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Steel Wire Wrapped Bamboo -As a Sustainable Reinforcement in Alkali Activated Fly Ash-Slag based Concrete

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Abstract

The cost ratio of steel to concrete exceeding 100 in most of the RCC structures, alternative materials for replacing steel are underway to develop a sustainable built environment. Bamboo has been in housing industry since time memorial as a standalone structural member for lighter loads of roofing and wall cladding units. It has been tested for its use as reinforcement in OPC based cement concrete structures replacing steel reinforcement with appreciable performance while requiring serious attention on serviceability and durational aspects. The alkali activated low calcium fly ash slag-based concrete with steel reinforcement as structural components cured at ambient temperature (RGPC) are being popularized in the most consumed sector of concrete construction industry. The present research work outlines the efficacy of binding wire wrapped bamboo splints as reinforcement along with bamboo fibers in alkali activated geopolymer concrete (GPC). The flexural behavior of Steel wire wrapped bamboo splints (SWBS) as reinforcement in GPC beams provide valuable feedback on the use of bamboo as reinforcement and fiber.

Index terms— bamboo, geopolymer concrete, flexural behavior, fly ash, GGBS alkaline solution, crack width.

The shortage of river sand was mitigated by using crushed granite stone powder known as manufactured sand (M-sand). Use of mixture of M-sand 80% and River sand 20% as fine aggregate in GPC & RGPC produced a more satisfying in situ concrete. [6] [10] Alkali activated fly ash-slag based geopolymer concrete cured at ambient temperature became more suitable and produced more satisfying steel reinforced structural application. These steel RGPC elements had inbuilt strength characters to produce attractive ductility compared to OPC based RCC structural components. [13] The cost ratio of steel to concrete kept on increasing due to heavy urbanization and national economy. The research on development of alternate reinforcing elements started as early as 1970's with bamboo reinforced cement concrete. Bamboos belong to the class of Bambusoideae which are orthotropic materials with more strength along the fiber directions with variations in its density along thickness. Several researchers have produced valuable material feedback on Bamboo Reinforced Cement Concrete (BRCC) while still a major research work on development of Bamboo Reinforced Geopolymer Concrete (BRGPC) is yet to be seen. [12] [2] Structural parameters which have influence on the performance of Bamboo in OPC based cement concrete (CC) environment are studied and their mitigating solutions are proposed which are also applicable in case of alkali activated geopolymer concrete.

1 a) Biodegradability of Bamboo in Cement Concrete

Environment Bamboo, like timber, is vulnerable to biodegradability due to insects and fungal attack. Bamboo like timber may also become weak when attacked by insects and fungus when improper conservation conditions prevail. Insect attack is mainly due to starch content with humidity more than 15 to 20% affecting physical and mechanical properties. Several preservatives are used to protect the properties like Modified Boucherie Method, Boucherie Method, leave transpiration, immersion, impregnation. [2] Preservative treated bamboo reinforced concrete have performed well against aggressive environmental steel corrosions in RCC elements.

2 b) Water Absorption

Study on several species of bamboo on water absorption have resulted in increase in dimensions up to 7% within a span 7 days [2] This may also cause micro to macro cracks in cured concrete. But when bamboo is used inside the geopolymer concrete environment with the surface treatment using geopolymer paste, it has less chance of water absorption due to ambient curing i.e., no water curing. In addition to this the presence of sodium silicate in binder solution of geopolymer concrete, with which the splints were pretreated, also works as a better water proof coating on the surface of splint. [27] These reinforced concrete structural components, used for lighter to medium loads in housing industry, are always surface treated with waterproof plasters, have lesser chances of moisture absorption during their serviceability life.

3 c) Bond Strength

One of the primary factors of RCC design is perfect bond between reinforcement and concrete during the entire serviceability life of the structure. But in bamboo reinforced concrete elements the dimensional changes of bamboo due to moisture and temperature influence, swelling, shrinking and differential thermal expansion are seen at different stages of serviceability life. Various preservative treatments have resulted in different degrees of success. The impermeability conditions can be enhanced using coatings of geopolymer paste in steel wire wrapped bamboo reinforcements.

4 d) Moisture Content

Most of the concrete develop micro pores inside the concrete which is a greater source of moisture entry into concrete from surrounding environment and affect bamboo performance in flexural & bond. The voids inside the concrete can be minimized by using proper amount of binder solution and compaction by using prescribed vibrator which may reduce pores significantly. Geopolymer concrete manufactured with adequate workability will have excellent moisture resistance.

