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REVIEW PAPER

Utilization of Bamboo Agro Residues in Structural Construction: A Review

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ABSTRACT

Bamboo is commonly used natural raw materials for construction of houses, huts etc since ancient times. In modern construction industry, steel is mainly used as reinforced materials along with concrete to improve the mechanical strength of the structures. However, due to high cost of steel, corrosion problem, high energy and emission of greenhouse gas during manufacturing process, researchers found alternative reinforcement raw materials like plant fibres, waste from mining industry and agricultural waste. Bamboo is one of the raw materials having high potential to be used in replacement of steel due to its low cost, natural resources and have good mechanical properties. It has been used in the preparation of composite and wood based panels. This review highlights the various applications of bamboo agro residues as reinforcement in cement concrete and bamboo-composite for construction.

HIGHLIGHTS

- Bamboo is an environment-friendly construction material that has high tensile strength, and compressive strength.
- It can be used in earthquake-prone areas since it has good elastic properties.
- The bonding between bamboo and concrete in the reinforced concrete beams can be improved through treatment with negrolin-sand-wire, Sikadur 32 Gel, bitumen coating with coir rope wound around and or with water repellent.
- Bamboo can be utilized for the development of composites due to its high cohesive and as a supplement for medium-density particle boards.

Keywords: Bamboo Reinforced Cement Concrete, Composites, Ductility, Tensile strength, Reinforcement

Human utilized different natural grass materials as reinforcement for the housing construction however, invention of cement and steel led construction industries improved further toward modern construction. In order to improve the mechanical strength of the building structures, steel bars are mostly used along with concrete as reinforcement. However, steel has high cost, availability issue and high energy consumption in manufacturing process and also corrosion problem as well. The researchers try to find an alternative reinforcement raw materials from plant and other natural fibres, waste from mining industry and agricultural waste. Bamboo is one such raw material having high potential which can act as a substitute for partial replacement of steel for low cost housing construction since it is cheaper, natural resources and good mechanical properties.

Bamboo is a naturally occurring composite belonging to *Bambusoidea* family, mostly grown in tropical and sub-tropical regions having high

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potential as building materials for the construction industry and for rural house construction due to its stiffness and high mechanical properties. Bamboo generally grows to full growth within few days and attained maximum mechanical strength in few years (3-4 years) (Ghavami, 1995, 2005; Sevalia et al. 2013; Lakkad & Patel, 1981). Bamboo plant is typically a hollow, anisotropic composed of long and parallel fibres where the fibres are mostly found close to the outer parts. The fibrous portions are uniformly distributed at the bottom part of the plant with long internodal distance the middle portion of the bamboo culm with varying thickness from lower part of the plant to the top portion. The shell of the bamboo culm is cylindrical in shape separated by a diaphragm at the nodes and orthotropic in nature having more strength along parallel to the fibers direction and low strength across it (Rahman *et al.* 2011; Archila *et al.* 2018).

Production of bamboo

Bamboos (*Bambusa vulgaris*) are the vast genetic resource of the country and have a great potential of producing higher biomass for the benefit of the society. India is the second largest country in the world in terms of bamboo cultivation next to China identifying about 136 species and 23 genera cultivated in an area of about 13.96 million hectares with an annual production about 3.23 million tones approximately. China, Vietnam, Indonesia, Thailand and Denmark are the major bamboo exporters countries of the world. The major bamboo producing states of India are the eight northeastern states and West Bengal (www.nbm.nic.in).

Physical and chemical characteristics of bamboo

The diameter and heights of hollow bamboo culms varies from 1cm to 25 cm and 1m to 40 m in which basal end has higher diameter than the tip portion. The outer surface of the bamboo is covered by a hard shiny cuticle preventing water loss from the bamboo culm. Generally, 40 to 70% of the fibers lies on the outer side and 15% to 30% on the inner part of the culm.[1] The density of bamboo lies in the range from 500 - 800 kg/m^3 and the diameter varies from 10 mm to 200 mm with wall thickness of about 10% of external diameter with nodal spacing of 250 mm to 500 mm respectively. The bamboo has lower specific modulus in the transverse direction than steel due to its an isotropic nature (Archila *et al.* 2018). However, the tensile strength of bamboo can reach upto a maximum of 370 MPa and it specific tensile strength is six times more than that of steel having high potential for application in building construction if tensile strength to its specific weight ratio is taken into account (Ghavami, 1995; Rahman *et al.* 2011; Agarwal *et al.* 2014).[2,5,8] The main chemical compositions of bamboo include 50-70% holocellulose, 30% pentosans and 20-25% lignin (Cheng *et al.* 2015). It also contains other organic composition such as starch, deoxidized saccharide, fats and protein. The strength and durability of bamboo depends on the chemical composition during their growth, age, type of species, climatic condition and their chemical composition (Li, 2004).

