BAMBOO AS A LOW COST AND GREEN ALTERNATIVE FOR REINFORCEMENT IN LIGHT WEIGHT CONCRETE

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ABSTRACT

Since ancient times, bamboo is used as a main constituent for the construction of the skeleton in adobe walls. However, in Sri Lanka, its applications has limited mainly for the construction of scaffoldings with coir yarns today. At present, the whole world is in a move for sustainable construction techniques and green building materials with low embodied energies to minimize the impact on nature. This paper is based on a literature survey conducted to find the suitability of such locally available material which is known as *"green bamboo"* as a low cost green alternative for reinforcing concrete for light weight constructions.

Suitability of the material was discussed and compared with respect to the mechanical properties, embodied energies and the cost of the construction materials. Extensive amount of data were found during the literature survey and are presented in this paper. Although the technique of using bamboo as a structural material is new in Sri Lanka, the suitability of this has proven with extensive tests and researches carried out by various researchers around the world.

The energy absorbed and associated with the extraction of raw materials, processed, manufactured, transported to site and constructed as the finished product is what makes up the embodied energy of a material. Embodied energy in bamboo is only 1.5 MJ/kg compared to steel which is in the range of 20 - 30 MJ/kg. From the cost comparison it can be seen that for a typical light weight concrete beam by using bamboo about 60% saving can be achieved over steel.

Key words: *Bamboo, sustainable materials, embodied energy,*

1. INTRODUCTION

Since ancient times, Bamboo is used as a construction material in Sri Lanka. Bamboo-reinforced adobe wall which is commonly known as *"warichchi biththi"* was one of the commonest building materials for housing construction. With the popularization of masonry walls building materials like burnt clay bricks, cement sand bricks/ blocks have now replaced the use of this ancient adobe walls with bamboo skeletons in buildings. At present, the major use of bamboo in Sri Lanka is for scaffoldings, though it is used in many countries as a construction material.

Majority of the single storey houses in Sri Lanka were "non-engineered structures" with very limited attention on disaster resistant construction techniques until the Tsunami in 26th December, 2004, which took over 30, 000 lives and displaced around 1 million people in the coastal belt. The belief that "Sri Lanka is in a disaster free zone" was proven a myth with this catastrophe. The post disaster surveys revealed that "lack of preparedness and lack of awareness" are the major reasons for this extensive damage. As a result, people in coastal areas and other disaster prone areas were compelled to use some kind of disaster mitigation measurements during the planning, re-construction and repair of future and existing buildings (houses).

Use of tie beams in plinth level, window sill level and lintel level has proven results for improved lateral strengths in masonry walls according to Mallawaarachchi and Jayasinghe [1]. Although there are very limited amount of studies done in Sri Lanka on locally grown bamboo as a main structural element, the researches done on bamboo in various other parts of the world provide sufficient data and design guidelines to use bamboo as a suitable material to provide sufficient lateral strengths when embedded in light weight concrete beams as an alternative for steel bars.

As shown in Figure 1, according to the data from Department of Census and Statistics on housing units [2], in Sri Lanka in year 2012, about 85% of the total units are single storey houses as shown in Figure 1. Therefore, alternative materials for low rise masonry buildings will be very important for the general public.

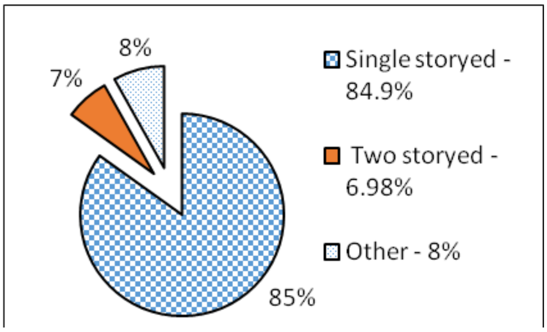

Figure 1: Housing population [2]

Having a very low embodied energy in the range of 1.5 MJ/kg and a very high growth rate, bamboo is an ideal sustainable material for green constructions. *"Embodied energy"* is the sum of all the energy required to produce goods or services (energy necessary for an entire product life-cycle) considered as if that energy was incorporated or "embodied" in the product itself. It can act like an alternative metric to reflect the sustainability of materials. The embodied energy can also be expressed in terms of the carbon dioxide emissions associated with this embodied energy, which is known as *"embodied carbon"*.

Low embodied energy building materials are those that use less energy and fewer resources and they are less harmful to the environment. In this paper, a detailed comparison among embodied energies of bamboo and other conventional building materials are presented.

2. OBJECTIVE

Since the entire world is moving towards "green", promoting a green material like bamboo with a very low embodied energy over steel will be a remarkable step in green construction techniques, and considered as a good area for a research. Although such researches are being carried out in other parts of the world, a very limited amount of studies have been done in Sri Lanka.

3. METHODOLOGY

To achieve the above objectives, an extensive literature survey was conducted covering the following basic areas:

- Different types of bamboo species, their chemical compositions, availability and applications in Sri Lanka
- Physical and mechanical properties of bamboo

- Durability of bamboo and preservation techniques
- The embodied energy of different materials for a comparison of that with bamboo
- Different applications of bamboo in various parts of the world

In addition, a cost calculation is also carried out to compare the cost effectiveness of a typical steel reinforced concrete beam and a same size bamboo reinforced concrete beam.