5 e) Mechanical Properties

Most of the species of bamboo improve their strength after a period of air dry with moisture content as major influencing variant. The density of bamboo varies from place-to-place ranging from 500 to 800 kg/m^3 while most of the Indian Bamboo have an average density around 614 kg/m^3. [15] The strength parameters of bamboo are comparable with mild steel, but it needs special treatment due to other issues. Few types of bamboo develop high tensile strength of 370 MPa while most of the Indian types develop tensile strength a round 250 MPa and compressive strength around 80 to 100Mpa without and with nodes respectively, Modulus of elasticity in the range of 20 GPa to 40 GPa. There are also few species of bamboo with modulus of elasticity around 2.5x10 6 psi compared to steel 2.5x10 6 Mpa.

6 f) Pozzolanic Activity

The pozzolanic activity of geopolymer concrete during its polymerization has more chances of developing bond with bamboo splints (vertically cut sections used as splints) apart from using mild steelbased binding wire wrapped on bamboo splints to be used as flexural reinforcement. The bamboo surface is to be treated with binder solution of geopolymer concrete to activate silica present in epidermis (in cellular level) of the bamboo splint to contribute to pozzolanic reaction. This will provide better bond with concrete and bamboo splint surfaces [2].

7 g) Swelling & Shrinkage

These are associated with change in moisture content of the bamboo reinforcement. The presence of binding wire controls the swelling while shrinkage will be under control if proper pretreatment chemicals are used.

8 h) Ductility

Geopolymer concrete has more ductility post cracking compared to OPC based steel reinforced cement concrete. Bamboo possesses ductility comparable with steel rebars and therefore when GPC with SWBS with prior chemical treatment will enhance ductility of composite.

9 i) Deflections & Cracks

Much depends on the structural forces acting and the design flexibility\safety factors used in BRGPC. Bamboo is known to deflect much and produce cracks in OPC based concrete environment. But use of binding wire wrapped bamboo splints in compression zone of a flexural element with appropriate safety factors for bamboo stresses, will be effective in controlling the deflection associated issues.

10 j) Water Tightness

With the increase in moisture content above 30% the bamboo splints show slight reduction in the mechanical properties while the bamboo relatively transits from brittle behavior to ductile behavior. Chemically treated bamboo splints show more water tightness during their service life. [2]

11 k) Thermal Compatibility

The thermal coefficients of bamboo are different in two directions because of which the dimensional changes occur in both directions affecting bond strength. The use of binding wire wrapped bamboo splints control the increase in dimensional changes and effective in transferring temperature stresses to binding wire.

12 l) Durability

The durability of BRGPC elements mainly depends on the continued bond over the years to come while the pure bamboo structures last for 15 to 20 years of life. Humberto C. Lima found 60 cycles of wetting and drying in solution of calcium hydroxide and tap water did not decrease the bamboo tensile strength neither the Young's Modulus [26]. However, the BRGPC structural elements may be sandwiched with small diameter steel rebar & wrapped with binding wire -for minimum serviceability conditions and duration to ensure continued service life. Further research is required in this regard.

13 m) Creep

Bamboo has the tendency to creep under sustained tensile loads, but creep resistance will increase if bamboo splints are used in compression zone also. Much depends on basic properties, design safety factors used and orientation of the bamboo splints/culms.

14 n) Temperature Resistance

Although steel and concrete have significant resistance to temperature\fire without degrading their properties, but the bamboo starts degrading its properties above 50 Degrees C. However prior thermal treatment helps to reduce biodegradability while partially reducing mechanical properties.

15 o) Bamboo Reinforced GPC Joints in Frames

For larger spans more than 6 meter or so and for lighter to medium structural loads the bamboo splint detailing inside the concrete, especially anchoragement length and development length, depends on the way boundary conditions are created/assumed. Steel reinforcements/flats sandwiched with bamboo reinforcements at the specific location can provide adequate joint strength. Further research is required in this regard.

