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Bamboo materials in cement, geopolymer and reinforced concrete as sustainable solutions for better tomorrow

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Bamboo materials in cement, geopolymer and reinforced concrete as sustainable solutions for better tomorrow

Prem Kumar V[1] and Dr. Vasugi V[2]
[1]School of Civil Engineering, VIT Chennai
[2]School of Civil Engineering, VIT Chennai
Email: premkumar.v2016@vitstudent.ac.in, vasugi.v@vit.ac.in

Abstract. It's well known that due to increase in population and abundant use of materials, there is a scarcity of materials in the construction industry. In this modern era, people prefer to have a modern construction which made usage of conventional building materials abundantly. Though increase in the usage of these materials leads to the scarcity, it also opens way for an unsustainable environment. In order to overcome this both scarcity and environmental issue and to develop an eco-friendly environment, many researchers were going on to replace these building materials by any other natural material. Bamboo is one of the exact alternative materials to be replaced in the construction industry because of its mechanical and chemical properties. Bamboo has a major application in the construction industry and used in roofs, flooring, foundations, trusses etc. Bamboo is preferred as the best sustainable material and suggested for low cost housing projects. In this paper all the physical and mechanical properties of bamboo reinforced structural elements, influence of bamboo materials in cement and geopolymer concrete is reviewed.

1. Introduction

Bamboo is a subfamily (Bambusiodeae) of flowering perennial evergreen plants in the grass family "Poaceae". It is one of the most important building materials since ancient times. Due to advancement in technologies and high market demand, bamboo has been used in household products and extended to industrial applications. The growth of Bamboo is extremely fast and within 2-3 years, it gets fully matured. There are1000 species of bamboo seen around the world and as per the review undergone, bambusa vulgaris and dendrocalamus strictus are the bamboo species that gives high tensile and compressive strength [1].

The literature showed that 0.94 ton of carbon dioxide is released in the atmosphere to produce 1 ton of cement [25-28]. Bamboo materials like fiber, leaf ashes and stem ashes can be used in mortar and concrete as a replacement of cement to minimize the presence of carbon dioxide in the atmosphere. The mechanically extreacted bamboo fibre is shown in the Figure 1.

Figure 1. Mechanically extracted bamboo fibre

The use of bamboo fiber in the concrete as an additive and also as reinforcement leads to certain drawbacks. All natural fibers absorb moisture and weaken the bond strength between the fiber and the concrete. The performance of bamboo and its materials depends on moisture and creep parameters [52-54]. The main reason for this limitation is the hydroxyl influence and some other certain polar batches in the fibers. This problem can be compromised by proper bonding treatment [40-47].

In some species of bamboo, the tensile property seems to be same as that of mild steel and sometimes greater than steel also. It got much application in the construction industry because of its good tensile and compressive strength properties. The tensile property of the bamboo depends on the type of species with respect to the seasoning length [49-51]. Therefore Bamboo reinforcement is more economical than the steel reinforcement and this bamboo reinforced structures can be preferred in places where there is lack of construction and manufacturing techniques.

2. Literature Survey

The use of bamboo in construction industry for various purposes and its properties and behavior in mortar, concrete, geopolymer concrete and structural elements are reviewed in detail in this paper.

2.1. Bamboo fibre cement composites

Xiaoli Xie et al.[2] investigated the impact attitude and flexural effects of bamboo fiber filled cement composites. In this study, composites from 4 to 16% of bamboo fiber are used over the plane control specimen. The results proved that the bamboo cellulosic fiber increased the fracture toughness of composites and raised impact resistance too. It is noted that the impact resistance is increased with increase in fiber up to certain level. Good relation between impact energy and failure pattern was observed.

Pradeep K et al [48] used different silanes to treat the bamboo fibre composites. The mechanical strengths were determined through the various tests undergone and compared before(Figure 2) and after mercerization (Figure 3). The addition of silane decreased the strength properties whereas the treatment with silane increased the flexural and tensile strength.

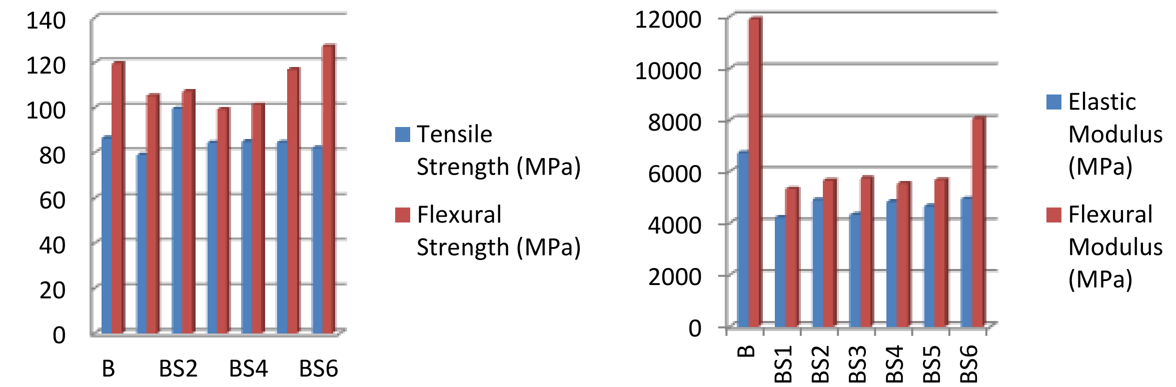

Figure 2. Strength properties of the composites treated with silanes

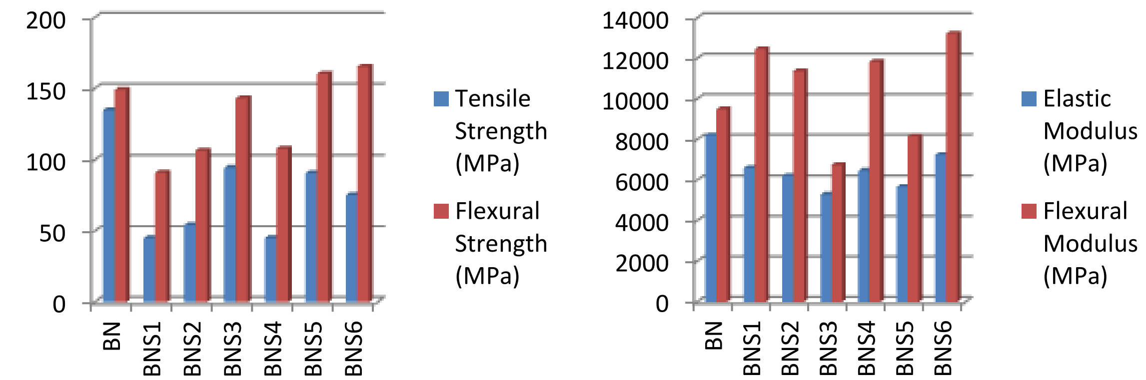

Figure 3. Strength Properties of the Composites Treated with Silanes after Mercerization

