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A Review on the Recent Development of Using Bamboo Element as Reinforcing Material in Plain Concrete

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ABSTRACT

Over the last few decades use of fiber to reinforce plain cement concrete (PCC) to improve its ductility, tensile strength and crack and shrinkage resistance has gained a lot of popularity. Bamboo (Bambusa) is a fast-growing grass and abundantly available in India. It possesses sufficient strength, flexibility, toughness and is also very light in weight. Bamboo can be processed to obtain bamboo fibers of required dimensions which could be used as a substitute of steel fibers in order to improve ductility, tensile strength which in turn improves crack and shrinkage resistance of plain cement concrete. Bamboo fibers are also environment friendly and much cheaper than almost all other types of fibers used in concrete construction. Many studies have been carried out on bamboo reinforced concrete (BRC) which mostly deals with bamboo strips as reinforcement in concrete similar to that of steel bars in concrete. However there are very few literatures available on using bamboo in the form of fibers to reinforce concrete. This paper reviews various studies carried out on bamboo as reinforcing material in concrete especially in the form of fibers. Based on previous studies two types of predominantly used bamboo fibers, i.e., i) long slender type and ii) flat chip type, have been identified. The authors intend to conduct experimental investigation using these two types of fibers and comparative analysis also to be made between the test results of concrete specimens reinforced with these two types of fibers to identify its technical viability. Further investigations will be conducted using the type of fiber resulting better concrete properties with various volume content and aspect ratio. In addition, experimental study will also be taken up on concrete specimen partially replacing cement by pozzolanic material and using the same type of fiber.

Introduction

Plain Cement Concrete(PCC) is brittle in nature. It has very little tensile strength capacity and also and also shows high shrinkage . Hence fibers are added to concrete in order to improve the tensile strength, ductility and crack and shrinkage control of PCC [2,3]. According to American Concrete Institute (ACI) Committee 544, fiber reinforced concrete can be broadly classified as shown in Fig. 1[1]. Fibers can be further grouped into two categories on the basis of its physical properties: 1) Fibers with low modulus of elasticity and high elongation property, and 2) Fibers with high modulus of elasticity. Synthetic and organic fibers such as nylon, polypropylene and polyethylene belong to the first category while steel, glass, asbestos and carbon fibers belong to the second one. Use of the former group of fibers does not lead to any increase in strength, but does improve material toughness and resistance to impact and explosive loadings. The latter group of fibers improves the strength and stiffness characteristics of concrete and, to a varying degree, its dynamic properties [4].

Steel fibers are the most common type of fibers that are used to reinforce concrete. Owing to the higher costl and susceptibility to corrosion of steel fibers, synthetic fibers are being widely used as a substitute to steel fibers. Most of the synthetic fibers are cheaper than steel, possess adequate physical and mechanical properties, light in weight and resistant to corrosion and other chemical attacks. However they are associated with health and environmental threat. For instance, Aramid fiber has been banned in many countries as they pose health hazard threat. Also it takes hundreds of years to decompose these fibers naturally. This demands to focus on natural fibers which are biodegradable, inexpensive, environmental friendly and easily available.

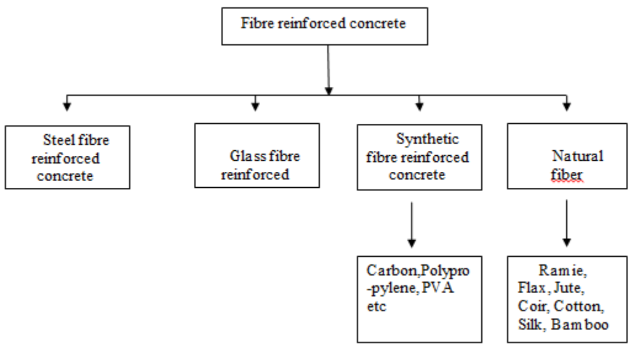

Fig 1. Classification of FRC as per ACI [1].

Use of natural fiber as an alternative to synthetic fiber has been suggested by many researchers. Various types of natural fibers those were investigated by various researchers are provided in Table 1. Very few Investigators have considered the use of bamboo fibers.

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Table 1 show that bamboo fibers possess sufficient mechanical properties to be used as bamboo fiber reinforced concrete.

Table 1. Mechanical properties of various types of fibers [5-9].

Fiber type	Density (g/cm^3)	Modulus of Elasticity (GPa)	Tensile Strength (MPa)	Elongation at break (%)
Steel	7.8	200	1500	3.2
Glass	2.7	72	1200-1700	2.4
Carbon	1.4-1.6	200-240	2330-4000	1.1-1.8
Aramid	1.44	62-117	2300-3150	3.3-3.7
Polypropylene	0.90-0.91	5-15	400-800	8.1
Polyester	1.4	8.4-16	400-600	3.0-11
Polyethylene	0.92-0.96	5-117	75-580	4
Nylon	1.14	5.17	896	18-45
Ramie	1.0-1.55	24.5-128	400-1000	1.2-4.0
Flax	1.4-1.5	27-103	343-2000	1.2-3.3
Jute	1.3-1.5	10-55	320-800	1.0-1.8
Hemp	1.4-1.5	23.5-90	270-1110	1.0-3.5
Harakeke	1.3	14-33	440-990	4.2-5.8
Coir	1.15-1.46	2.8-6	95-230	15-51.4
Sisal	1.3-1.5	9.0-38	363-855	2.0-7.0
Silk	1.3	5-25	100-1500	15-60
Cotton	1.5-1.6	5.5-13	287-800	3.0-10
Bamboo	0.6-1.1	11-32	140-800	2.5-3.7

Bamboo is a fast-growing grass and therefore abundantly available in various counties. It has higher strength-to-weight ratio than steel and concrete. Its lightness, strength, flexibility and toughness make it a promising material for construction. It has a large number of applications particularly in pulp industry, furniture and crafts. It is also widely used in construction industry as scaffolding in South-East Asian countries. Local houses in parts of these countries are also constructed using this marvellous timber.

