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State of The Art: Bamboo as a Structural Material

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Abstract- State of the art is presented in this paper to find suitability of bamboo as a structural member. Many research workers have studied different properties of bamboo. They have presented properties which attract attention of structural engineer to try and use bamboo, bamboo strips in structural elements. Bamboo is light in weight, easily available and available in ample and also unskilled workers can handle very easily, with vary less cost, so may fulfill requirements of good building material.

Keywords: Bamboo, Culm, tensile strength

I. Introduction

Bamboo being easily available, available in ample quantity, cheap ,light in weight and can be operated by anybody(unskilled persons) prompts civil /structural engineer to use it as reinforcing material in structural members ,mainly concrete over last so many years. A review in this regard is presented in the form of state of art of bamboo as a structural/building material by going through various research papers.

II. Literature Review

Ghavami (1995) [7] discussed the mechanical properties of Bamboo, specifically pertaining to Bamboo in concrete. This study showed that the ultimate load of a concrete beam reinforced with Bamboo increased 400% as compared to un-reinforced concrete. It was found that, compared to steel, there was lower bonding between the Bamboo and concrete, and the Bamboo had a Modulus of elasticity 1/15 of steel. Bamboo's compressive strength was much lower than its tensile strength, and there was high strength along the fibers, but a low strength transverse to the fibers. Stated is the need for the development of a simple design code for the application of Bamboo as a construction material

The United States Naval Civil Engineering Laboratory (1966, 2000) [14] reported a study providing a set of instructions on how to properly construct a variety of structures and structural elements using Bamboo. This study suggested not to use green, unseasoned Bamboo for general construction, nor to use un-waterproofed Bamboo in concrete. Concerning Bamboo reinforced concrete, it was found that the concrete mix designs may be the same as that used with steel, with a slump as low as workability will allow. It was Bamboo reinforced concrete is a potential alternative light construction method at a low cost.

Amada s., Y. Ichikawa, T. Munekata, Y. Nagase, and H. Shimizu. (1997) [2] investigated the mechanical and physical properties of Bamboo. They conducted a thorough investigation into the structure and purposes of the nodes, which they found to strengthen the Bamboo Culm. They also commented on the advantage Bamboo has over other natural building materials with its fast growth rate.

Lo TY, Cui HZ and Leung HC. (2004) [10] gave a detailed description of the mechanical properties of Bamboo in their study. They found that the physical, as well as mechanical attributes vary with respect to diameter, length, age, type, position along culms, and moisture content of Bamboo.

Masani, N.J, Dhamani, *B.C.*, Sing, *B.* (1977) [11] conducted an in-depth study outlining the proper ways to utilize Bamboo in construction. A listing of the positive aspects of Bamboo is given, citing examples pertaining to its economical, mechanical, and environmental properties. Used as reinforcement in concrete, directions are given to insure a better performance, including discussions on waterproofing, pressure-treating, concrete design, and beam design. This study found that the bamboo reinforcement area should be 5 times the typical steel reinforcement area, and that even when fine cracks develop on the surface of Bamboo, the load carrying capacity of the member is not reduced. The only negative properties of Bamboo given are its susceptibility to attack by insects, fungi and dried bamboo is prone to catch fire.

Amada and Untao (2000) [3] studied the fracture properties of Bamboo. In contradiction to other studies, this study states that the tensile strength of Bamboo fibers almost corresponds to that of steel. The main discovery is that the fracture properties of Bamboo depend upon the origin of fracture. In the nodes, it is found that the average fracture toughness is lower than the minimum value of the entire Culm, suggesting that the fibers in the nodes do not contribute any fracture resistance.

A study reported in International Network for Bamboo and Rattan (INBAR) (2005) [8]compared Bamboo to other plants such as trees by looking at how fast it grows the basics of the plant, its habitat, its history and its modern uses. For instance, we see that the same height tree takes just as many years to replace as Bamboo takes days. A single Bamboo clump can spread 15 km in its lifetime. Bamboo is the most diverse group of plant in the grass family and has tropical and subtropical distribution spreading from 46N to 47S latitude, giving many cultural uses for Bamboo.

A study reported in International Network for Bamboo and Rattan (INBAR) (2002) [8]coordinated research and a project located in Costa Rica with the Technical University of Eindhoven as the supervisor, with the aim as Bamboo to be used as a building and engineering material. They found that their project in Costa Rica has become a success story due to the fact that it was "a local initiative and the staff was fully national." In 1999, 3 drafts were submitted to National Standard Institutes of 20 growing nations seeking support, which lead to having the drafts accepted as draft International Standard Organization texts in 2001.

A Study reported in International Standard Organization (ISO) (1999) provides the first draft for

International Standard that applies to Bamboo structures based on their performance and on limit state design. The limit states are defined as states beyond which the structure no longer satisfies the design performance stipulations. The two limit states are split into ultimate limit states and serviceability limit states. Ultimate limit states are those related with structural failure which may jeopardize the safety of people. Serviceability limit states match up to states beyond specified criteria. This International Standard is only worried about the necessities for serviceability, mechanical resistance, and durability of structures. Bamboo used as composite makeup may require additional considerations beyond this Standard. This article is a compliment of Determination of Physical and Mechanical Properties of Bamboo (1999) and Laboratory Manual on Testing Methods for Determination of Physical and Mechanical Properties of Bamboo (1999).