Martha L. Sanchez et al.[3] analyzed the properties of a bamboo fiber reinforced bicomposites. The experimental investigation was done by immersing the extracted fiber in the commercial borax and boric acid salts at 3% concentration and for the matrix of composite, Polyurethane is used. The crushed material is surface treated by adopting three treatments. The moisture content and the water absorption were done as per ASTM standards. Pycnometer method was used to determine the density of the fibers. The modulus of elasticity and tensile strength was performed on fiber. X – ray diffraction and infrared spectroscopy were used to study the impact of the different treatments. To analyze the fiber morphology and roughness, scanning electron microscopy and transmission microscopy was used. The biocomposites was manufactured by placing the mixture in a 300 X 300 mm2 mould with 6 mm thickness. The resin, the matrix of the composites, was prepared in the ratio of 1:1.5. The panels were made with hydraulic press with a load of 1000 kN. The results of the treated biocomposites were compared with the results of untreated untreated fiber biocomposites. From the test results, it is revealed that the mechanical strength and dimensional stability of the panels can be increased by more than 50 %.

2.2. Concrete reinforced with bamboo strips
Karthick et al.[3] investigated the strength properties of bamboo and steel reinforced concrete by adding the supplementary cementitious materials. Cement is partially replaced by combination of ground granulated blast furnace slag (GGBS) and fly ash and the fine aggregate is partially replaced by M-sand. For experimental investigation, bamboo strips were used as reinforcement in concrete.

Cube, cylinder and beam specimens were cased and tested within the stipulated period. Micro-structural study of bamboo is done by SEM and FTIR. The test results proved that bamboo is firm and a ductile. The test results of bamboo reinforced concrete by adding alternative cementitious materials and BRC with conventional materials is compared over conventional steel reinforced concrete. BRC reinforced with conventional materials produced high flexural strength than SRC, as seen in Table.1 and BRC with M-sand, fly ash and GGBS resulted in high compressive and split tensile strengths.

Table.1: Flexural Strength Properties of the Samples

	Sample	Description	7th day (MPa)	14th day (MPa)	28th day (MPa)
1	Mc	SRC	6	9	17
		BRC	7	9	18
2	M1	SRC	12	14	33
		BRC	9	5	7
3	M2	SRC	7.5	12.5	13
		BRC	2.5	4	7

2.3. Bamboo fibre as reinforcement additives for geopolymers

Ribeiro et al. [31] used Potassium-sodium geopolymer reinforced by bamboo strips and fibers to investigate the suitability for sustainable construction. Several researches were done in the field of metakaolin based geopolymer using natural fibers wool, jute, sisal etc. [33-39]. Based on these researches undergone, the binder used for bamboo strips was geopolymer (mixed sodium and potassium) reinforced with bamboo fiber. X-ray diffraction, flexural test and compression test was conducted one the specimens. SEM analysis identified the interaction between geopolymer matrix and the bamboo fiber. The bamboo reinforced geopolymer sample gave less compressive strength than control geopolymer samples but proved its ability for sustainable construction. The flexure value was increased by 3.5 times over GPC samples reinforced by bamboo fibers with addition of bamboo strips. From all the test results, it is proved that bamboo strips and fibers in geopolymer composites are best materials for sustainable construction.

2.4. Bamboo leaf ash production for use in concrete

Moraes et al. [4] proposed the manufacture of bamboo leaf ash for use in concrete by investigating its pozzolanic characteristics. The physical and chemical characterization of BLA was carried out by several mirco level analyses like X-ray diffraction, X-ray fluorescence, FTIR and FESEM as shown in Figure 4. BLA was prepared by auto combustion at 738 °C and contains 74.23% silica with an amorphous nature. The electrical conductivity and pH calculation was done to study the pozzolan reactivity of BLA. Thermogravimetric analysis and Frattini analysis of BLA paste and OPC pozzolan pastes have classified BLA as highly reactive though produced by auto combustion. Trial mortars in which OPC was replaced by BLA (5 – 30%) were cured and tested for 7, 28 and 90 days and compared with control mortar. The compressive test results (Figure 5) revealed the improvement of the mechanical behaviour of the trial mortars by giving the similar compressive strength of control mortar. Even the mercury intrusion porosimetry analysis also gave higher tortuosity for 20 – 30% BLA paste. Thus from the experimental research, it is proved that BLA is a best alternative material for the replacement of OPC.