India is very rich in bamboo resource. It along with China constitutes more than half of the total bamboo resource available globally [13]. 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 [14]. The annual production of bamboo in India is about 4.6 million tonnes; about 1.9 million tonnes is used by the pulp industries [15]. These data proves that India has abundant resource of bamboos which can be utilised for various purposes other than paper production. Hence there is a need to harness this huge resource of our country. Fig. 2 shows the distribution of bamboo resources among the largest producing countries in the world.

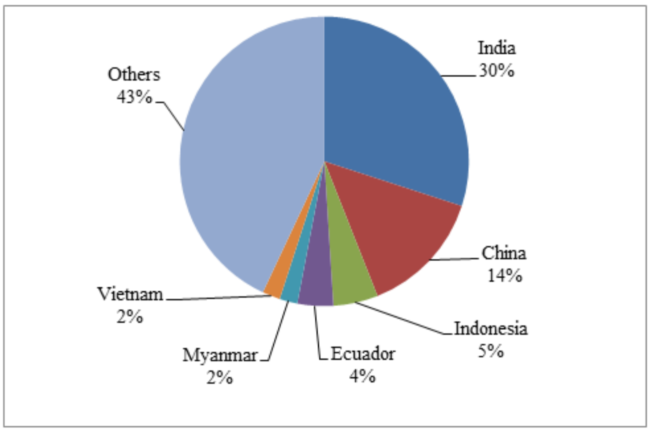

Fig. 2 Countries with largest bamboo resources [25]

Literature Survey

Several studies on different types of fibers were carried out to understand the effects of fibers on concrete. This paper discusses mainly the studies carried out on use of bamboo to reinforce concrete especially in the form of bamboo fibers.

Ramaswamy et al. (1983) [16] undertook experiment with various vegetable fibers namely jute, coir and bamboo fibers to examine their suitability for incorporation in cement concrete. The dimensional stability of the fibers was investigated by simple wetting and drying cycles for a period of 280 hours. Water absorption of the fibers was found to be in between 120% to 180% but visual signs of swelling were not observed. The strength characteristics of the fibers were tested in natural air dry state and also in alkaline environment by immersion up to 28 days in Sodium Hydroxide solution of pH value 11. An Electron Microscope was also used to observe the cross-sections of the fibers. It was found that deterioration of these fibers when embedded in concrete was very unlikely. It was identified that particle interference and balling of fibers are the two phenomena that must be avoided when mixing of concrete. Therefore in order to avoid these problems, a higher fine to coarse aggregate ratio of 1:1.25 was used and the mix was designed based on the principles of 'optimum sand content'. Also for obtaining a more homogeneous mix, fibers and water were alternately added to the mix during the process of mixing. Compressive strength test, split tensile strength test, modulus of rupture test and impact resistance test were conducted on each type of vegetable fiber reinforced concrete (VFRC). The optimum fiber content from compressive strength consideration was found to be 0.5, 1.0 and 0.5 % of the total volume of concrete for jute, coir and bamboo fibers respectively. Except for 1% coir fiber additions, the 28 day split tensile strengths and moduli of rupture of all other VFRCs were found to be lower than those of the control specimen by 5 to 25%. The impact energy for first cracking of all the VFRC was found to be higher than the control specimens by 10 to 20%. The load-deformation diagram obtained from the test showed that the failure in case of VFRC was ductile rather than the brittle failure which happens in case of PCC. Shrinkages for all the VFRCs was found to be reduced significantly but creep was found to be increased by 12 to 25%. However the results of the experiments were too limited to draw conclusive results on creep and shrinkage and therefore it was suggested that further studies were required for the same. It was concluded that jute, coir and bamboo fiber can be used with advantage in concrete in a similar manner to those of other fibers like steel, glass, polypropylene etc. Improvement in impact strength of over 25%, increased ductility under static loading and considerably lower shrinkage characteristics in the order of 50% to70% compared to those of PCC were noted positive features of VFRCs. No serious adverse effects of fiber additions were observed.

Byung Hwan Ho (1992) [5] experimentally investigated the effect of steel fibers on the flexural strength of concrete. 9 beams consisting of two series of singly reinforced beam and one series of doubly reinforced beam were tested. The fiber volume content for each series was 0, 1 and 2%. The load was applied in four-point flexural loading condition. It was found that the crack widths increased almost linearly with the increase in steel stress and the crack widths at the same loading stages was greatly reduced when steel fiber content was increased. The ductility and ultimate resistance of the beams were also found to be remarkably enhanced due to addition of steel fibers. It was also found that effect of adding steel fibers were more pronounced in case of lightly reinforced concrete beams. The fiber-reinforced concrete beams showed considerably less cracking than that of plain cement concrete at the same applied load and had remarkable resistance to tensile cracking.

Ghavami (1995) [10] conducted an experimental investigation to study the physical and mechanical properties of bamboo reinforced light-weight concrete beams. The lightweight concrete mix proportion was 1:3.22:0.78 of cement: fine aggregate: coarse aggregate and water-cement ratio of 0.55, all measured by weight. The width, depth and the length of the beams were 12 cm, 30 cm and 340 cm, respectively. The physical, mechanical and water absorption properties of seven different types of bamboo were tested. It was found that Dendrocalamus Giganteus was the most appropriate among the seven types of bamboos. Also it was found that treating bamboo strips with Negrolin-sand coat and winding with 1.5 mm diameter wire at a spacing of about 40 mm improved the water resistance as well as the bond strength between concrete and bamboo effectively. Therefore Dendrocalamus Giganteus strips coated with Negrolin-sand-wire treatment was adopted as reinforcement in the beams for further studies. Beams of dimension 120 x 300 x 3000 mm were subjected to two-point loading system. The main variables tested in the beams were reinforcement type and the percentage of tensile reinforcement. It was found that the ultimate load for bamboo reinforced light-weight concrete was up to 400% more than the ones without any reinforcement. 3% bamboo reinforcement of the gross cross section of the beams was recommended as the most appropriate amount of tension reinforcement. Also the Negrolin-sand-wire treatment improved the bonding between concrete and bamboo by 90%.

