6.2	-	12.3	29.8
2.1	-	11.1	29.8	6.3	-	12.3	29.8
2.2	-	11.3	29.8	6.4	-	12.3	29.8
2.3	-	11.3	29.8	6.5	-	12.3	29.8
2.4	-	11.3	29.8	6.6	-	12.3	29.8
2.5	-	11.3	29.8	6.7	-	12.3	29.8
2.6	-	11.3	29.8				
2.7	-	11.3	29.8				
2.8	-	11.3	29.8				
2.9	-	11.3	29.8				
3	-	11.3	29.8				
3.1	-	11.3	29.8				
3.2	-	11.3	29.8				
3.3	-	11.3	29.8				
3.4	-	11.3	29.8				
3.5	-	11.3	29.8				
3.6	-	11.3	29.8				
3.7	-	11.3	29.8				
3.8	-	11.4	29.8				
3.9	-	11.5	29.8				
4	-	11.6	29.8				
4.1	-	11.7	29.8				

APPENDIX-27	Flexure test on doubly reinforced beams, load-vs.-displacement data after 28 days of curing						
	PCC-3	BRCC-3	MBRCC-3		PCC-3	BRCC-3	MBRCC-3
Displacement (mm)	Load (KN)			Displacement (mm)	Load (KN)		
0	0	0	0	4.2	-	22.6	37.8
0.1	13.7	22.5	4	4.3	-	22.6	37.9
0.2	-	22.6	18	4.4	-	22.6	38.1
0.3	-	22.6	18.4	4.5	-	22.6	38.5
0.4	-	22.6	24	4.6	-	22.6	38.6
0.5	-	22.6	27	4.7	-	22.6	38.8
0.6	-	22.6	30.3	4.8	-	22.6	38.9
0.7	-	22.6	30.3	4.9	-	22.6	39
0.8	-	22.6	30.5	5	-	22.6	39.1
0.9	-	22.6	31.1	5.1	-	22.6	39.2
1	-	22.6	31.8	5.2	-	22.6	39.4
1.1	-	22.6	32.3	5.3	-	22.6	39.5
1.2	-	22.6	32.9	5.4	-	22.6	39.6
1.3	-	22.6	33.3	5.5	-	22.6	39.7
1.4	-	22.6	33.4	5.6	-	22.6	39.7
1.5	-	22.6	33.8	5.7	-	22.6	39.8
1.6	-	22.6	34.1	5.8	-	22.6	39.9
1.7	-	22.6	34.2	5.9	-	22.6	39.9
1.8	-	22.6	34.4	6	-	22.6	40
1.9	-	22.6	34.7	6.1	-	22.6	40.1
2	-	22.6	35	6.2	-	22.6	40.2
2.1	-	22.6	35.1	6.3	-	22.6	40.5
2.2	-	22.6	35.3	6.4	-	22.6	40.5
2.3	-	22.6	35.6	6.5	-	22.6	40.5
2.4	-	22.6	35.7	6.6	-	22.6	40.7
2.5	-	22.6	35.9	6.7	-	22.6	40.7
2.6	-	22.6	36.1	6.8	-	22.6	40.7
2.7	-	22.6	36.2	6.9	-	22.6	40.7
2.8	-	22.6	36.4	7	-	22.6	40.7
2.9	-	22.6	36.5	7.1	-	22.6	40.7
3	-	22.6	36.6	7.2	-	22.6	40.7
3.1	-	22.6	36.8	7.3	-	23.4	40.7
3.2	-	22.6	36.8	7.4	-	24.6	40.7
3.3	-	22.6	36.9	7.5	-	26.1	40.7
3.4	-	22.6	37.1	7.6	-	27	40.7
3.5	-	22.6	37.1	7.7	-	27.8	40.7
3.6	-	22.6	37.2	7.8	-	27.8	40.7
3.7	-	22.6	37.3	7.9	-	27.8	40.7
3.8	-	22.6	37.4	8	-	27.8	40.7
3.9	-	22.6	37.5	8.1	-	29.7	40.7
4	-	22.6	37.6	8.2	-	29.7	40.7
4.1	-	22.6	37.7	8.3	-	29.7	40.7

	Flexure test on doubly reinforced beams, load-vs.-displacement data after 28 days of curing						
	PCC-3	BRCC-3	MBRCC-3				
Displacement (mm)		Load (KN)					
8.4	-	29.7	40.7				
8.5	-	30.9	40.7				
8.6	-	30.9	40.7				
8.7	-	30.9	40.7				
8.8	-	30.9	40.7				
8.9	-	30.9	40.7				
9	-	30.9	40.7				
9.1	-	30.9	40.7				
9.2	-	30.9	40.7				
9.3	-	30.9	40.7				
9.4	-	30.9	40.7				
9.5	-	30.9	40.7				
9.6	-	30.9	40.7				
9.7	-	31.9	40.7				
9.8	-	31.9	40.7				
9.9	-	32	40.7				