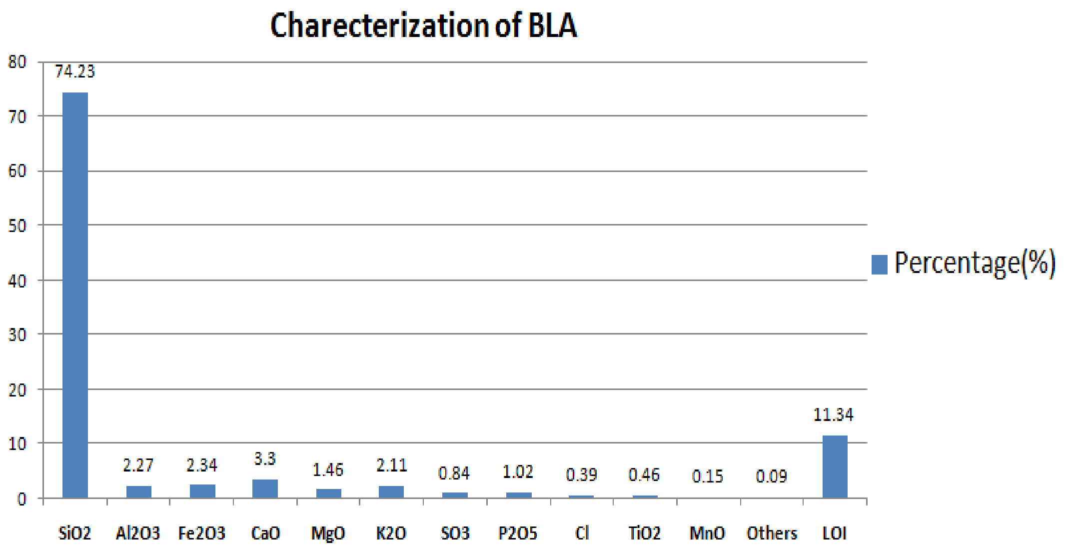

Figure 4. Charecterization of BLA

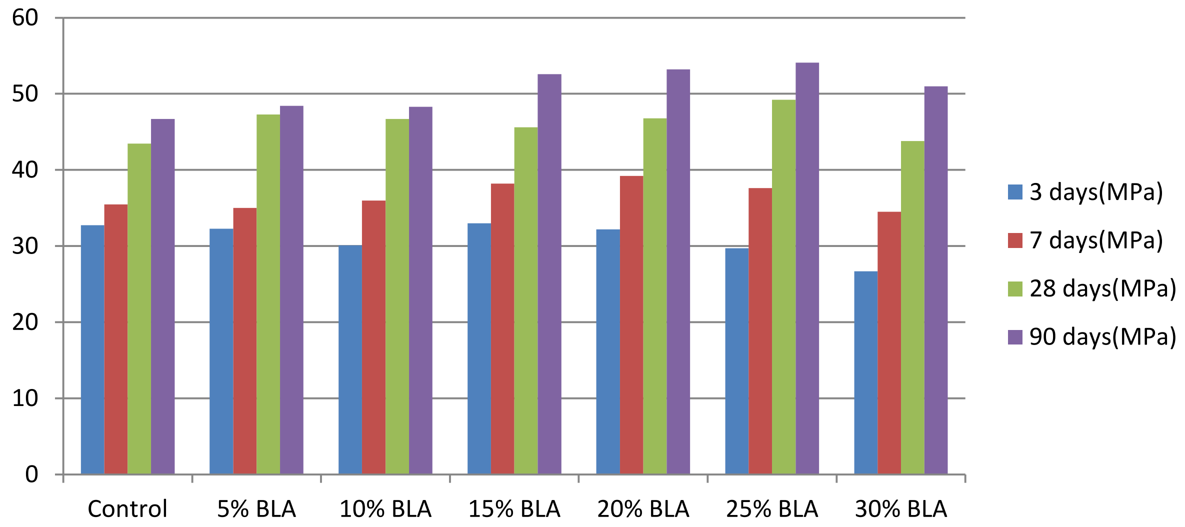

Figure 5. Compressive strength of the samples

2.5. Pozzolanic characterization and kinetic parameters of BLA

The addition of agricultural solid waste ashes to the concrete as an admixture or replacement of cement is a worldwide process. From the researches undergone, it is found that these ashes are chemically reactive during the cement hydration reaction [5-9].

Ernesto Villar-Cocina et al. [10] identified experimentally, the characterization and the pozzolanic behavior between BLA and calcium hydroxide(CH) by producing BLA by calcining at 600°C in furnace. Electrometric conductivity measurement in BLA/CH solution with reactive time was adopted to evaluate the pozzolanic characteristics. The kinetic parameters were quantified by kinetic-diffusive model as shown in Figure 6. The investigation showed that BLA is amorphous and highly pozzolanic in nature.

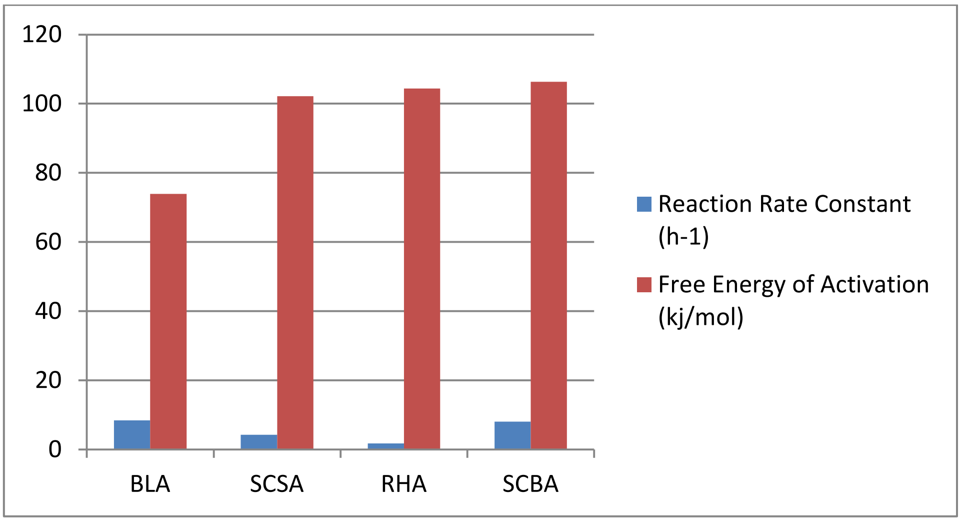

Figure 6. Kinetic Parameters of Ashes

2.6. Bamboo leaf and stem waste in cement matrices

Moises Frias et al. [11] by calcining the bamboo leaf ash and adding in cement evaluated the characterization and behavior of cement matrices. The compressive strength evolution was done using blended cement mortar with 10% and 20% by mass of BLA. The test values of the BLA mortars at 7 days were decreased by 1.2% and 6.7% for 10% and 20% of BLA respectively with respect to the compressive strength values of the control mortar. Later for 28 and 90 days test, the compressive strength of the BLA mortar was similar to that of the conventional mortar. The results (Figure7) showed that strength of the BLA mortar increase in accordance with longer cement hydration time.

Loic Rodier et al. [12] used sugarcane bagasse and bamboo leaf ash to develop green cementitious materials. The results proved that the use of waste ashes from industries in binary and ternary cement blend gives better strength and brings benefits for industries to adopt a sustainable construction as shown in the figure.