A study reported in International Standard Organization (ISO) (1999) composed a second standard that covers a group of tests on specimens of Bamboo that are carried out to find data, which can be used to institute characteristic strength functions and to land at the allowable stresses. The figures can also be used to establish the connection between mechanical properties and factors such as density, moisture content, and growth site, incidence of node and internodes, and arrangement along the culms. The article supplies methods of testing Bamboo for evaluating the characteristic physical and strength properties to follow: density, moisture content, shrinkage, Compression, shear, bending, and tension. The purpose of the article overall is to provide clear essentials for standard tests that need to be carried out in order to determine the properties of Bamboo as a building or engineering material. This article is a complement to Bamboo Structural Design (1999) and Laboratory Manual on Testing Methods for Determination of Physical and Mechanical Properties of Bamboo (1999).

A study reported in International Standard Organization (ISO) (1999) fashioned, Lab manual for determining the physical and mechanical properties of Bamboo. The purpose for publishing this manual was first of all so that these methods were available all over the world. Research was done in so many places, very precise, yet was stuck in the laboratories. With this document, the methods were made available. Secondly, this document gives a practical step by step explanation of how to perform each test specifically following the International Standard Complement Document "Determination of Physical and Mechanical Properties of Bamboo." Another complement document is Bamboo Structural Design (1999).

The investigation reported in International Network for Bamboo and Rattan (INBAR) (2002) [8] suggested bamboo's advantages and disadvantages as a constructive material. The advantages of bamboo are ecological value, good mechanical properties, social and economic value, and energy consumption. The other sides, the disadvantages of bamboo are preservation, fire risk, and natural growth.

Amada and Untao (2000)[3] mention that bamboo is the most effective material in construction by the superior character of bamboo such as being physically powerful, tough, and a low-cost material. Normally, the Culm of bamboo with outer surface layer withstand strongly to any loading with stronger fracture resistance than the node. It suggests that the fibers in the node do not contribute any fracture resistance. The tensile strength of bamboo fibers almost corresponds to that of steel. The main discovery is that the fracture properties of bamboo depend upon the origin of fracture. In the nodes, it is found that the average fracture toughness is lower than the minimum value of the entire Culm, suggesting that the fibers in the node do not contribute any fracture resistance.

Agarwal A. and Maity D. (2009) [5] studied axial compression and bending test was performed on Plain, Steel & Bamboo reinforced members. As explained in there experimental program, For example, a total of 12 columns (150×150×1000 mm) were cast using design mix (M20) as per IS code. These columns included 3 columns of steel reinforcement, 3 columns of plain concrete, 3 columns of untreated bamboo reinforcement & 3 Columns of treated bamboo reinforcements (with varying percentage of reinforcement; i.e. 3, 5, & 8%). The load deformation curves displayed significant nonlinearity, indicating that the bamboo has the capacity to absorb energy. Failure of Columns predominately occurred in shear under compressive loading. Plain concrete and untreated bamboo columns showed brittle behavior in which, tiny cracks occurred at the surface of the column at about 80% of maximum axial force. There were no visible signs of spoiled concrete covering to warn of impending failure.

Bamboo concrete composite structural members can provide tailored solutions to the eco housing initiatives at cheaper costs. The results obtained accrue the advantage obtained by the composite members when compared to standard reinforced concrete and plain concrete. However, further studies to achieve higher mechanical properties and understanding their behaviors in details would make this a reality.

Md. Ahsan Sabbir, S.M. Ashfaqul Hoq, Saiada Fuadi Fancy [12] has carried out experimental studies on bamboo by carrying out tensile strength test on bamboo strip with and without g.i.wires. He concluded if tension tests are conducted without specimen end preparation, actual results may not be found due to smashing at the grip location but if the grip is prepared by using GI wire then no smashing and slippage occurs at that location. , In case of specimens with ends wounded by G.I wire, the tensile strength failure was observed is nearly uniform and their failure pattern is also similar as splitting parallel to the grain. The average tensile strength with prepared ends (wounded with G.I wire) has been found to be higher than the specimens without prepared ends. Bamboo specimen shows some nonlinearity before its failure. The modulus of elasticity, E of bamboo is found to be much lower than the steel reinforcement. Therefore, the deflection will be higher considering the steel reinforcement.

Kaware, A., Awari, U. R. and Wakchaure, M. R. [1] Tested and reported in their paper compressive and tensile strength. After experimental study they concluded Water absorption of bamboo is quite high. , tensile strength of bamboo is good and can be used as reinforcement in R.C.C structure for low cost housing project. And compression strength of round bamboo ranges from 47.9 to 69.9 MPa. They also coclude bamboo is weak in shear and bond, it cannot be used as shear

reinforcement in R.C.C structure, hence it should be treated by epoxy coating, tar coating etc.