4. LITERATURE SURVEY

4.1 Chemical Composition, Different Species, and Applications in Sri Lanka

Bamboo is a giant grass, not a tree. Bamboo culms are cylindrical shells divided by solid transversal diaphragms at nodes. The chemical composition of bamboo is similar to that of wood and about 90% of the total mass is govern by the cellulose, hemi-cellulose and lignin. The 2-6% of starch content available in bamboo plays a major role in its durability. The long tapered fibers in bamboo culms are generally larger than that for wood and highly concentrated in the outer 1/3 of the wall and upper part of the culms giving it a superior slenderness [3].

In Sri Lanka, 14 bamboo species were reported growing and out of them, 10 species are endemic [4]. However, there are so many other species introduced and commercially planted in Sri Lanka for various reasons. Bamboo which is locally known as *"Una"* belongs to the family *"Poaceae"* and the subfamily *"Bambusoidea"* has approximate plot coverage of 5000 hectares. Out of all the species, only 5 species support the cottage industries, housing and construction projects in the country. *"Bambusa vulgaris"* which is commonly known as *"Green bamboo"* and *"Yellow bamboo"* are the two types used in construction industry as a scaffolding element. *"Dendrocalamus giganteus"* known as *"Giant bamboo"* is another type of bamboo species introduced and still abundant left unexploited [5].

A recent development in bamboo related activities in Sri Lanka is the launching of the project *"Bamboo Processing for Sri Lanka"* by increasing the current bamboo plot coverage to 15,000 hectares with an idea of harvesting 150,000 tons of dry bamboo annually to generate and add 113 MW of electricity to the national grid using *"Dendro"* power plants.

4.2 Physical and Mechanical Properties of Bamboo

In natural materials like wood and bamboo, mechanical and physical properties change from specimen to specimen and their allowable stresses are much lower than the failure stresses, compared to steel. Allowable stress of steel is close to the failure stress. But the difference between allowable stress and failure stress is more. In a disastrous situation, a wooden or bamboo structure designed within the allowable stress limits could have stresses exceeding the allowable stress, but the actual stress is more likely to remain below the failure stress compared to steel. As such, a structure made of wood or bamboo has better chances of surviving in a disastrous situation compared to steel [6].

The physical and mechanical properties of bamboo greatly depend on the chemical compositions which significantly vary with age, height, and specific layer of culm. In general, maximum strength characteristics can be found in *"mature culms"* which is typically in 3-4 year old ones. According to Xiobo [3], across the culm also, there is a remarkable variation in the strength of a bamboo.

Values obtained for Physical and Mechanical parameters of bamboo from various literatures are indicated in Table 1 below. Their variation with respect to the age, height and location of the particular layer is also presented in Table 1.

An extensive amount of data on structure of bamboo culms, preservation techniques, structural details and other properties of bamboo culms can be found in A. Abang. and A. Aband [7], J. G. Moroz and S. L. Lissel [8], D. J. Cook et al.[9], N. K. Naik [10], K. Ghavami [11], F. E. Brink, P. J. Rush [12] and J. A. Gutiérrez [13].

4.3 Durability

The durability of the culm is also directly related with the chemical composition of the culm. Hence the inner area is more susceptible for the fungal and insect attacks. Typical life time of a untreated natural culm varies from 1-36 months depending on the spices and climatic conditions [3]. For structural uses, whether indoor or outdoor, whether in tropical or temperate region, bamboo should be treated with preservative chemicals to provide adequate service life [14].

Table 1: Physical and Mechanical Properties of a typical 3year old mature bamboo culm

Property	Average value	Remarks
Density *(in kg/m³)*	700-800	• Increases with age and from inner layer to outer most layers • Increases with height (High values at higher levels)
Avg. Moisture Content for Green Bamboo *(as a %)*	60	• Decreases with age and from inner layer to outer most layers • Decreases with height (High values at lower levels)
Compressive strength *(in MPa)*	15-35	Transverse direction • Increases with age and from inner layer to outer most layers • No significant variation with height
	45-95	Longitudinal direction • Increases with age and from inner layer to outer most layers • No significant variation with height
Tensile strength parallel to grain *(in MPa)*	45-170	Strengths as high as 220-400 MPa have also recorded in some cases
Elastic modulus *(in MPa)*	180-600	Transverse direction • Increases with age and from inner layer to outer most layers • Highest at the top and no much of a variation in the middle and bottom parts of the culm
	6000-20,000	Longitudinal direction • Increases with age and from inner layer to outer most layers • Highest at the top and no much of a variation in the middle and bottom parts of the culm
Flexural strength *(in MPa)*	160-180	Directly related with the density of the bamboo culm

Since the outer most surface is covered by a hard epidermis, when harvesting attention should be paid to not to remove these outer most coating. If bamboo splints are to be used, the inner wax layers should be cleaned with water and treated with preservatives. Oil bath treatments can also be used for treating bamboo against fungal and insect attacks [3]. When untreated bamboo is embedded in concrete as an alternative for steel reinforcement, it will swell by absorbing water from concrete causing it to crack. Care should be taken to control the water absorption of bamboo before using in concrete as a reinforcing material.