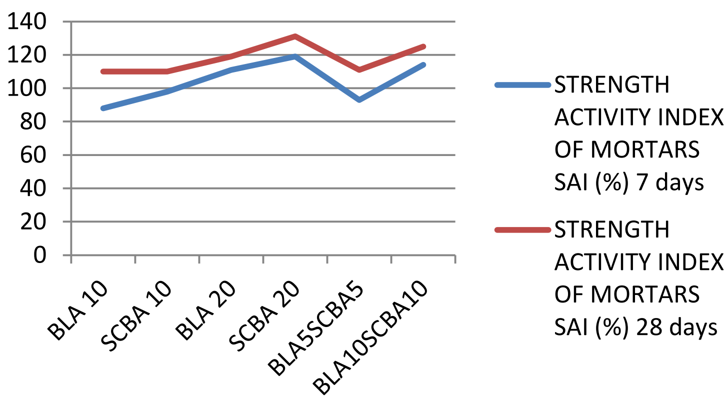

Figure 7. Strength activity index of mortars

Rodier et al.[13] preferred bamboo stem ash to replace cement in concrete. Based on the literature, bamboo stem and sugarcane bagasse was calcinated at 600°C [29-30]. To study the cementitious properties of this ash, Chapelle test, thermo gravimetric analysis, saturated lime method and strength activity index was conducted. The concentration of calcium hydroxide in the sample paste is shown in the Figure 8. It is proved that the mortar containing 10% of bamboo stem ashes given high values.

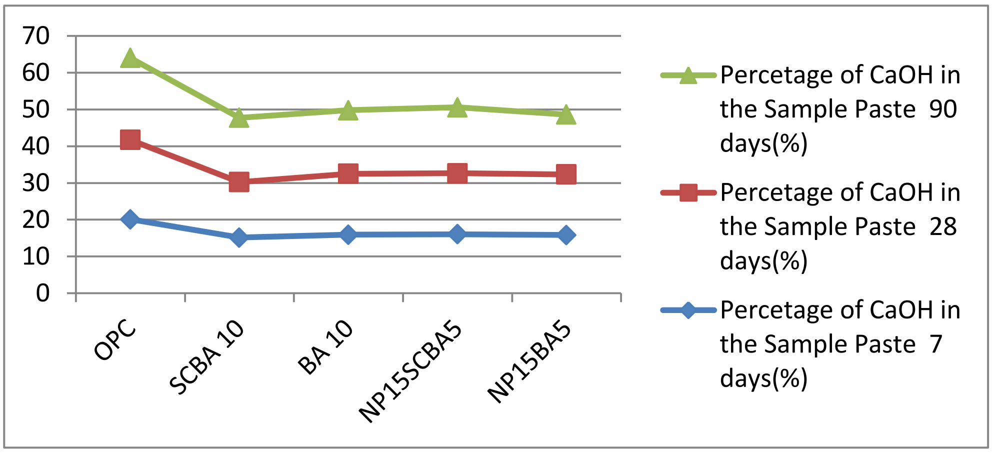

Figure 8. CaOH % in the sample paste

2.7. *Bamboo as carbon fibre*

Lam et al. [14] converted raw bamboo into carbon fibre through microwave pyrolysis, solvent extraction, and thereby chemical impregnation techniques and the carbon and bamboo fibre yield is shown in the figure 9. The carbon fibre obtained at different microwave power and irradiation time exhibit improved phase structure.

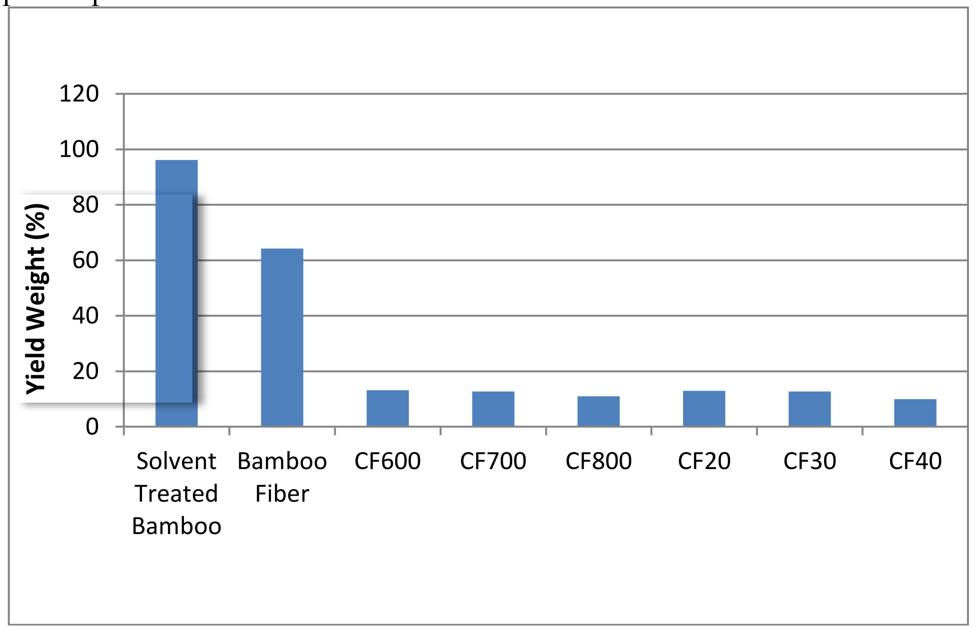

Figure 9. Yield weight of the samples

2.8. *Behaviour of bamboo fibre with PP/EPDM/talc composites*

Inacio et al. [15] examined the thermal and mechanical behaviour of composites of recycled polypropylene/ethylene-propylene-diene monomer/talc with bamboo fibre reinforcement. An inadequate transfer of stress from matrix to fibres is due to adhesion between PP/EPDM matrix and the bamboo fibres. Due to this the ductility, fatigue life and energy absorption properties of composite declined rapidly. The stiffness of fibre increased the flexural modulus of aged composite. Degradation temperature rises as the fibre content reduces in the composite. At higher ratios of maleic anhydride grafted polypropylene content, tensile modulus of composite will be more. The mechanical strength values are shown in the Figure 10 & 11.