Yao et al. (2003) [7] compared concretes containing different types of hybrid fibers at the same volume fraction (0.5%) in terms of compressive, splittingtensile and flexural strength properties. Three types of hybrid composites using fiber combinations of polypropylene andcarbon, carbon and steel, and steel and polypropylene fibers were made. Experimental results showed that the fibers, when used in a hybrid form, resulted in superiorcomposite performance compared to their individual fiber-reinforced concretes. Among the three types of hybrids, the carbon–steelcombination gave concrete of highest strength and flexural toughness because of the similarity in modulus and the synergistic interactionbetween the two reinforcing fibers.

Yao and Li (2003) [17] investigated the preparation and flexural properties of a newly developed bamboo - PVA fiber - reinforced mortar laminate. The laminate plate was a sandwich plate combined with reformed bamboo plate and PVA fiber reinforced mortar sheet. The dimensions of the reformed bamboo plates were 600 x 50 x 5 mm. These plates were produced by hot pressing steamed bamboo strips of required dimension. Their physical and mechanical properties were better than that of natural bamboo. The PVA fiber reinforced mortar sheet was obtained by mixing white cement, microslag, silica sand and superplasticizer in the ratio 0.5:0.5:0.325:0.01 with water binder ratio of 0.28. The PVA fiber added at 2% volume content were of 6 mm length and 14 micron average diameter. The adhesive used in the study was Thermoplastic ethylene-acrylic acid copolymer polygrand granules. The beams constructed were of dimension 350 x 50 x 14 mm. Three-point flexural test was conducted on the beams based on ASTM D3042-87. The result of their investigation shows that flexural strength of the beams could be improved over 90 MPa using the composite material. Due to the higher strength to weight ratio, the beams developed were also very light.

Song and Hwang (2004) [30]investigated the mechanical properties of high-strength steel fiber reinforced concrete. The properties investigated included compressive strength, splitting tensile strengths, modulus of rupture and toughness index. Steel fibers were added at the volume fractions of 0.5, 1.0, 1.5 and 2.0%. Experimental results showed that the compressive strength of the fiber-reinforced concrete reached a maximum improvement of 15.3 percent over the control specimen at volume fraction of 1.5%. The splitting tensile strength and modulus of rupture of the fiber reinforced concrete improved with increase in the volume fraction achieving a maximum improvement of 98.3% and 126.6% respectively, both at 2.0% volume fraction. The toughness index of the fiber reinforced concrete improved with increase in the volume fraction. The indexes I_5, I_{10} and I_{30} registered values of 6.5, 11.8 and 20.6 respectively, at 2.0% volume fraction. Strength models to predict the compressive strength, splitting tensile strengths and modulus of rupture of the fiber-reinforced concrete were also developed which could fairly predict the results.

Ghavami (2005) [11] conducted an extensive research to study the feasibility of various bamboo-concrete composite structures. It was found that drying bamboo before its application is very much essential for improving its durability. The durability of bamboo was also dependant on the type of preservative used and the method of its application. A BRC beam, which was treated against insect attacks as well as for better bond strength, was exposed to open air for 15 years to study the weathering effects. It was found that the beam was in satisfactory condition and there was not much deterioration in the mechanical properties of bamboo. It was suggested that use of low-alkali cementitious materials and chemical admixtures would further improve the durability. High water absorption of bamboo was found to seriously affect the bond between bamboo and concrete. In order to improve the bond strength as well as to reduce water absorption, it was suggested to coat the bamboo strips by an impermeable adhesive layer which will avoid ingress of water and application of sand over it to improve the bond strength. To study the effect of coating bamboo with various types of products on bonding strength between bamboo and concrete, pull-out test were carried out. 20 different types of products were studied. Sikadur 32-Gel was found to improve the bonding strength most significantly. It was also suggested that use of asphalt paints, tar based paints and bituminous material for the same purpose would reduce the cost. BRC beams of 340x12x30 cm were tested after treating the bamboo splints. It was found that treatment of bamboo splints led to more than 100% improvement in bond strength. Ultimate load capacities of the beams were increased by 400% as compared to concrete beams without reinforcement. Concrete slabs with bamboo permanent shutter forms were also experimented. The main concern with its application was shear resistance of the structure. It was found that shear resistance could be improved significantly by providing bamboo strips in the traverse direction to bamboo culms shutter. Bamboo reinforced circular concrete columns were also studied. External permanent shutters were provided to the columns. The bamboos were treated with Sikadur 32-Gel.

It was found that the 3% of bamboo reinforcement treated with Sikadur 32-Gel was as good as the conventional steel reinforcement as recommended by Brazilian norms. The results of the investigation show that bamboo can be effectively used as a substitute for steel when proper treatments are provided.

Sudin and Swamy (2006) [18] conducted experiments on bamboo and wood fiber cement composites. Bamboo flakes and fibres from oil palm tree fronds were produced. Their sugar content was determined and its effect on the setting time and strength development of the Portland cement matrix was studied. The average thickness and length of the flakes were 0.39-0.61 mm and 14.0-17.2 mm respectively. It was found that high sugar content in the bamboo fibers had adverse effect on the composite, delaying the hydration time by about 2 hours. To counteract the adverse effects of cement hydration, chemical accelerators, cement replacement materials (fly ash, rice husk ash and latex) or a combination of both were used in the manufacture of the composite boards. The properties that were varied for the bamboo cement composite were bamboo-cement ratio and the type and amount of chemical admixture. It was found that a bamboo-cement ratio of 1:2.75 with addition of 2% aluminium sulphate by mass produced bamboo-cement composite boards with acceptable properties according to the Malaysian Standards MS 934. For the production of wood fibre cement composites, cement replacement materials such as fly ash, rice husk ash and latex were used in conjunction with chemical admixtures to counteract the adverse effect on the hydration characteristics of the cement matrix. Tests were then performed to optimize the amount and type of cement replacement material and chemical admixtures to produce boards with adequate strength and dimensional stability. Results showed that at 10% cement replacement, latex showed better performance than fly ash and rice husk ash but at 20% replacement, it was fly ash which was better of the three. For fly ash as cement replacement material, best performance was obtained at 20% cement replacement. All the strength and dimensional stability tests reported in the paper were carried out according to Malaysian Standard MS 934. The study confirmed that bamboo and wood fibers can be effectively used along with cement with addition of chemical admixtures or cement replacement materials. There is still a need to study the effects of adding cement replacement materials to bamboo-cement composite which have been missed out in the experiment.