Water absorption & Bond Strength

Bamboo contains cellulose, hemicelluloses and lignin and respective functional groups are responsible for high moisture content which ranges from 45 to 70%, so it is highly hygroscopic in nature during growth stage. It influences to absorb water when used as reinforcement with concrete leading to swelling and finally resulted into formation of micro or macro cracks in the cured concrete. Pretreatment of bamboo with an epoxybased adhesives polyester resin or synthetic rubber followed by broadcasting sand improves the durability or bonding strength with concrete. It is also reported that samples are heat treated under pressure and dried below 10% moisture content before coating with any adhesive agents and sand. It was reported that Sikadur 32 adhesive coating of the bamboo splints increase the bond strength upto about 350 % to 430 % (Ghavami, 2005; Archila *et al.* 2018; Agarwal *et al.* 2014; Terai & Minami, 2012). Bitumen application followed by sand coating can also lower the water absorption capacity of the bamboo before using as reinforcement as reported by Akeju & Falade (Terai & Minami, 2012). Adhesives like Tapecrete P-151, sikadur 32 Gel, Aradite and Anti Corr RC have also been reported to increase the bonding strength of bamboo reinforcement by Agarwal *et al.* (2014) and ALGICOAT RC-14 as water proofing agent to minimize swelling of bamboo by Sakaray *et al.* (2012).

Durability & tensile strength of bamboo

Bamboo is liable to environmental degradation by insects and moulds like timber due to its chemical composition content. Alkali treatment is not recommended for bamboo bars since alkali removes high amount of hemicelluloses and lignin which reduce the inter-fibrillar cohesion and decrease the tensile modulus of the bamboo. Low humidity less than 15% is desirable to prevent from mould attacks which also improve the mechanical properties and penetration during treatment like immersion, impregnation, modified Boucherie method etc. (Ghavami, 2005; Archila *et al.* 2018). Boron and copper base wood preservative can be apply to bamboo on the external surface to prevent from fungal and insect attack. The pre-chemically treated bamboo increases the durability for permanent structures as reported by Kaminski *et al.* (https://www.researchgate.net/publication/). Pretreated bamboo in the bamboo reinforced beam shows satisfactory condition even after fifteen years while the steel reinforced bars are severely corroded when kept in an open environment (Ghavami, 2005). The bamboo should be dry and seasoned for at least three to four weeks for the tensile test and before using for structural construction. The bamboo strips with different dimensions as per requirement were tested with both end roughed for better grip during test (Sevalia *et al.* 2013). The tensile strength of bamboo varies from 97 MPa to 118 MPa with an average value of about 105 MPa with no much significant changes in stress due to the number of nodes present in it as reported by Rahman *et al*. (2011).

Application of bamboo as construction materials

Many literatures have reported on the application of bamboo as one of building materials in the construction industry. In one of the study, the result shows that singly reinforced beam and doubly reinforced beam with bamboo can increase the ultimate load carrying capacity to about 2 times and 2.5 times with maximum deflection of about 4.5 times and 8 times to that of plain concrete beam after 28 days curing as reported by Rahman *et al.* (2011) Sethia & Baradiya (2014) also developed bamboo reinforced concrete beam as per IS code for low cost housing and they found that the load carrying capacity of the reinforced beam can be increase to about three times with a maximum deflection of about 1.5 times to that of conventional plain concrete. Archila *et al.* (2018) reported that the bamboo reinforced concrete beam show high deflection, low ductility, brittle failure, cracking and swelling due to poor bonding as compared to steel reinforced specimens. They recommended using of 3-4% bamboo as reinforced materials in the beam to achieve tensile stress of 34-41 MPa and 55-69 MPa maximum stress with prior treatment with asphalt emulsions.