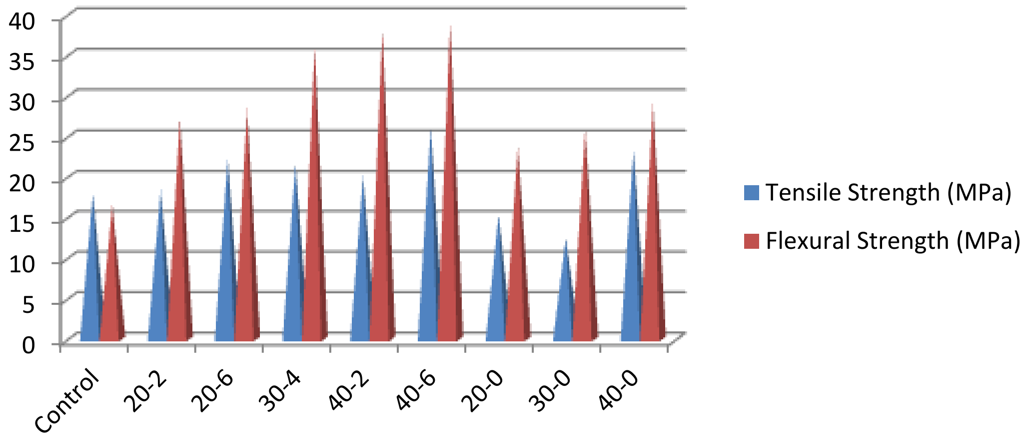

Figure 10. Flexural strength and tensile strength of the composites

Figure 11. Flexural modulus and tensile modulus of the composites

2.9. Bamboo fibre with epoxy-hybrid composites and salacca zalacca powder

Yvonne et al. [16] carried out X-ray diffraction investigations on the samples of epoxy-hybrid composite prepared from epoxy resin (20 – 50% of weight),600µm fine Salacca zalacca powder (10%) and bamboo fibres of age 1, 3 and 5 years old (10 – 40%) to study the properties like modulus of elasticity, density, modulus of rupture, thickness swelling and water absorption. All these materials were mixed at 100 rpm, placed in steel moulds and cold compressed for 24 hours at room temperature. The reduction in the thickness swelling of the composite was observed with the increase in fibre content and this was due to the higher cellulose content in the bamboo fibre. The hydrophilic nature of bamboo fibre absorbs surrounding water and this influences the water absorption capacity of composite. The lower epoxy content reduces the density of composite. One year aged bamboo fibres exhibited weaker properties when compared to 3 and 5-year-old bamboo fibres. The experimental results obtained are shown in the Table 2.

Table 2. Experimental results of the test samples

Composition of Bamboo Fiber (%)	Age of Composites	Density (g/cm3)	Water Absorption (%)	Thickness Swelling (%)	Modulus of Elasiticity (MPa)	Modulus of Rupture (MPa)
10	1 Year	1.12	10	3	100	4
	3 Years	1.18	8	5.4	100	2.1
	5 Years	1.2	10	1.2	80	1.2
20	1 Year	1.14	12	3.1	300	5
	3 Years	1.09	12	5.5	290	5.1
	5 Years	1.1	12	6.3	120	4
30	1 Year	1.05	31	4.2	950	5.8
	3 Years	0.9	22	6.1	780	8.6
	5 Years	1.09	28	6.4	830	8
40	1 Year	0.69	48	7.8	1000	7.7
	3 Years	0.78	68	9.2	990	10.2
	5 Years	1.1	31	7.8	1000	10.3

2.10. Bamboo fibre with tapioca starch composites

Yusof et al. [17] studied the mechanical properties of alkaline and permanganate treated bamboo fibres. The surface properties of bamboo fibre were modified due to the chemical treatment. It even achieved the reduction in bamboo fibre water absorption capacity and increased the bond strength between matrix and fibre. The alkali treated bamboo fibre showed best results over untreated fibre followed by permanganate treated fibre in both flexural and tensile tests. The strength properties of different treated samples are shown in the Figure 12.

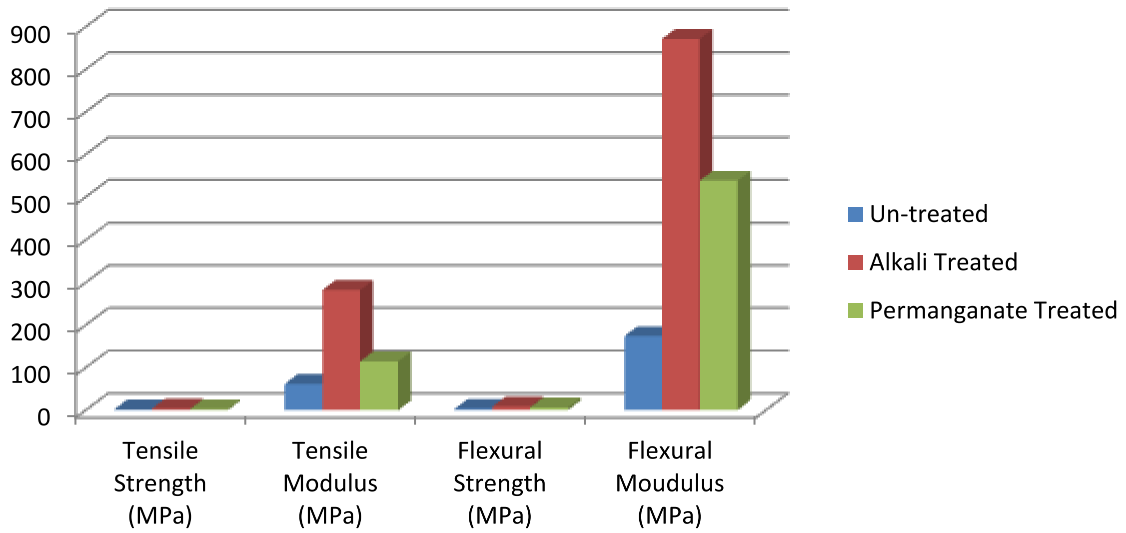

Figure 12. The strength properties of different treated samples

2.11. Treated bamboo as reinforcement in beams and columns

Atul Agarwal et al. [18] investigated on concrete beams and columns with chemically treated bamboo reinforcement. Different adhesives were used to treat bamboo and their effect on bonding strength was studied. Based upon the test results, the feasible type of adhesive was identified and used for beams and columns reinforced with bamboo. Tensile strength test, pull out test, axial and transverse load test on columns and flexural test on beam specimens were conducted. From the results obtained (Figure 13) it is suggested and concluded that bamboo with proper treatment can replace the steel reinforcement.