Lima et al. (2008) [19] conducted an experimental investigation to evaluate durability of bamboo to be used as concrete reinforcement. The durability was evaluated based on change in the tensile strength and Young's Modulus of bamboo splints. 500 bamboo splint specimens were extracted from bamboo culms (Dencrocalamus Giganteus). A part of them were set into concrete prisms of 5 cm^2 cross section and 50 cm length (5 prisms each for 4 different batches of concrete). A set up was developed to expose these specimens to alternate wetting and drying cycles with each cycle lasting for 24 hours. The bamboo splint specimens were subjected to alternate wetting and drying cycles in Calcium Hydroxide solution maintaining a pH of 12.8 while the samples which were set in concrete prisms were subjected to alternate wetting and drying cycles in tap water maintaining a ph of 7.5. The results of the experiment showed that the tensile strength of bamboo is comparable with the best woods used in constructions and even with steel. The tensile stress vs. Strain curve of the bamboo was found to be linear up to failure. Average tensile strength was found to be approximately 280 MPa in the specimens without nodes and 100 MPa in the specimens with nodes. Tensile strength and Young's Modulus of the samples were measured after 7, 15, 30, 45 and 60 cycles of alternate wetting and drying. Their results showed that there were no significant affects on either tensile strength or modulus of elasticity of the samples even after 60 cycles. Their work suggested that bamboo could be a quite durable material which can be used as reinforcement in concrete.

Sabbir et al. (2011) [26] conducted an experiment to determine the tensile strength of bamboo. It was found that the bamboo specimens, when tested in Universal Testing Machine for tensile strength, faced gripping problem due to their slippery surface. The specimens were also found to fail at the gripping end due to lateral compression from the machine. To overcome these problems they used GI wires of 2 mm diameter which were wound around the bamboo specimens at both the gripping ends. Seven bamboo specimens with approximate circular cross-sectional areas ranging from 155 mm^2 to 197 mm^2 were used for the experiment. 3 of the specimens were tested without GI wires and remaining 5 with GI wires. It was concluded that it is very much essential to prepare the gripping ends of bamboo specimens before testing their tensile strength as specimens tested without GI wires were found to either fail at the gripping ends or it would slip out. Some nonlinearity in the behaviour of the bamboo specimens before its failure was also observed. The modulus of elasticity was also found to be very much lower than that of steel. It was suggested that a comprehensive study involving both experimental and finite element study is required to understand the behaviour of bamboo more accurately. Further similar investigations on bamboo twigs and cane to assess their feasibility as reinforcement in concrete were also suggested.

Terai and Minami (2011) [22] conducted a study on the feasibility of using bamboo as reinforcing material in concrete members. Concrete beams with cross section of 125 x 250 mm were used in their experiment. The beams were tested for four variables; type of reinforcing material (steel, black bamboo and Japanese timber bamboo), type of stirrups (φ4, PP-band, PP-rope, flax rope and no stirrups), stirrup spacing (100 mm for φ4 and 50 mm for others) and shear span to depth ratio (ranging from 0.68 to 2.28). A total of 11 beam tests were performed to examine the flexural cracking and the shear cracking strength of the beams. Additionally, monotonic compression tests were carried out on 16 column specimens (200 mm diameter and 500 mm height) reinforced with either steel bars or PP-band spirals, in order to study fracture behavior and mechanical property of bamboo confined concrete. It was found that the cracking patterns in BRC beams is similar to that of normal RC beams, and the predicted crack load of bamboo reinforced concrete beam were in agreement with the test data. Hence it was concluded that the fracture behavior of BRC beams can be evaluated by using existing formula of RC beams.

Terai and Minami (2012) [27] conducted a study on mechanical properties of BFRC. BFRC cubes, cylinders and prisms were casted. The variables were compressive strength of concrete (10, 20 MPa) and fiber content (0, 1, 2 and 3% by volume). Bamboo fibers used were of size 30 x 0.4 x 0.7 mm. Fresh properties tested for the composite material were the workability (slump) and the air content of the fiber-concrete mix. It was found that regardless of the strength of concrete, increase in fiber content led to decrease in slump value and increase in air content. The increase in air content was attributed to the difficulty in compacting concrete with higher amount of fibers. The compressive strength of the cubes was tested after 7, 28 and 56 days. The compressive strength of BFRC decreased significantly with increase in fiber volume content. This observation was attributed to the reduction in bond strength between the cement matrix and the aggregate. The splitting tensile strength tests were performed after 28 and 56 days on the BFRC cylinders. Tensile strength was found to increase significantly with the increase in fiber content. Flexural strength test were conducted on BFRC prisms following the Japanese code JCI-DF (Japanese Concrete Institute 1984). It was found that bamboo fibers did not have much contribution on the maximum flexural strength of concrete but it did increase the flexural toughness significantly. The elastic modulus as well as specific gravity of BFRC, both were found to decrease with the increase in fiber content. The bamboo fibers used in this experiment were produced by the process of mallet hitting. However this method of producing bamboo fibers might cause rupture in the fibers leading to lower performance of the fibers. Hence a study is required to study effect of bamboo fibers derived by some other method like cutting by a skilled person. Also effect of variation in fiber dimension on the mechanical properties of BFRC should be further studied.