16 II. Material Properties and Mix Proportions

17 A. Tests on GPC Cubes with Bamboo Fibers

The mix design used for preparing geopolymer concrete cubes is detailed in the Table 1. Use of slag made the ambient curing develop early strength. Use of 80% and 20% combination of M-Sand and River sand provided good workable concrete along with strength. [6] [10] The aspect ratio of bamboo fibers and their diameter play a major role in influencing the mechanical properties of bamboo fiber reinforced geopolymer concrete. Bamboo fibers used in the GPC cubes and cylinders are tested for their compressive strength (CS) and tensile strength (TS). The bamboo cuts containing natural sizes from SAW mills were procured and seggregated from larger sized pieces and fibers and used in GPC cubes, cylinders and flexural beams. Most of the fibers were with aspect ratio ranging from 40 to 60 with diameter lesser than 1 mm. These fibers were air dried in open air inside the room before being used in GPC cubes. The compaction of cubes was achived using VB Vibrator which resulted in bamboo fibers being forced to interconnect the remaining voids inside the concrete. Two percentages of fibers were tried i.e 5% and 10% of the weight of the binder material i.e fly ash and slag. For the mix proportion (Table 1) the avearge compression strength (CS) of control cubes (0% fibers) after 7 days of room temperature curing was 27.7 Mpa but with bamboo fibers at 5% the average CS increased to 29.78 MPa which is increased by 7.5%. But with 10% fibers average CS dropped to a lower value of 23.73 Mpa resulting in reduction of CS by 14.3% indicating an optimum fiber dosage occuing well before 5%. The green weights of each cube before CS test indicate the possible reduction in CS because higher percentage of fibers reduce the content of binder solution/concrete. During the ambient curing period of GPC cubes for 7 days, the bamboo fibers did not undergo any degradation instead increased the CS.

The relation between CS and TS of control specimen of cubes and cylinders of GPC is nealry an etsablished theory [6][10] and follow BIS Code IS456-2000 obervations i.e for CS of 27.7 MPa the TS developed 3.93 Mpa following the relation TS = 0.7?CS. The split tensile strength of cylinders with BF at 5% and 10% show serious reduction in strength compared to control specimen. The reduction is nearly 17.2% for 5% fibers and 62.8% for 10% of fibers. These test results indicate that the optimum dosage of the selected fibers is at far lesser than 5%. Steel fibers up to 1.5% with aspect ratio around 60 provide excellent TS to geopolymer concrete [6][10] [13]. But with bamboo fibers up to 10% the relation between CS & TS in GPC is seriously affected with the coefficient varying from 0.3 to 0.75. The alternate way to use BF is to partially use steel fibers along with BF so that the loss of TS is brought back into material by steel fibers. This needs further research on this.

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19 B. Axial Tensile Test on Bamboo Splints

Bamboo culms and splints help to provide tensile strength to concrete similar to steel reinforcements. The splints (longitudinally cut bamboo sections) have better bond strength than with the culms (small diameter full cross section bamboo specimen). The axial tensile strength of splints of 300 mm length with anchoring length of 150 mm on both ends are tested with one node and without any node in UTM.

20 Figure 2: Bamboo Culms and Splints

The splint without node have taken load 24.65 kN with 131.2 Mpa as tensile strength (average) while that with node developed 127.8 Mpa as average tensile strength. As seen in the figure 3, the failure of splints followed linearity up to yield points. The splints with node show three different slopes while without node show two slopes exhibiting more deflections at same load than splint with node. The bamboo specimen with node has more ductility but has less tensile strength. The bamboo specimen without node has less ductility but carry more load compared to specimen with node.

21 C. Load Tests on Bamboo Fiber (BF) Reinforced GPC Beams

To assess the strength of bamboo fiber in plain GPC beams, specimens were cast of size 100mmx 100 mm x 500mm length with bamboo fibers at 0%, 5% and 10% of binder contents i.e., fly ash and GGBS. These plain GPC beams with bamboo fibers are ambient cured for 7 days and tested in UTM for single point central load. The details load testing and their failure loads are noted in Table 7. These failures are characterized by brittle failures under the load point at mid span with a crack widening gradually with no other cracks near supports. The failure loads increased from 7.5 kN at 0% to 9kN for 5% BF. But with the addition of 10% BF made the plain GPC beam fail at much lower load 6.45 kN as shown in table 7. These tests further confirm the pattern of split tensile strength and suggest the optimum dosage of bamboo fibers is around 5%.

22 D. Load Tests on Plain Bamboo Splint Reinfoced GPC Beams

Here GPC sections of size 100mm x 100 mm x 500 mm length with 3 plain bamboo splints as reinforcement were tested for a single point central load. The size of the splint used were of 15mm x 10mm. There was no reinforcement for shear. The beams were ambient cured for 7 days and tested. The test results as shown in Table 8, exhibit flexural behavior with appearance of first crack under the load and then gradual appearance of hair cracks near support. The peak load was marginally in line with yield load while the stresses in splints and concrete developed were around 50 to 65 Mpa and 10 to 15 Mpa respectively and the beam failed much before reaching their full capacity. The failure is mainly attributed to lack bond strength between bamboo and surrounding concrete. From flexural failure point of view the beams did not reach their full peak load but failed at an early load when the bond between bamboo and concrete lost.