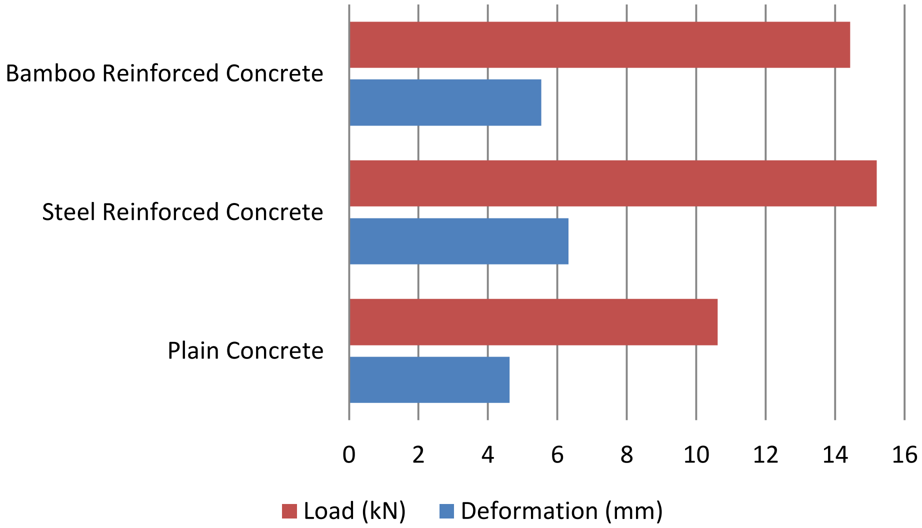

Figure 13. Load and deformation of the column specimens

Adom-Asamoah Mark et al. [32] used bamboo to reinforce concrete beams by using various stirrup materials. Ratten cane, bamboo and steel materials were used as stirrup for the beams. The comparative study was made over the conventional beam with steel stirrups. After the study undergone, it is suggested that beams with steel stirrups reinforced with bamboo can be preferred over the conventional steel reinforced concrete beams for rural construction. The obtained deflection pattern of the test samples at the first crack and at the failure is shown in the Figure 14.

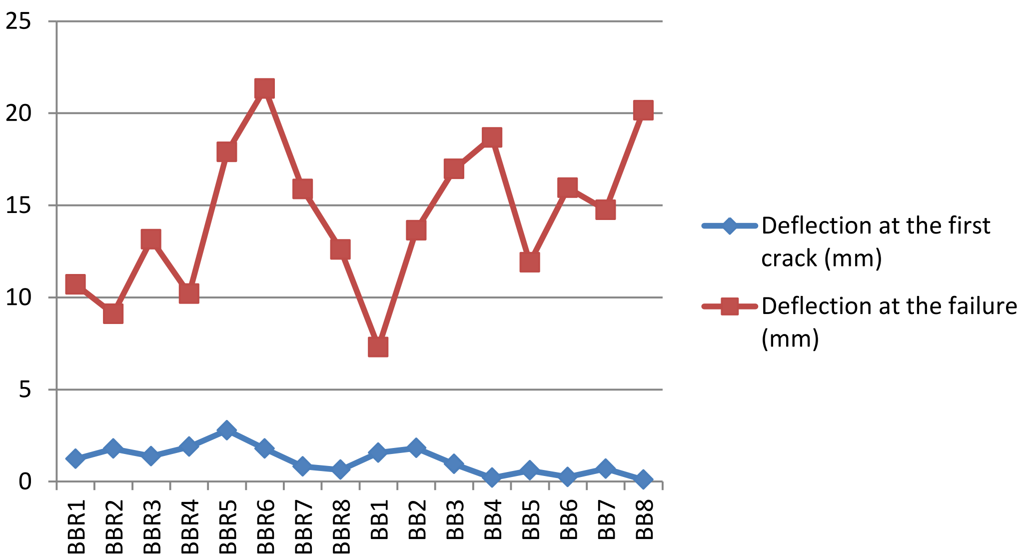

Figure 14. Deflection pattern of the test samples

2.12. Bamboo reinforcement of structural elements

Ghavami [19] clearly represented about the usage of bamboo in the reinforcement of structural elements. A beam specimen reinforced by bamboo with normal, lightweight and laterite aggregate has been casted and kept ready for testing. The roughened surface of bamboo splints were coated with impermeable product which is followed by coating of fine sand. From the three-point loading test of the beam specimen, it is observed that the treated bamboo increased the bonding strength by 100% and the applied ultimate load increased by 400% with comparison of plane concrete beams without reinforcement. The pull-out test is carried out to examine the bond strength of the bamboo reinforced concrete and the results are shown in the Figure 15.

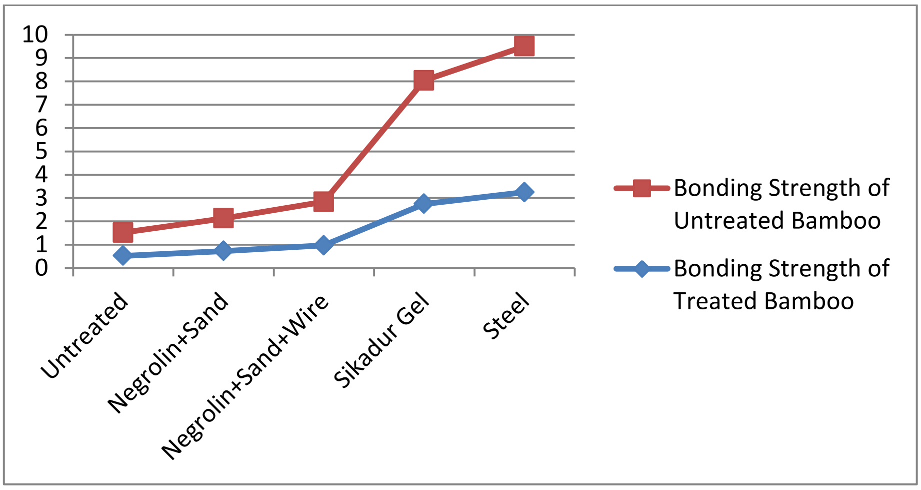

Figure 15. Bonding strength of treated and untreated bamboo by pull-out test

Bamboo is reinforced with of the section of concrete slabs. To examine the structural and mechanical behavior of structural elements with bamboo reinforcement, bamboo reinforced concrete slab of dimensions 80*14*316 cm with span of 300mm is casted. The bamboo is treated by the application of Sikadur 32-Gel. FEM is adopted to have a parametric study on this slab. From the analysis, it is observed that the most significant influencing factor is shear resistance of the bamboo diaphragm. The shear strength obtained for half bamboo is 10.89MPa with a deviation of 2.56MPa. To increase this strength entire bamboo diaphragm is considered and also it is improved by fixing a steel strip close to the bamboo diaphragm. These types of techniques doubled the shear strength and ultimate load of such slabs and it is successfully in use in Brazil.