Agarwal et al. (2014) [20] conducted various experimental investigations on chemically treated BRC beams and columns. Varieties of adhesives such as Tapecrete P-151, Sikadur 32 Gel, Araldite and Anti CorrRC were used as treatment to bamboo strips to study their effect on bond strength between bamboo and concrete. Pull-out tests were conducted on bamboo strips coated with the mentioned adhesives. These strips were inserted for a depth of 100 mm at the centre of 100 mm diameter and 200 mm depth concrete cylinders. From the pull-out tests that were conducted on 3 samples for each type of adhesive, Sikadur 32 Gel was found to be the most suitable adhesive. This adhesive was further used in casting BRC beams and columns. The axial compression and transverse loading tests were performed on plain, steel and bamboo reinforced columns of dimension 150 x 150 x 1000 mm to study the load carrying capacity, lateral deflection, and failure mode patterns. It was found that both plain concrete and untreated BRC columns exhibited brittle behaviour and showed very little warning before axial failure while treated BRC exhibited ductile behaviour and provided sufficient warning before failure. Also, two-point load test was performed on the beams to study their behavior under bending. It was found that by providing reinforcement of 1.49% of the total cross section area, the load carrying capacity of the beam was increased by 29.41%. Hence it was concluded that with proper treatment bamboo has the potential to substitute steel as a suitable reinforcement in beam and column members.

Ahmad et al. (2014)[28] conducted two sets of experiments on BRC. In the first experiment bamboo fibers were used to reinforce concrete cubes and were tested in a compression testing machine. The corresponding stress-strain curves were obtained and it was compared with that of PCC. The bamboo fibers used were treated with lethal anti-termite solution. Nine different sizes of bamboo fibers were used in the experiment with length ranging from 15-25 mm, breadth as 5 or 7 mm and thickness ranging from 1-3 mm. Three cubes were casted for each type of fiber size. The fiber volume content was kept constant at 1% by volume for all the samples. The cubes did not show much improvement in the compressive strength after 28 days but the strength was doubled after 50 days. The cubes also showed great improvement in modulus of elasticity. In the second set of experiments bamboo strips of approximately 200 mm^2 cross sectional area were used to reinforce concrete beams of dimension 150 x 150 x 750 mm both in tension and as well as in compression. Four point bending test was conducted and the corresponding load deflection curves were plotted. These curves were compared with that of beams without any reinforcement. Bamboo strips used were coated with coal tar and sand to improve the bond strength as well as water proofing property of the strips. The flexural strength of concrete beams was significantly improved with the use of bamboo strips in comparison to PCC beams. It was concluded that bamboo fibers and bamboo strips can be effectively used to reinforce concrete in low cost constructions. In the experiment, the fibers used were flat type rather than the commonly used long-slender fibers. Hence a comparison of the two types of fibers is essential to establish superiority of one over the other. Also the fiber volume content was kept constant throughout the experiment and therefore the effects of fiber content on the properties of the concrete were not evaluated.

Kute and Wakchaure (2014) [21] conducted a study to find out a suitable treatment for bamboo specimens which would significantly reduce the water absorption of bamboo splints without affecting the bond strength. Water absorption leads to volume changes in bamboo which ultimately leads to crack formations. Therefore it is very much essential to treat bamboos to make them water resistant and at the same time, treatment must not lead to reduction in bond strength between bamboo and concrete. In the experiment the bond strength of treated and untreated bamboo specimens with that of steel bars were compared. The tensile strength of the bamboo splints of 450 mm length was also tested. Water absorption test were conducted after treating the bamboo splints with various treatments. Pull out test were conducted to study the bond strength. For the pull out test, length of the bamboo specimens were 750 mm which were fully embedded in concrete cubes of 150 x 150 x 150 mm^3. It was found that coating with bituminous paint known as 'Black Japan' reduced the water absorption by 75% but it also reduced the bond strength by 10%. Fine zeolite powder applied with a coat of oil or bituminous paints showed reduction in water absorption by 50-90%. Hence a combination of the two can be adopted to reduce water absorption as well as maintaining certain bond strength. However the bond strength of bamboo was found to be inferior to mild steel or TMT steel for same grade of concrete.

Wahyuni et al. (2014) [24] investigated the affect of addition of bamboo fibers at 0.5% of weight of cement on the tensile strength of concrete. The bamboo fibers were of 20 mm in length. In order to improve the strength of concrete, combination of Rice Husk Ash (RHA) and Sea Shell Ash (SSA) was used to replace 10, 20, 30 and 40% of fine aggregates by weight. The ratio RHA:SSA was varied as 65:35, 50:50 and 35:65 for each type of fine aggregate replacement. Hence a total of 13 different type of concrete cylinder of 150 mm diameter and 300 mm height were casted which also included a PCC cylinder. Splitting tensile strength test was conducted on the cylinders after 28 and 90 days.

In general the tensile strengths of BFRCs were comparable to that of normal concrete. It was found that BFRC with 30% fine aggregate replacement by combination of RHA and SSA in the ratio of 35:65 showed best results. However their test showed a lot of anomalies due to which the need of further studies and tests for the specimen at later stages was suggested to get a better picture of the affects of additives and bamboo fibers on concrete.

Javadian et al. (2016) [23] investigated the bonding properties of a newly developed bamboo-composite reinforcement in concrete through pull-out test. The water absorption of bamboo is one of its major drawbacks as it leads to volume changes which ultimately lead to cracks. Also the bamboo reinforcements and concrete must possess sufficient bond strength to be applicable as a structural member. These were the problems identified by the researchers and accordingly the research was carried out. The bamboo fibres were first obtained by processing the entire bamboo culms. The fibres were then added to a two component epoxy resin system and then pressed into high tensile strength composite materials using a hot-press fabrication technology. This process yielded a bamboo composite material which was densely compressed. These bamboo-composite materials were cut into different sizes to be used as reinforcement in concrete. Various coatings were applied to these bamboo-composite materials to determine the bond behavior between the concrete and the bamboo-composite reinforcement. These bamboo-composites were embedded in the centre of the concrete cylinders of 300mm height and 150mm diameter for a specified depth of 200mm. Pull-out tests were conducted in a standard UTM machine. The results of their study showed that even the bamboo-composite reinforcements, which were not provided any coating, developed adequate bonding with the concrete matrix. However an epoxy based coating with sand particles provided extra protection and marginally improved the bond strength. It was concluded that the bamboo-composite reinforcements can be used without any coating to provide adequate bond strength but in order to make it more durable, it is desirable to coat them with a water based epoxy coating and fine sand particles. Further studies are being carried out to study the long term bonding behavior of the composite against alkaline environment of concrete, acid rain and exposure to sunlight.