23 E. Load Tests on Steel Wire Wrapped Bamboo Splint (SWBS) as Reinfocements in GPC Beams

In these set of beams the splints were wrapped with the normal binding wire -normally used for RCC works, with adequate anchoragement at splints ends as shown in figure 4. The size of the test beams 100mm x 100 mm x 500mm length. The bottom cover for these splints provided was 20mm. The beams were ambient 8.

The results show flexure failure of beams similar to plain splint reinforced GPC beams with an increased load carrying capacity. The deflections were more than the plain splint beam tests. The beams failed well before reaching their peak stresses in concrete and bamboo, due to loss of bond between splints and concrete. However, the increased failure load indicates enhanced bond strength due to binding wire.

Bamboo splints wrapped with binding wire This work helps in minimizing the standalone issues of bamboo as reinforcement in geopolymer concrete. As there are nearly 2000 species of bamboo, the strength & other properties of bamboo vary vastly due to so many influencing parameters like moisture content, age, species type, size & location etc. To use bamboo from a particular location as reinforcement the properties needs to be studied frequently to arrive at most common and frequent values to be used in design with appropriate design safety factors and further develop design guidelines. Some Species of Indian Bamboo are comparable with mild steel having tensile strength up to 250MPa with internode distance of 300 mm to 500 mm or so. Bamboo with nodes are the reinforcements required to be used in flexural elements of beams, slabs, and columns. Bamboo splints of sectional sizes 16 to 20 mm are best suited as reinforcements as they provide better bond with geopolymer concrete.

The use of bamboo fibers fill up the micro voids in the concrete and increase the direct crushing strength but excess fibers partially develop the bond with concrete and thus reduce the strength. This is also evident in bamboo fiber reinforced geopolymer concrete plain beams. The reduction in split tensile strength due to bamboo fibers is due to inadequate bond with geopolymer concrete when the splitting force is applied. Therefore, use of bamboo fibers in concrete needs careful consideration and attention on optimum percentage along with proper design parameters of aspect ratio and diameter.

Here in the present study the bamboo splints were wet coated with geopolymer slurry before placing inside the concrete to avoid water absorption from the surrounding environment. The geopolymer concrete needs water for workability purpose therefore absorption of water by bamboo has negligible effect on concrete strength development. The use of binding wire to bamboo splints helps in minimizing swelling, shrinkage, and creep related issues while increasing the bond strength significantly.

Two types of GPC beams were tested with bamboo splints, with and without binding wire, as flexural reinforcements but without any shear reinforcements. Addition of binding wire wrapped splints increased the load carrying capacity of the beams by 15 to 20% but the stresses in concrete and splints did not reach their peak values as the beams failed well before due to inadequate bond strength. From the load testing details it is observed that only 40 to 50% of the bond strength is developed at breakage point and around 60% at failure stage.

There are other inexpensive and effective methods to improve the bond strength to allow the bamboo to develop full bond with concrete like using higher yield strength binding wires, using sandwiched rebar of less diameter with bamboo splints, covering bamboo splint with light gage steel mesh, using staggered small cuts in bamboo at designed spacing and so on.

With the proper moisture content retention and protection, the biodegradability of bamboo may be prevented and the life of bamboo reinforced geopolymer concrete elements may have life of 15 to 20 years. More works on these are required to make bamboo a userfriendly reinforcement and formulate relevant design codes.

With this following conclusion can be drawn on use of bamboo products in alkali activated flay ash slag based geopolymer concretes. 1. From the present research work it can be concluded that the steel binding wires wrapped bamboo splints in alkali activated geopolymer concrete are the better solution to replace steel reinforcement. This has many structural, serviceability and economic benefits. 2. Bamboo splints with binding wires wrappedprovide better bond with geopolymer concrete than bamboo culms as reinforcement. And thus, they satisfy the long-term requirement of continued bond with concrete for flexural members. 3. The tested bamboo splints have a tensile strength of 130 Mpa at 18% moisture content. These type of bamboo species are suitable for lighter loads of housing industry. 4. Use of bamboo fibers have the same effect on geopolymer concrete as any other fiber with OPC based ordinary concrete Bamboo fibers increase the compressive strength of geopolymer concrete composite by 7.5 to 10%, but beyond 2.5 to 5% addition of fibers will affect the compressive strength. 5. Depending upon the species type, aspect ratio and diameter of bamboo fibers, the split tensile strength of GPC is influenced which have definite relations with compressive strength. [1]