Dinesh Bhonde et al. [20] carried out an experimental study on a bamboo reinforced concrete slab. The specimen was tested for its crack pattern and load-elongation curve. Dendrocalmus Strictus is a common species of bamboo which is selected as a reinforcing material for BRC slab test specimen. One of the main limitations in the reinforcement of bamboo is water absorption which results in swelling and finally it leads to the decrease in the bond strength. To overcome this issue, various alternative materials were searched and asphalt was selected as a best economical alternative. Asphalt was embedded with bamboo reinforcement which is followed by sprinkling of sand and dried. During testing, cracks were visible at a load of 15.65kN. However it started to take up the load at an ultimate load of 16.2kN. The stress-strain relationship was linear. The design moment was comparatively less to that of experimental ultimate moment. Based on the test observations, it is concluded that BRC can be effective alternative to steel and to prevent bamboo from water absorption sealant materials like asphalt can be preferred so that swelling and degradation of bond won't take place. The load extension graph is shown in the Figure 16.

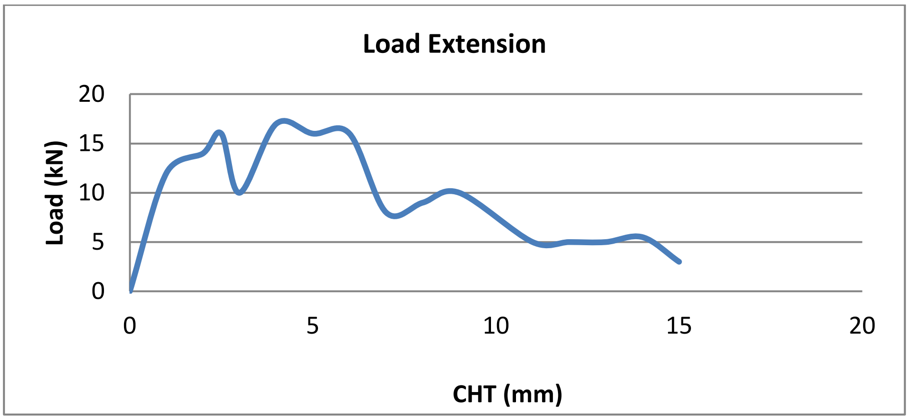

Figure 16. Load extension graph of the slab

Masakazu Terai and koichi Minami [21] investigated the mechanical properties of Bamboo Reinforced Concrete structures. This study proposed a detailed investigation of the bamboo corrosion, bond properties of the bamboo bars and flexural behavior of bamboo reinforced concrete slab. The tensile test conducted with the bamboo specimen filled with cement paste with w/c ratio of 80% and 100% showed that strength of bamboo increases with aging time. Based on the researchers on bamboo, it is revealed that the shrinkage effect of bamboo is more than the concrete and the rate of speed is also more. Due to this, the bamboo reinforced with concrete will be exposed to repeated expansion and contraction. This often leads to loss of bond stress. To overcome this limitation, and to improve the bond stress between bamboo reinforcement and the surrounding concrete, pull-out test was carried out. The behavior of pull-out test of bamboo was same as that of plain steel bar. It is suggested that treated bamboo reinforcement will yield high bond strength. During the testing of bamboo reinforced concrete slab, cracks occurred just below the loading point and the width of the flexural crack increased with increase in deformation. The obtained experimental results on 28th day and 84th day of curing are shown in the Figure 17.

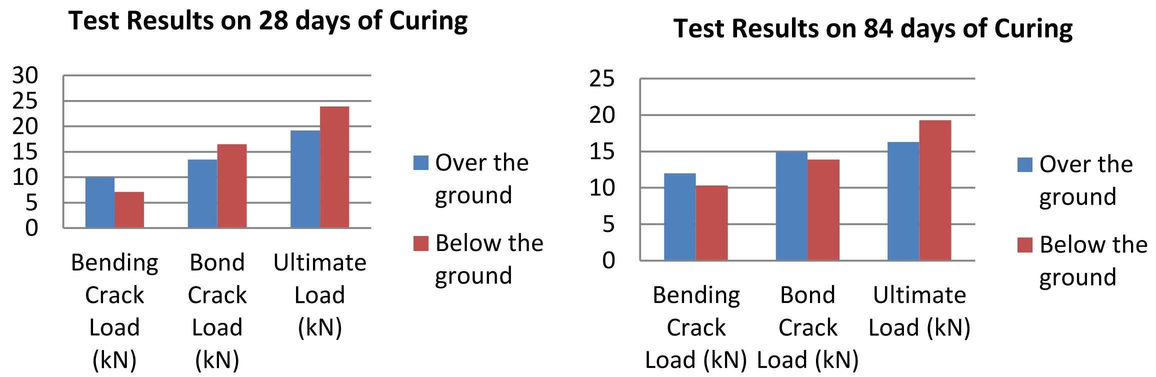

Figure 17. Test results on the 28th and 84th days of curing

Van der Lugt et al. [22] presented about bamboo as a building material against steel, concrete and timber, taking case studies on bamboo buildings, bridges and structures. They have taken Guadua angustifolia bamboo culms which are produced and air dried in Costa Rica and used in Netherlands. In this paper they environmentally analyzed the bamboo using life cycle analysis (LCA). The projects analyzed are the bamboo tower at phenomena and Rotterdam bridge. After analyzing, the results showed that the bamboo is the most sustainable alternative building material. But in financial point of view bamboo is the worse than the alternatives since it has shorter life span. Some success factors of bamboo are low purchasing cost and ease of dismantle.

Ajinkya Kaware et al. [23] compared the bamboo reinforced column of various shapes and cross-section with the conventional steel reinforced columns of similar dimensions with steel reinforcement as per IS 456:2000. The reinforcement of the columns varied gradually from 2.5% to 4%. In the test results of the column specimens, it is observed that, to attain the desired strength of BRC, the lateral dimensions are to be increased. The failure occurred in compression are of similar pattern as that of steel. The load displacement and stress strain curves of bamboo reinforced columns showed the same typical pattern as that of steel. It is concluded that bamboo reinforced columns can replace the steel reinforcements and it can be preferred for low cost housing projects and region of limited availability of steel.

2.13. Beams reinforced with bamboo for frictional properties
Abhijeet Dey and Nayanmoni Chetia [24] studied the frictional properties of beams reinforced with bamboo. 18 trial beams of size 15cm*15cm*70cm were casted and achieved by bamboo reinforcement with coir, G.I wire and sand. During the testing of specimens under four-point bend test, it is noted that beams with long curing time and bigger reinforcement size performed better tensile strength of 250 N/mm^2 while compared to that of beams with less curing time and smaller reinforcement size. Added to that, from the pull-out test examined on the test specimens, it is noted that bamboo reinforced beams with G.I wire achieved maximum bond stress while compared with other trail beams. The test results on the 28th days, 45th days and 60th days of curing are shown in the Figure 18(a), 18(b) and 18(c).