Summary of Literature Survey

Table 2. Summary of Important Literatures

Author	Fiber Type	Dimensions (mm)	Effect on Compressive strength	Effect on Tensile Strength	Effect on Flexural Strength	Other Remarks
I. Terai and Minami	Bamboo	0.4x0.7x30 (approx.)	Decreased	Increasd upto 50%	No Contribution	Modulus of elasticity also decreased with increase in fiber content
II, Ahmad et al.	Bamboo	20x6x2 (average)	No Contribution	NA	Doubled	Bamboo reinforcement used for flexural test
III. Ramaswamy et al.	Jute, Coir & Bamboo	NA	Increased upto 40%	Decreased by 5-25%	No significance change	Effect considered only for Bamboo Fibers, Significant improvement in Impact resistance
IV Wahyuni et al.	Bamboo	Length: 20	NA	Increased upto 26%	NA	Anomaly: For some samples decrease observed upto 30%
V. Sudin and Swamy	Bamboo & Oil Palm Tree	Length: 14.0-17.2 Thickness: 0.39-0.61	NA	NA	Decrease in Strength	Effect considered only for Bamboo Flakes
VI. Hughes and Fattuhi	Polypropylene Fiber	NA	NA	NA	Very modest increament in flexural strength	Large improvement in toughness. Ductile type of failure..
VII. Craig et al.	Deformed steel fiber	50mm in length and aspect ratio of 100	NA	The section ductility increased with higher concrete grades and lower strength of tension reinforcement..	NA	The use of fibers improves ductility of the section...
VIII. Byung Hwan Ho	Steel fiber	NA	NA	Considerably less cracking than that of plain cement concrete at the same applied load and had remarkable resistance to tensile cracking..	NA	The crack width increased almost linearly with the increase in the steel stress..

IX. Ghavani	Bamboo Strips	120X300X3000 mm	NA	NA	NA	The ultimate load for bamboo reinforced light weight concrete was up to 400% more than the ones without any reinforcement...
X. Yao et al.	Hybrid fibers	NA	NA	NA	Highest strength and flexural toughness	Compared concretes containing different type of hybrid fibers at the same volume fraction...
XI. Song and Hwang	High strength steel fiber reinforce concrete	NA	The compressive strength of fiber reinforced concrete reached a maximum improvement of 15.3%	The tensile strength of fiber reinforce concrete improved with increase in the volume fraction..	NA	The mechanical properties of high strength steel fiber reinforced concrete..
XII. Lima et al.	Bamboo splint specimen	NA	NA	The tensile strength of bamboo is comparable with the best woods used in construction even with steel..	NA	The bamboo could be quite durable material which can be used as reinforcement in concrete..
XIII. Sabbir et al.	Bamboo	Areas ranging from 155 mm2 to 197 mm2	NA	NA	NA	The modulus of elasticity was also found to be very much lower than that of steel...
XIV. Aggarwal et al.	Bamboo strip	NA	NA	NA	NA	It was concluded that with proper treatment bamboo has the potential to substitute steel as a suitable reinforcement in beam and column member....
XV. Kute and Wakchaure	Bamboo specimen	450mm	NA	NA	NA	The bond strength of bamboo was found to be inferior to mild steel or TMT steel for same grade of concrete...
XVI. Javadian et al	Bamboo composite reinforcement	NA	NA	NA	NA	It was concluded that the bamboo composite reinforcement can be used without any coating to provide adequate bond strength...

Summary of the Review

One of the major drawback of using bamboo as reinforcement is its durability concern. Ghavami [11] showed that BRC could be quite durable by using treated bamboo for reinforcement. He further suggested that the durability of BRC can be improved by using low-alkali cementitious materials and chemical admixtures. This has been backed by other researchers as they found that high alkaline environment lead to lower durability of bamboo fibers [18]. Flyash is a Pozzolanic material which has lower alkalinity than cement. Flyash is also known to improve the workability and impermeability of concrete [29]. Addition of bamboo fiber leads to lower workability. They are also known to absorb a high amount of water leading to volume changes and ultimately to deleterious properties. Hence addition of fly ash will not only reduce the alkalinity to some extent but also address both of these drawbacks.

The other major concern when using bamboo fiber is that many of the researchers faced what is commonly called as 'balling of fibers' problem, when mixing of concrete. It is a phenomena seen when the fibers are not dispersed homogeneously and they get strangled with each other forming balls of fibers. This has adverse effect on concrete weakens the concrete at locations where balling occurs. Therefore care must be taken to avoid this problem. Fiber must be added gradually maintaining a homogeneous mix.

Terai and Minami [27] conducted experiments on BFRC to study the effect of volume content of fibers on its fresh and hardened properties. The volume content of bamboo fibers were varied as 0, 1, 2 and 3%. They also varied the characteristic strength of concrete as 10 and 20 MPa. However the dimension of bamboo fiber remained constant with constant aspect ratio of 50. Hence the effect of bamboo fiber aspect ratio on various properties of BFRC was not studied. This area of study could be further researched to establish a suitable relationship between aspect ratio and various properties of BFRC.

The bamboo fibers used in Ahmad's [28] in their study were more like flat chips rather than long-slender thin fibers used in Terai's study. Comparative analysis of the properties of BFRC developed using the two different types of bamboo fibers is required to establish the superiority of one over the other. The volume content of fiber was kept constant in Ahmad's study and therefore effect of change in volume content was not studied. They also suggested that bamboo fibers must be treated with anti-termite solution before using them as fiber reinforcement in concrete. This will prevent attacks from termites, fungus, rodents etc which will ultimately improve the long term durability of BFRC.