Ghavami[5] developed bamboo reinforced light weight concrete beams and concludes that 3% bamboo reinforcement ratio with negrolin-sand-wire improves the bonding between the bamboo concrete and made a recommended that it can be used as steel substitute for light weight concrete beams. Similar result have been reported on bamboo reinforced concrete beam treated with Sikadur 32 Gel with a reinforcement ration of 3% (Ghavami, 2005). Akeju & Falade (2001) found an increase in strength of 135% for beam containing 2.7% reinforcement while unreinforced concrete beams show flexural failure. They suggested for light and low-cost housing projects. Li *et al.* (2012) also reported that bamboo steel composite slabs has a potential to act as an alternative to concrete or wood slabs in low cost housing construction. Another study reported that bamboo reinforced concrete beam with reinforcement ratio 4 % and bitumen coated bamboo strips with coir rope wound around and or with water repellent increases the bonding of bamboo and concrete having high potential to be use in the construction industry (Sakaray *et al.* 2012; Krishnamurthy, 1988). Puri *et al.* (2017) developed bamboo reinforced prefabricated wall panels that are are 56% lighter in weight and 40% cheaper with better strength than partition brick walls. These bamboo base wall panels have a great potential in the construction industry. Chithambaram & Kumar (2017) found that combination of bamboo and flyash with adequate proportion improves the flexural strength of the developed ferrocement slab panels and further recommended to be use in lost cost building construction. Brink & Rush (1966) suggested a bamboo having 28 MPa allowable tensile stress, 124 MPa an ultimate capacity, 0.34 MPa bond strength with 17.2 GPa modulus of elasticity of for developing bamboo reinforced concrete beam. Leelatanon *et al*. (2010) found that 1.6% of steel reinforcement replacement with Sikadur-32 CFN treated bamboo with 3.2% reinforcement ratio in the concrete column increases the bonding strength and ductility. Gazalba *et al*. (2015) reported that combine use of bamboo slab and steel as reinforcement can increase the slab capacities. Ikponmwosa et al.[23] suggested that using an optimum require proportion of fine aggregate with polyvinyl waste can increase the flexural properties of the bamboo reinforced foamed concrete slab. Agarwal & Maity (2014) experimented on chemically treated reinforced concrete beam and column with adhesive agents and concluded that column with untreated bamboo show brittle failure while the sikadur 32 gel treated bamboo reinforced concrete beam exhibits ductile behavior. They also reported that bamboo reinforced column with reinforcement ratio 8% almost shows similar with 0.89% steel reinforcement. Mansur & Aziz (1983) in their experimental studies reported that tensile, flexural and impact strength of the beam can be increase by using bamboo woven mesh as reinforced materials with the cement. Kaminski *et al*. (2016) suggested that bamboo should be used as structural members mainly in axial tension and compression side and the beam should be applied only to light loaded roofs and floors due to risk of crushing at the hollow cross-section and shear failure at the supports. Moso bamboo show higher load carrying capacity and more deflection than that of solid bamboo. It was suggested that bamboo can be use as reinforcement materials in areas where steel is scarcely available and where only plain concrete members are commonly being used (Khare, 2005).

Natural fibre based composite for construction

Biocomposite comprised of natural fibre as reinforcement and a synthetic polymeric resin as matrix. Plant fibres are mostly used as reinforcement, whereas vinyl ester, epoxy, polyester, and phenol formaldehyde resins are used as resins. The benefit of the natural fibre based composites is high specific strength and low weight, so it could be an attractive material for construction. It also contributes in lowering cost of construction since low amount of fiber can be used without sacrificing structural stability. The natural fiber based composites has high mechanical and resistant properties, easily recyclable, low cost processing and production and have low toxicity than synthetic fiber composites. Reduction in the cost of natural fibers, locally available natural fibres, less weight of final product, recycling ability, and the desire for green products are the main motives for the switch over to the natural fibre based composites. It also finds various applications in the construction industry as raw materials for reinforcement. The natural fiber based reinforced composites mainly depends on fibre characteristics and properties, matrix use and its interation with the fibers, preparation method and the chemical compositions of the composites.

The main drawback of the biocomposites could be weak mechanical and dimensional durability due to presence of functional hydroxyl group. In ancient times, different natural reinforcements like rice straw and horsehair have been used to reinforce the clay for the development of natural brittle bricks (Ridzqo *et al.* 2019). Generally bagasse and cereal straw are used for panel production since the high percentages of silica made naturally fire-resistant property. It is also classified as a structural biocomposite product and non-structural biocomposite product which have been developed from thermoplastics, wood particles, and textiles. Composites have been utilized for the construction in three types i.e. Conventional wood based panels, natural fibre reinforced composite and inorganic based composites (Suhaily *et al.* 2013). All plant fibres and their residual biomass like stick, leaf & stem have been utilized for the development of different types of composites; however, a review on utilization of reinforcement from bamboo is still scanty and this portion will focus on the application of bamboo based composite for construction.