Most of the studies in this area highlights the use of boron treatment is an effective method of improving the life time of a bamboo culm and splints [15]. A brush coat or dip coat of asphalt emulsion is also preferable as a waterproof coating.

4.4 Embodied Energy

Bamboo can be easily considered as a sustainable construction material mainly because of its rapid growth rate. Some species grow 5-6 inches per day producing a very high cellulose material per year than most of the other woods [15]. In addition to that, bamboo can be introduced as a low embodied energy material due to various reasons such as:

- It can be processed simply –labour consumption and machine usage is minimum (very little amount of energy in production stage).
- Treatments for durability (for example boron treatment) are also not complex and do not produce any toxic waste to the environment.
- Wider availability makes it easy to find nearer to the construction sites. Hence the energy for transportation is very low.

Table 2 below is an *"Inventory of Carbon and Energy (ICE)"* prepared by the University of Bath (UK) [16]. Typical value for embodied energy of bamboo is in the range of 1.5 MJ/kg. However, in most of the literature this value is very high due to the massive contribution from the raw material transportation. Therefore, in some parts of the world use of bamboo is more harmful to the nature than use of steel.

Table 2: Embodied energy and embodied Carbon values of some typical building materials

Material	Energy MJ / kg	Carbon kg CO_2/ kg	Density kg/m3
Aluminum (general & incl. 33% recycled)	155	8.24	2700
Stainless steel	56.7	6.15	7850
Copper (average incl. 37% recycled)	42	2.6	8600
Iron (general)	25	1.91	7870
Steel (general, av. recycled content)	20.1	1.37	7800
Plywood	15	1.07	540 – 700
Timber (general, excludes sequestration)	10	0.72	480 – 720
Medium-density fiber board	11	0.72	680 – 760
Bricks (common)	3	0.24	1700
Cement mortar (1:3)	1.33	0.208	
Concrete (1:1.5:3)	1.11	0.159	2400
Concrete block (Medium density)	0.67	0.073	1450
Aggregate	0.083	0.0048	2240

(a). In Constructing temporary bridges

(b). In temporary floating rafts due to its hollow stem

(c). In soil-cement pavement slabs

(d). In woven reinforcing mats for wall panel construction

(e). In Dendro power generation

(f). Cottage industries in manufacturing furniture and handicrafts

Figure 2 (a, b, c, d, e and f): Different applications of bamboo in various parts of the world

Another study by Janseen [17], indicates that it requires only 30 MJ/m^3 per N/mm^2 compared to concrete, steel and timber which require 240, 500 and 80 MJ/m^3 per N/mm^2, respectively

4.3 Different Applications of Bamboo

Figure 2 indicates some of the various applications of bamboo in different parts of the world. In Sri Lanka also studies can be found on bamboo as a suitable material for scaffoldings [18], [19]. Given its durability and strength, bamboo is an easily accessible, readily workable and extremely stable building material.

5. COST CALCULATIONS

Figure 3 indicates the relative costs of structural materials per one unit of stress carried according to D. Seward [20]. Our calculations also reveal that there is a remarkable saving of 60% in the use of bamboo instead of steel in reinforcing concrete.

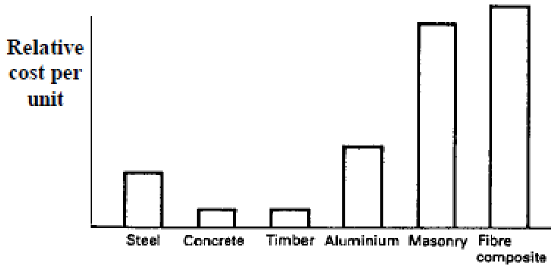

Figure 3: Relative costs of building materials

Since this is part of an ongoing research work, the same dimensions used in the testing specimens were used in cost calculations. For this a sample concrete beam of 225 x 225 x 1200 mm (H x W x L) was used. During the calculations and attention was paid to make sure that longitudinal and transverse bamboo reinforcement areas are 4 times that of the steel reinforcement areas [12]. Concrete grade of the beam is C30 and the bamboo type used is *"Green bamboo"*. Longitudinal reinforcement of from 10 mm diameter tor steel bars (T10) and the shear links are from 8 mm diameter mild steel (R8) bars.

6. CONCLUSION

The research presented in this paper is carried out in the form of a literature survey to assess the suitability of using bamboo strips as a low-cost and green alternative for steel reinforcement in light weight concrete beams. From the available literature on physical and mechanical properties of bamboo it can suggest that bamboo is no longer the "Poor man's timber" and it can be used confidently in structural applications as highlighted in this paper. Since this can also be promoted as an green and sustainable alternative material, this need further studies on local bamboo species. Therefore, further researches are needed in this area to promote and make people aware about the use of this material.

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