Nirav B. Siddhpuraa, Deep B. Shaha, Jai V. Kapadiaa, Chetan S. Agrawal and Jigar K. Sevaliaa [13] have carried out study on flexural element using bamboo as reinforcement. They have concluded in their study Bamboo specimen failed at the mid height by splitting of the fibers, all the beam elements reinforced with surface coated bamboo strips showed ductile failure

Anurag Nayak, Arehant S Bajaj, Abhishek Jain, Apoorv Khandelwal, Hirdesh Tiwari *[*4] have studied replacement of steel by bamboo reinforcement. They have cast one way concrete slab with advanced bamboo reinforcement technique instead of traditional steel reinforcement. Reinforcement was used for both main and distribution reinforcement. It has wide scope in Low Cost Constructions it was three times cheaper then steel reinforcement technique. From results bamboo reinforcement technique was absolutely cheaper then steel reinforcement technique especially for single storey structure.

Rassiah K. and Ahmad Md. H.A. [9] other studied Bamboo Fiber Reinforced Polymer Composite and concluded in general, the modification of bamboo fiber will effectively removing the impurities and bond between fibers in which the various compositions classified in the different percentage will get the different results of testing, due to the hydrophilic nature of bamboo fiber, where the different methods required for improving interfacial surface adhesion, and characteristics that influence to composite performance, it could lead to the development of additives, coating, binders, or sizing of the natural fiber and a variety of polymeric matrices. Beside as an interesting alternative for reducing the inconveniences of polymer utilization, bamboo also give the advantages if we preserving and conserving its. Previous mechanical testing results shows that bamboo fiber can be suggested for capability's mechanical product. Fiber lengths, orientation, concentration, dispersion, aspect ratio, selection of matrix, and chemistry of the matrix need to be investigated thoroughly.

C.S. Verma, V.M. Chariar, R. Purohit [6] studied Tensile properties of bamboo laminate, prepared from bamboo slivers, selected from different regions of bamboo culms (*Dendrocalamus strictus*), increases from inner to outer region for any cross section and the same is experienced from bottom to top. Whereas, fibers modulus decreases and matrix modulus increases from bottom to top of bamboo culms. They concluded The experimental investigations show that tensile strength and Young's modulus of bamboo increases from inner to outer region across any cross section and from bottom to top of bamboo culms due to increase in volume fraction of fibers. The culms strength increases with height to compensate for the deterioration of rigidity due to the culms geometry.

III. Advantages and Disadvantages of Bamboo

Bamboo has many advantages as well as disadvantages. Before actual use structural /civil engineer has to consider all advantages and disadvantages.

Advantages of bamboo

1. Light in weight and Environmental friendly material
2. Very cheap and easily available in ample quantity
3. One can grow/cultivate and produce in the farm

Disadvantages of bamboo

1. Bamboo requires to preserve otherwise over time it may perish and loose its strength
2. Bamboo has its natural shape which is not uniform
3. Bamboo gets attacked by fungi, insects so coating needs to apply
4. Always joints are weak in bamboo
5. Need advanced guidance, detail study and codes
6. They are not fire resistance but helps fire so dangerous to use in fire prone zones.

Various uses of bamboo [14]

1. Use of bamboo as plant
   a) Ornamental horticulture
   b) Ecology
      i. Stabilize of the soil Houses
      ii. Uses on marginal land
      iii. Hedges and screens
      iv. Minimal land use
   c) Agro-forestry
      i. Natural stands
      ii. Plantations
      iii. Mixed agro-forestry systems

2. Use of bamboo as material
   a) Local industries
      i. Artisanat
      ii. Furniture
      iii. A variety of utensils
      iv. houses
   b) Wood and paper industries
      i. Strand boards
      ii. Medium density fiberboard
      iii. Laminated lumber
      iv. Paper and rayon
      v. Parquet
   c) Nutritional industries
      i. Young shoots for human consumption
      ii. Fodder
   d) Chemical industries
      i. Biochemical products
      ii. Pharmaceutical industry
   e) Energy
      i. Charcoal
      ii. Pyrolysis
      iii. Gasification

IV. Reference from BIS can be referred in further study.

- ✓ IS 6874:2008-Method of test for bamboos(1 July 2011)
- ✓ IS 8242:1976 Method of test for split bamboos(1 July 2011)
- ✓ IS 9096:2006 Preservation of bamboo for structural purposes (1 July 2011)

- ✓ Doc.ced 13(7702) Finalized draft under print, draft of Indian standard code of practice for structural design using bamboo. (1 July 2011)
- ✓ SP 7(Part 6): 2005 National Building Code of India 2005: Part 6 Structural design
- ✓ Section 1: Loads, forces and effects, Section 3: Timber and bamboo

V. Conclusions

Literature available suggests try and use bamboo with the structural elements. For structural and civil engineer systematic study is necessary to carry out to find and confirm different properties of bamboo. From literature it also can be concluded that from place to place bamboo is not remaining the same. Therefore one cannot generalize the properties of bamboo as it was done with steel and other building material. It seems from literature before using bamboo, every time one has to find out its properties which seems to be difficult to apply on actual worksite. Make all end users aware of its advantages and make easily available all properties of bamboo along with a very simple method to carry out testing.

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