Bamboo as composite materials

Bamboo can be harvested frequently several times from the same single plant since it can grow very fast having high strength to weight ratio (Zakikhani *et al.* 2014). It has high-quality cellulose fibers and mainly utilized for plywood, pulp-based products, fiber products, charcoal, and fiber-based composite (Khalil *et al.* 2012). Other than green and dried bamboo plants, it can also be utilized for the development of composites due to its high cohesive strength as reported by Manandhar *et al*. (2019).

The bamboo stripe is also heterogeneous and it contains culm wall, fiber bundle, and elementary fiber (Liu, 2012). The high strength and flexibility of its elementary fiber characteristics contribute to bamboo's superior strength, toughness, bending ductility, and low density as reported by Wang *et al.* (2008) and Yu *et al.* (2014). Strand particle reinforced composite and sandwich panel consolidated composite based products can be developed from the construction industry. Bamboo based polymer composites can be prepared by vacuum infusion, compression moulding and hand lay-up methods. In the hand lay-up method, the require amount of the epoxy resin and the suitable amount of hardener were taken, mixed well and spread on the surface of the bamboo mat to make uniform coating and then hot press for 30-60 minutes (Widiastuti *et al.* 2018). Kim *et al.* (2013) developed bamboo/vinyl ester composites by vacuum assisted resin transfer moulding method. Bamboo fibre/polyester resin based composites and bamboo mat/epoxy resin based composites can also be made from hand lay-up cum compression moulding method.

Bamboo Composites

Laminate fiber reinforced composite prepared from bamboo strips and epoxy resin with 3, 5 and 7 layering has shown 243 MPa tensile strength, 129 MPa compressive strength and 255 MPa flexural strength while unidirectional composite has shown 175 MPa tensile strength. Bamboo fiber-reinforced composite has been prepared from bamboo particles in 20, 40 and 60 mesh size along with bamboo fiber and Polyvinyl Chloride resin by compression moulding method. It is also reported that 265 MPa tensile strength and 12.4 GPa tensile modulus could be obtained from composite with 70% of bamboo fiber composition. The increment in tensile strength of composite is increasing with bamboo fiber fraction (15, 30, 45%) and alumina (0,5,10,15%) added to the polyester matrix (Wang & Chen, 2017). Bamboo residue fiber and bamboo pulp fiber (BPF) was grinded with virgin high density polyethylene (0.945 g/cm^3) in presence of maleated polyethylene (MAPE) pelletized through twin-screw extruder to developed bamboo plastic composites (Xian *et al.* 2016). The tensile strength of untreated and chemically cyanoethylated bamboo mat/epoxy composites have 86 MPa and 125 MPa with a flexural strength of 119 MPa and 133 MPa respectively (Kushwaha & Kumar, 2010). Also, the tensile and flexural strength of unidirectional bamboo fibre/ polyester composites were 126 MPa and 134 MPa respectively. Oriented Strand Boardfrom Indonesian bamboo satisfied the Indonesian recommended standard strength value due their good bonding property (Ibrahim & Febrianto, 2010).

Commercial application of biocomposites in construction

Other than conventional construction, bamboo is also used in structural materials and for preparing a composite material from polybutylene resin and bamboo fiber. It is informed that it can minimize the production cost and carbondioxide gas emissions. Lingrove (San Francisco, Calif., U.S.) is utilizing flax: thermosetting and thermoplastic resin based composite as a lightweight sandwich panel for 3D applications range from walls, floors and furniture to automotive interiors. Easy Composites Ltd, U.K. in collaboration with Eco Technilin, France have developed different composites through hand layup, vacuum bagging, press molding and resin infusion methods for various architecture and vehicle molding and body panels. Sunstrand (Louisville, KY, US) has developed chopped strand mat (CSM): synthetic binder / lignin binder based composite in wet layup and infusion processes. They also developed composites using long fibres like hemp, flax, kenaf and bamboo in 38-115 mm using either a thermoset or thermoplastic resin in sheet molding compound method for architectural applications. Lanxess (Cologne, Germany) launches a green composite material made from flax fibers with polylactic acid and it can be produced on a large scale continuously. It is informed that this product has high strength and stiffness due to uniform transfer of the load via the continuous fibers and they can be used in housing components.