Sabbir et al. [26] in their study observed early failure at the gripping end due to increased stress developed from lateral compression. Moreover they noticed that bamboo specimen were very slippery due to which the samples in some cases experienced slip at the time of tension test. In order to solve this gripping problem GI wire of 2 mm diameter were wound around at both the ends of the specimen. Similar procedure must be adopted when testing the tensile strength of bamboo strips.

Proposed Experimental Investigation

From the critical review it has been proposed that an experimental investigation will be conducted to compare the two types of bamboo fibers: long-slender type (T-1) and flat-chip type (T-2) bamboo fibers. Based on previous studies, proposed dimensions of T-1 fiber is 2 mm diameter and 40 mm length approximately. T-2 fiber dimension is based on study carried out by Ahmad. T-2 fibers of average dimensions as 25 mm length, 5 mm width and 2 mm thickness will be used for the experiment. Bamboo fibers will be obtained from locally available bamboo. T-1 fibers used in Terai's study were produced by hitting the bamboo with a mallet until they were reduced to thin fibers. However this process might affect the mechanical properties of bamboo fibers significantly. Therefore T-1 fibers for the experiment shall be produced manually by carefully cutting the bamboo culms into fibers with required dimension by a skilled labour.

Fibers volume content of 0.5% of the total volume of concrete was proved as the optimum fiber volume content from strength considerations in the study carried out by Ramaswamy et al. [16]. However the volume content that will be used in the present investigation, which will compare two types of fibers, will be kept constant at 1% to magnify the effect of bamboo fibers on concrete. Although it is proposed that once the better of the two fibers is determined, the fiber volume content shall be varied to determine the optimum fiber content. Compressive strength test, split tensile strength test and flexural strength test will be performed on the specimens developed following the guidelines from Indian Standard Codes. The affect of each type of fiber on the compressive strength, tensile strength and flexural strength of concrete shall be studied and compared.

Also water absorption test on BFRC and tensile strength test of bamboo specimen shall be separately conducted. The better of the two fibers will be further investigated to determine the optimum volume content of bamboo fibers, aspect ratio of bamboo fibers and the affect of addition of flyash on BFRC. Table 3 (i), (ii) and (iii) shows the specimen properties for various tests.

Fig 2. The two types of Bamboo fibres.

Novelty of the Research

The significance of the research lies in the use of natural fibers which are abundantly available in nature. This research investigates the feasibility of bamboo fibers to replace commonly used fibers such as steel, carbon, glass, polypropylene etc in concrete. This will not only reduce the cost of construction material but also reduce the environmental and health threat posed by other types of fibers. Literature available on use of bamboo fibers is very scarce and hence we cannot entirely depend on these few literatures to draw conclusion on the behaviour BFRC. More studies are required before adopting BFRC as a composite for construction and my research will certainly contribute positively to this field of research.

Conclusion

- It can be concluded from previous literatures that bamboo can be used as reinforcement in concrete both in the form of strips as well as fibers.
- It has been proved that bamboo is durable enough to be used along with concrete.
- Although for most of the researchers, adding bamboo fibers to concrete led to decrease in its compressive strength, but it also led to significant improvement in its tensile strength. A particular volume content at which decrease in compressive strength is within limits while the tensile strength is significantly increased is to be determined.
- It is clear from the literature that there are predominantly two types of bamboo fibers, mentioned as T-1 and T-2 in the study, that have been researched by various researchers. A comparative study of the two is essential to establish the superiority of one over the other. Once the better of the two is determined, effect of fiber volume content and aspect ratio on the performance of BFRC can be carried out in the future.
- Care must be taken mixing fiber in concrete to avoid 'balling of fiber' and obtain a homogeneous mix.
- The effect of addition of low-alkali cementitious materials and chemical additives on the performance of BFRC and BRC is a research area which is yet to be addressed.
- As studies already confirmed that bamboo must be protected from termites, fungus etc, therefore it is essential to treat them with anti-termite solution before their use.
- Whenever bamboo is used as tension or compression bars, they must be coated with suitable adhesive coating (coal tar or bitumen) and sand must be applied over it to improve bond strength and impermeability to water.

References

[1] American Concrete Institute (ACI) Committee 544

[2] Robert John Craig, Jack Decker, Lawrence Dombrowski Jr., Robert Laurencelle and John Federovich (1987), "Inelastic Behavior of Reinforced Fibrous Concrete", Journal of Structural Engineering, Vol. 113, Issue 4, pp. 802-817

[3] B. P. Hughes and N. L Fattuhi (1976), "Improving the toughness of high strength cement paste with fibre reinforcement", ELSEVIER, Composites, Vol. 7, No. 3, pp. 185-188

[4] AhsanParvez and Stephen James Foster (2015), "FatigueBehavior of Steel-Fiber-Reinforced Concrete Beams", ASCE, Journal of Structural Engineering, Vol. 141, Issue 4, 04014117

[5] Byung Hwan Oh (1992), "Flexural Analysis of Reinforced Concrete Beams containing Steel Fibers", ASCE, Journal of Structural Engineering, Vol. 118, No. 10, pp 2821-2835

[6] K.L. Pickering, M.G. AruanEfendy and T.M. Le (2016), "A review of recent developments in natural fibre composites and their mechanical performance", ELSEVIER, Composites: Part A, Vol. 83, Pages 98-112

[7] Wu Yao, Jie Li&Keru Wu (2003), "Mechanical properties of hybrid fiber-reinforced concrete at low fiber volume fraction", ELSEVIER, Cement and Concrete research, Vol. 33, Pages 27-30

[8] M. Kakemi& D. J. Hannant (1996), "Effect of Autoclaving on Cement Composites Containing Polypropylene, Glass and Carbon Fibres", ELSEVIER, Cement and Concrete Composites, Vol. 18, Pages 61-66