APPENDIX-28	Flexure test on singly reinforced beams, load-vs.-displacement data after 28 days of curing						
	PCC	BSRCC	MBSRCC		PCC	BSRCC	MBSRCC
Displacement (mm)	Load (KN)			Displacement (mm)	Load (KN)		
0	0	0	0	4.2	-	38.9	52.2
0.1	13.7	23.7	22.8	4.3	-	39	52.2
0.2	-	25.8	23.5	4.4	-	39.2	52.2
0.3	-	26.4	25.6	4.5	-	39.3	52.2
0.4	-	27.4	27.3	4.6	-	39.4	52.2
0.5	-	29	29.6	4.7	-	39.5	52.2
0.6	-	29.8	30.6	4.8	-	39.6	52.2
0.7	-	30.6	31.2	4.9	-	39.6	52.2
0.8	-	31.3	32.9	5	-	39.6	52.2
0.9	-	31.6	34.5	5.1	-	39.7	52.2
1	-	32.1	36.1	5.2	-	39.8	52.2
1.1	-	32.7	38.7	5.3	-	40	52.2
1.2	-	33	40.5	5.4	-	40	52.2
1.3	-	33.4	41.3	5.5	-	40.3	52.2
1.4	-	33.8	43.1	5.6	-	40.5	52.2
1.5	-	34.1	45.5	5.7	-	40.7	52.2
1.6	-	34.3	47.2	5.8	-	40.8	52.2
1.7	-	34.7	47.9	5.9	-	41	52.2
1.8	-	34.7	49.3	6	-	41.1	52.2
1.9	-	35.1	50.4	6.1	-	41.2	52.2
2	-	35.1	50.7	6.2	-	41.3	52.2
2.1	-	35.1	50.9	6.3	-	41.4	52.2
2.2	-	35.1	50.9	6.4	-	41.5	52.2
2.3	-	35.1	50.9	6.5	-	41.6	52.2
2.4	-	35.1	50.9	6.6	-	41.6	52.2
2.5	-	35.1	50.9	6.7	-	41.6	52.2
2.6	-	36.1	51.3	6.8	-	41.6	52.2
2.7	-	36.4	51.3	6.9	-	41.6	52.2
2.8	-	36.7	51.6	7	-	41.6	52.2
2.9	-	36.9	51.6	7.1	-	41.7	52.2
3	-	37.1	52	7.2	-	41.7	52.2
3.1	-	37.4	52.2	7.3	-	41.7	52.2
3.2	-	37.6	52.2	7.4	-	41.8	52.2
3.3	-	37.8	52.2	7.5	-	41.9	52.2
3.4	-	37.9	52.2	7.6	-	42.1	52.2
3.5	-	37.9	52.2	7.7	-	42.2	52.2
3.6	-	38	52.2	7.8	-	42.3	52.2
3.7	-	38.1	52.2	7.9	-	42.4	52.2
3.8	-	38.2	52.2	8	-	42.5	52.2
3.9	-	38.3	52.2	8.1	-	42.6	52.2
4	-	38.4	52.2	8.2	-	42.7	52.2
4.1	-	38.8	52.2	8.3	-	42.8	52.2

	Flexure test on singly reinforced beams, load-vs.-displacement data after 28 days of curing						
	PCC	BSRCC	MBSRCC		PCC	BSRCC	MBSRCC
Displacement (mm)	Load (KN)			Displacement (mm)	Load (KN)		
8.4	-	42.9	52.2	12.6	-	43.3	52.2
8.5	-	42.9	52.2	12.7	-	43.3	52.2
8.6	-	42.9	52.2	12.8	-	43.3	52.2
8.7	-	42.9	52.2	12.9	-	43.3	52.2
8.8	-	43.1	52.2	13	-	43.3	52.2
8.9	-	43.1	52.2	13.1	-	43.3	52.2
9	-	43.2	52.2	13.2	-	43.3	52.2
9.1	-	43.2	52.2	13.3	-	43.3	52.2
9.2	-	43.3	52.2	13.4	-	43.3	52.2
9.3	-	43.3	52.2	13.5	-	43.3	52.2
9.4	-	43.3	52.2	13.6	-	43.3	52.2
9.5	-	43.3	52.2	13.7	-	43.3	52.2
9.6	-	43.3	52.2	13.8	-	43.3	52.2
9.7	-	43.3	52.2	13.9	-	43.3	52.2
9.8	-	43.3	52.2	14	-	43.3	52.2
9.9	-	43.3	52.2	14.1	-	43.3	52.2
10	-	43.3	52.2	14.2	-	43.3	52.2
10.1	-	43.3	52.2	14.3	-	43.3	52.2
10.3	-	43.3	52.2	14.4	-	43.3	52.2
10.4	-	43.3	52.2	14.5	-	43.3	52.2
10.5	-	43.3	52.2	14.6	-	43.3	52.2
10.6	-	43.3	52.2	14.7	-	43.3	52.2
10.7	-	43.3	52.2	14.8	-	43.3	52.2
10.8	-	43.3	52.2	14.9	-	43.3	52.2
10.9	-	43.3	52.2	15	-	43.3	52.2
11	-	43.3	52.2	15.1	-	43.3	52.2
11.1	-	43.3	52.2	15.2	-	43.3	52.2
11.2	-	43.3	52.2	15.3	-	43.3	52.2
11.3	-	43.3	52.2	15.4	-	43.3	52.2
11.4	-	43.3	52.2	15.5	-	43.3	52.2
11.5	-	43.3	52.2	15.6	-	43.3	52.2
11.6	-	43.3	52.2	15.7	-	43.3	52.2
11.7	-	43.3	52.2				
11.8	-	43.3	52.2				
11.9	-	43.3	52.2				
12	-	43.3	52.2				
12.1	-	43.3	52.2				
12.2	-	43.3	52.2				
12.3	-	43.3	52.2				
12.4	-	43.3	52.2				
12.5	-	43.3	52.2				