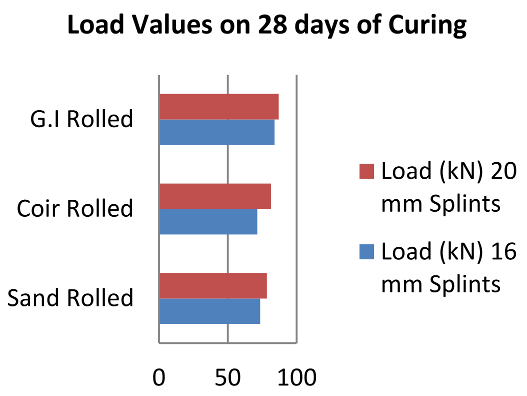

Figure 18(a). Load Values on 28th days of curing

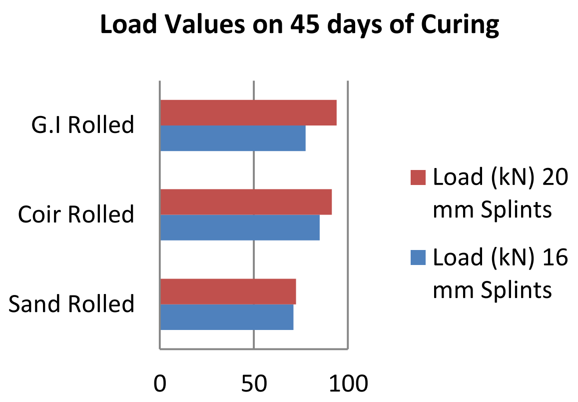

Figure 18(b) Load Values on 28th days of curing

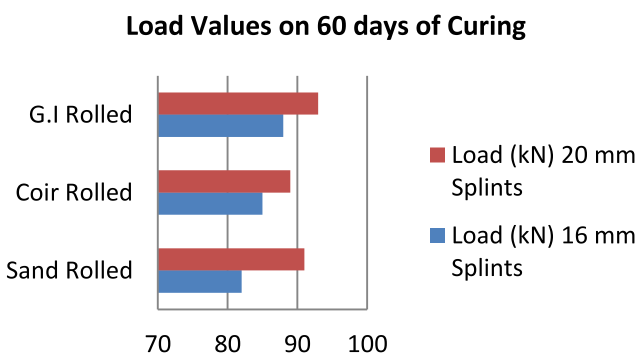

Figure 18(c). Load Values on 60th days of curing

2.14. Bamboo panels

Vishal Puri et al. [39] conducted experiments on bamboo panels for very economical projects. The environmental impact, strength and cost estimation analysis was carried out the bamboo panel. Design of experiment (CCD method) was used for the formulation of the model. The prefabricated bamboo panels are 56% less in weight when compared to that of a brick walls. Also, the cost analysis showed that, the bamboo walls is also 40% cheaper than the conventional wall. Since the use of conventional materials to cast these bamboo walls are reduced to maximum extend, these walls are considered as environmental friendly. The test results as shown in the figure proved that these prefabricated bamboo panels are suitable for the low cost housing projects. The load vs deflection curve of the bamboo panels is shown in the Figure 19.

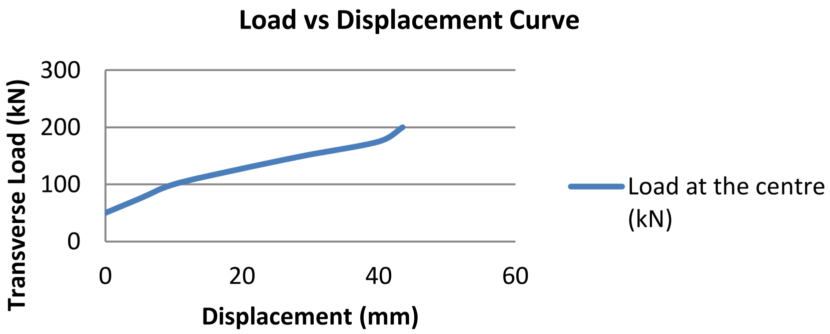

Figure 19. Load vs deflection curve of the bamboo panels

3. Recommendations

Bamboo is one of the potential building materials which possess good engineering properties. Bamboo materials like fibers, leaf ash, stem ash and strips can be used as alternative materials in conventional concrete to achieve sustainable construction. The steel reinforcement in concrete can be partially or fully replaced by the bamboo reinforced concrete and this type of bamboo construction can be preferred in low-costing houses and in tsunami affected areas. It can also be suggested in minimal load application like kitchen slabs, books slabs etc. It is suitable in the top floors of high-raised buildings. The steel reinforced concrete slab for fence walls can also be replaced by the bamboo reinforced concrete slab. Though bamboo reinforced concrete possesses good application in the construction industry, it has some significant drawbacks like water absorption and moisture content. This mainly affects the strength of the concrete. To overcome this limitation proper treatment and seasoning of bamboo should be done before it is used for reinforcement.

4. Conclusions

Based on the review done on the experimental investigation by researchers, the conclusions are as follows

(1) Proper seasoning and treatment should be done to increase the bonding strength between the bamboo reinforcement and the surrounding concrete.
(2) The free energy of activation and reaction rate constant of bamboo leaf ash are in accordance with theoretical concepts as reported in the literature.
(3) Though addition of fibers increased the impact resistance and the flexural strength of composites, the energy absorption capability with respect to age should be studied further.
(4) Bamboo material in geopolymer concrete enhanced the strength and proved its suitability for sustainable construction
(5) Shear resistance of the bamboo diaphragm is the most significant influencing factor. To increase this strength entire bamboo diaphragm is considered and also it is improved by fixing a steel strip close to the bamboo diaphragm.

(6) The research revealed that the quality of BRC concrete slab is better than that of SRC slab. The deflection and crack pattern also followed the same path.
(7) The load displacement and stress strain curves of bamboo reinforced columns showed the same typical pattern as that of steel.
(8) BRC can be effective alternative to steel and to prevent bamboo from water absorption sealant materials like asphalt, Sikadur 32-Gel etc can be implemented.
(9) The behavior of pull-out test of bamboo was same as that of plain steel bar. It is suggested that treated bamboo reinforcement will yield high bond strength.
(10) Major failure of bamboo is observed at its node since bamboo is week at its node.

References

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