[9] Libo Yan, BohumilKasal and Liang Huang (2016), "A review of recent research on the use of cellulosic fibres, their fibre fabric reinforced cementitious, geo-polymer and polymer composites in civil engineering", Composites Part B, Volume 92, Pages: 94-132

[10] K. Ghavami (1995), "Ultimate load behavior of bamboo-reinforced light weight concrete beams", ELSEVIER, Cement and Concrete Composites, Volume 17, Issue 4, Pages: 281–288

[11] K. Ghavami (2005), "Bamboo as reinforcement in structural concrete elements", ELSEVIER, Cement and Concrete Composites, Volume 27, Issue 6, Pages: 637–649

[12] S. SitiSuhaily, H.P.S. Abdul Khalil, W.O. Wan Nadirah and M. Jawaid (2013), "Bamboo Based Biocomposites Material, Design and Applications", InTech, Materials Science - Advanced Topics, Chapter 19, Pages: 489-517

[13] Sharma, Y.M.L. (1987), Inventory and resources of bamboos. pp 14-17, inRecent Research on Bamboos (A.N. Rao, G. Dhanarajan and C.B. Sastry, eds.). CAF, China and IDRC, Canada

[14] Bahadur, K.N. and Verma, J. (1980), Country Report India. Pp. 19-46 in Proceedings of the Workshop on Bamboo Research in Asia, Singapore (G. Lessard and A. Chorinard, eds.).IDRC, Ottawa, Canada.

[15] Katwal, R.P.S., Srivastva, R.K., Kumar, S. and Jeeva, V. (2003), "State of Forest Genetic Resources Conservation and Management in India", Forest Genetic Resources Working Papers, Working PaperFGR/65E. Forest Resources Development Service, Forest Resources Division. FAO, Rome

[16] H.S. Ramaswamy, B.M. Ahuja and S. Krishnamoorthy (1983), "Behaviour of concrete reinforced with jute, coir and bamboo fibres", Elsevier, International Journal of Cement Composites and Lightweight Concrete, Volume 5, Issue 1, Pages 3-13

[17] Wu Yao and Zongjin Li (2003), "Flexural behavior of bamboo–fiber-reinforced mortar laminates", ELSEVIER, Cement and Concrete Research, Volume 33, Pages 15–19

[18] Rahim Sudin& Narayan Swamy (2006), "Bamboo and wood fibre cement composites for sustainable infrastructure regeneration", Springer, Journal of Material Science, Volume 41, Pages: 6917–6924

[19] Humberto C. Lima Jr., Fabio L. Willrich, Normando P. Barbosa, Maxer A. Rosa &Bruna S. Cunha (2008), "Durability analysis of bamboo as concrete reinforcement", Materials and Structures, Volume 41, Pages: 981–989

[20] AtulAgarwal, Bharadwaj Nanda &DamodarMaity (2014), "Experimental investigation on chemically treated bamboo reinforced concrete beams and columns", ELSEVIER, Construction and Building Materials, Volume 71, Issue 30, Pages 610-617

[21] S. Y. Kute& M. R. Wakchaure (2014), "Performance Evaluation for Enhancement of Some of the Engineering Properties of Bamboo as Reinforcement in Concrete", Springer, Journal of the Institution of Engineers (India): Series A, Volume 94, Issue 4, Pages: 235–242

[22] Masakazu Terai, Koichi Minami (2011), "Fracture Behavior and Mechanical Properties of Bamboo Reinforced Concrete Members", ELSEVIER, Procedia Engineering, Volume 10, Pages: 2967–2972

[23] AlirezaJavadian,Mateusz Wielopolski, Ian F.C. Smith and Dirk E. Hebel (2016), "Bond-behavior study of newly developed bamboo-composite reinforcement in concrete", ELSEVIER, Construction and Building Materials, Volume 122, Pages: 110–117

[24] Ade Sri Wahyuni, FepySupriani, Elhusna and Agustin Gunawan (2014), "The performance of concrete with rice husk ash, sea shell ash and bamboo fibre addition", ELSEVIER, Procedia Engineering, Volume 95, Pages: 473 – 478

[25] Maxim Lobovikov, ShyamPaudel, Marco Piazza, Marco Piazza and Junqi Wu, "WORLD BAMBOO RESOURCES: A thematic study prepared in the framework of the Global Forest Resources Assessment 2005", Food and Agriculture Organization of United Nations, Rome 2007

[26] MdAhsanSabbir, S.M. AshfaqulHoq, and SaiadaFuadi Fancy (2011), "Determination of tensile property of bamboo for using as potential reinforcement in the concrete", International Journal of Civil & Environmental Engineering, Volume 11, No 5, Pages: 47-51

[27] Masakazu Terai& Koichi Minami, "Basic Study on Mechanical Properties of Bamboo Fiber Reinforced Concrete", Proceedings of IABSE-IASS 2011 Symposium, London (UK), proceedings (DVD)

[28] Shakeel Ahmad, AltamashRaza, and Hina Gupta (2014), "Mechanical properties of bamboo fiber reinforced concrete", 2nd International Conference on Research in Science, Engineering and Technology, Dubai (UAE)

[29] Fly ash for cement concrete: Resource for high strength and durability of structures at low cost, Ash Utilization Division, NTPC Limited, Noida-201301

[30] P.S. Song and S. Hwang (2004), "Mechanical properties of high-strength steel fiber-reinforced concrete", ELSEVIER, Construction and Building Materials, volume 18

[31]J Zhuang, J Zheng – Experimental study of fly ash content influence on bond performance between reinforcement and self-compacting concrete...

[32]X Hu, D.Niu, Y.Zhang – Experimental research on bond performance of early age fly ash concrete...
[33](Gopalan and Haque)- Design of fly ash concrete...
[34]T.Lo- strength analysis of bamboo by microscopic investigation of bamboo fiber...
[35]K.Ghavami- Ultimate load behaviour of bamboo reinforced lightweight concrete beams...
[36]M.Terai- Fracture behaviour and mechanical properties of bamboo reinforced concrete members...
[37]H.T.Li- Mechanical performance of laminated bamboo column under axial compression..