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3 

Figure 1: Figure 3 :

4 

Figure 2: Figure 4 :

5

Figure 3: Figure 5 :

Figure 4:

Figure 5:

1

Manufatcured sand	River sand	Slag	Fly Ash

[Note: 12.5 to 4.75 mm CA 20 to 12.5mm CA Bamboo Mill Cuts Bamboo Fibers Bamboo Pieces Bamboo Splints with nodes SWBS with/witout nodes Figure 1: Ingradients used for BRGPC structural elements Global Journal of Researches in Engineering Volume Xx XII Issue II V © 2022 Global Journals ( ) Manufactured Sand: Sodium Silicate (Na2 Sio3): The sodium silicate solution used is of A53grade with Si02-to-Na20 ratio by mass of 2, i.e., Si02 = 29.4%, NazO = 14.7% & water = 55.9%. Binding Wire used for Bamboo Splints: Locally available and used for normal RCC works of building construction binding wire from mild steel are used to prepare bamboo splints as shown in figure (1).]

Figure 6: Table 1 :

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Figure 7: Table 2 :

3

Specimen	%age of	W (kg)	Ave.wt	F Load	Split tensile	Avg split
1		12.278		315	4.45	
2	0%	12.234	12.26	275	3.89	3.931
3		12.272		245	3.46	
1		11.952		225	3.183	
2	5%	11.782	11.85	215	3.041	3.253
3		11.802		250	3.536	
1		10.454		50	0.7073	
2	10%	10.644	10.65	150	2.122	1.46
3		10.862		110	1.556	

Figure 8: Table 3 :

4

Sl. N	PARAMETERS	Without Node	With Node
1	Length (mm)	300	300
2	Width (mm)	10.8	10.9
3	Thickness (mm)	15.4	17.9
4	Peak load (kN)	21.3	25.8
5	Tensile strength (N/mm 2)	128.1	132.2
6	Weight of bamboo (Kg)	0.080	0.090
7	Density (Kg/m 3)	802	769

Figure 9: Table 4 :

5

1	Length (mm)	300	300
2	Width (mm)	10.5	10.8
3	Thickness (mm)	15.4	16.7
4	Peak load (kN)	20.6	23.47
5	Tensile Strength (N/mm 2)	127.4	130.1
6	Weight of bamboo (Kg)	0.076	0.080
7	Density (Kg/m 3)	783	740

Figure 10: Table 5 :

6

				Volume Xx XII Issue II V ersion I ( ) E
Sl. N 1 2 3 4 5	PARAMETERS Length (mm) Inner diameter (mm) Outer diameter (mm) Failure Load (kN) Tensile strength (N/mm 2)	Without Joint 300 22 33.3 59.8 121.8	With Joint 300 13.5 30.5 67.6 115.0	Global Journal of Researches in Engineering
6	Weight of bamboo (Kg)	0.22	0.25	
7	Density (Kg/m 3)	747	709	
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Figure 11: Table 6 :

7

Load Details	0% BF	5% BF	10% BF
W(kg)	11.9	11.3	10.9
Breakage Load (kN)	5.5	6.6	4.8
Peak Load (kN)	7.5	9	6.45

Figure 12: Table 7 :

8

Load -Deflection Details	FB1	FB2	FB3	Average Value
W (Kg)	10.9	11.2	11.8	11.50 kg
Breakage Load (kN)	4.8	5.3	5.8	5.3 kN
Yield Load (kN)	11.6	12.5	13.5	12.5 kN
Deflection at Yield Load (mm)	3.2	2.4	4.1	3.2mm
Peak Load (kN)	12.6	13.5	14.8	13.6 kN
Max. Deflection (mm)	5.8	6.4	7.2	6.5 mm

Figure 13: Table 8 :

9

					Volume Xx XII Issue II V
Load -Deflection Details W (Kg) Breakage Load (kN) Yield Load (kN) Deflection at Yield Load (mm) Peak Load (kN) Max. Deflection (mm)	FB1 11.2 5.4 13.1 3.8 14.6 6.2	FB2 11.6 6.20 14.4 3.1 16.2 7.1	FB3 12.2 6.8 15.8 4.8 17.4 7.9	Average Value 11.67 kg 6.13 kN 14.43kN 3.9mm 16.07 kN 7.07 mm	Global Journal of Researches in Engineering
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Figure 14: Table 9 :

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Figure 15:

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