The application of bamboo based composite for construction sector can be improved by developing some innovative composite products with home or heterotypic structure with desirable properties.

SWOT analysis on Bamboo as reinforcement for building material

Bamboo is used in building since ancient times. Recently there are so many advancement in the building material i.e., wide range of synthetic material used in the construction which diverse the development of different construction materials and furniture with moderate durability and non-biodegradability. The consumption of those materials in the modern era ultimately increases the solid pollution and physical dumping. To sustain the environment, stakeholders need the durable and bio-degradable building materials and furniture with easy manufacturing techniques. One of the alternatives is bamboo and the strength, weakness, opportunities and threats are addressed here.

Strength

Bamboo is a natural biomass and its has the following strength parameters in terms of building materials:

- Being a conventional, traditional and potential reinforcement, it is always preferred to build a small and individual house in village and remote areas since it grows abundantly in tropical rain forest and temperate region.
- It has high tensile strength , compressive strength since the fibrils are aligned in longitudinal axially
- It can used in the earthquake-prone areas since it has good elastic property
- Being rich in lignin and natural amino compounds, it has good fire resistance
- Being grown fast, it is economical and easy to procure
- The density is lesser than hard wood and so it is lightweight material
- It is an environment friendly construction material
- Can be used in wide range of application like scaffolding, bridges and structures and houses
- Being natural, the marketing of bamboo based building is wide

Weakness

Being a natural lignocellulosic material, and it has the following weakness parameters in the applications of building materials and it needs proper considerations to overcome those demerits:

- It has high hydrophilicity and it hinders the compatibility with concrete mixture during curing
- It shrinks with respect to time due to loss in f moisture from 70% to 8%
- It needs proper chemical or physical modification treatment for the durable building material
- There is no standard collection and delivery of bamboo for the building materials
- There is wide variation in the quality of the bamboo, because of its different species
- Being cellulosic in nature, it is prone to fungi and insect attacks
- There is no standard government policy for marketing of bamboo in the building industry

Opportunities

Bamboo is considered as a building materials and it has potential to utilize in wide application if follows the following opportunities:

- Bamboo is fast grown grass and there is no need to proper harvesting plan for them , so that farmers have great opportunity for growing
- It has diverse application in building construction
- The increase in the cost of timber makes bamboo an an alternative material in building
- Potential to use as a supplement in the production of medium density particle boards
- Bamboo fibers can be used in the production of regenerated cellulosic fibres
- Bamboo can be supplemented in the solid energy
- Bamboo can be also used in the hotel industry due to presence of antioxidants, which might benefit for enhancing food quality
- It can be used in diverse application in nearby cultivating area like crafts

Threats

However bamboo grown rapidly and available in most of the climatic conditions, it has the following threats in terms of ecological, industrial and social issues.

- Being as fat grown grass, it might impact the nearby natural ecosystems due to its spreading rhizomes
- It always competed with cost economic and durable synthetic raw material
- There is no standard processing protocol and industry for the bamboo based building materials
- It is declared as a construction materials for the economic people
- There is no standard path way for the promotion of bamboo based building materials in the modern era.

CONCLUSION

Construction industry grows rapidly due to diverse synthetic based building material; however to maintain the environment, construction industry seeks environmental friendly and durable building material**.** Bamboo has a potential to reinforce concrete mixture and the respective concrete has the good load carrying capacity and deflection however, it cannot prevent cracking of concrete and it needs suitable pretreatment to improve durability. Majority of the researchers inferred that bamboo reinforced concrete can be utilized for low-cost housing system with moderate load carrying capacity. Bamboo based composite for construction can be developed through homo or heterotypic structure with prior chemical treatment in order to improve bonding with resins and to prevent water absorption. However, it is suggested by some researchers that bamboo is not an alternative to steel in terms of its durability, strength and stiffness issues and it did not meet the environmentally friendly credentials due to the use of large amount of chemicals to increase the surface roughness, durability, bonding strength and high cost of chemicals. The application of bamboo based composite for construction sector can be improved by developing some innovative composite products with homo or heterotypic structure with desirable properties for mainly low load bearing housing for animal shed.

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