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Bamboo reinforced prefabricated wall panels for low cost housing

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ABSTRACT

With the increasing population there is a tremendous exploitation of natural resources to produce conventional building materials such as bricks, cement and reinforcing bars. This exponentially increases their prices and also deteriorates the environment by production of large amount of greenhouse gases. So, there is a need to develop cheap and sustainable infrastructure. This paper presents an alternative sustainable infrastructure component – prefabricated bamboo reinforced walls beneficial for low cost housing. To determine the potential of these panels in the construction industry, the strength analysis along with the cost estimation and environmental impact analysis were also carried out for these panels. It was observed that these walls are 56% lighter in weight, 40% cheaper and have good strength as compared to partition brick walls. The benefits of these walls over the traditional brick walls were observed to be significant, through which it can be concluded that these wall panels have a great potential for low cost housing.

1. Introduction

Even though the industrialization was started century ago, but still mankind is unable to provide shelter to all. Housing problem is at alarming level with millions worldwide without shelter especially in developing countries. As per the report of Ministry of Housing and Urban Poverty Alleviation, Government of India, the housing shortage in India itself was estimated as 18.78 million at the beginning of 12th Five Year Plan (2012–17) [1]. With the ever increasing population there is already a tremendous exploitation of natural resources, which has increased the price of conventional building materials substantially. Millions of people across the world are living below poverty line without proper shelter. This brings a lot of pressure on Government to provide cheap alternative solution to this group of people.

Beside this, the production of conventional building materials such as steel, cement and bricks involves high energy consumption and production of greenhouse gases which damages the environment. The average temperature worldwide has reached alarming levels causing the glaciers to melt and increase in the sea level. Due to which various coastal regions are at the verge of drowning underwater. Countries such as Maldives have already lost a large chunk of their land due to global warming [2]. In the UN climate change conference (Paris, 2015), it was decided to limit the temperature increase by 1.5 °C above pre-industrial levels which requires a lot of reduction in carbon dioxide emission into the atmosphere [3]. Thus there is a great need to look out for alternative materials for construction industry which should be cheap, sustainable, environmental friendly and must have satisfactory structural properties.

Number of studies has been undertaken to look out for such unconventional building materials. In the last few decades' number of materials such as kevlar, polyster, carbon fibers, metal alloys were looked upon as a building material [4]. However, the production of such materials is a complex process which cannot be manufactured at a village level from the locally available materials and technologies. To resolve the problem of housing shortage, which is predominant for the people living below poverty line, it is essential to develop building technologies which can be used at a village level from the locally available materials to construct the building components such as beams, columns, slabs and walls at a much cheaper cost than the traditional building materials. Also with the increasing population and shortage of land it is imperative to look for multi-storied structures and prefabricated technology is one of the best options for that.

In the present study, a new approach to develop one such building component – walls have been presented by the authors. These wall components are prefabricated, cheap, made from sustainable materials such as bamboo and fly ash and have a great potential in the construction industry.

2. Bamboo as an engineering material

Bamboo is a giant grass with more than 1200 species, some of them growing at a phenomenal growth rate of 91 cm per day as per the

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Table 1
Comparison of different properties between bamboo and steel [7].

Sl. No.	Property	Steel	Bamboo
1	Density (kg/m^3)	7850	(515–817) for different species in Green Condition (640–758) for different species in Air Dry Condition [8]
2	Modulus of Elasticity (N/mm^2)	2×10^5	(0.61–15.01)x10^3 for different species in Green Condition (3.77–21.41)x10^3 for different species in Air Dry Condition [8]
3	Grading for Structural Utilization	As per its Yield stress, ultimate tensile stress, elongation.	As per diameter, taper, straightness, inter nodal length, wall thickness, density and strength, durability and seasoning [8]
4	Compression Strength	Mild Steel - Compression in column bars:130 MPa	(25–100) [9] MPa
5	Tensile Strength	Mild Steel - Permissible stress in tension 140 MPa (upto 20 mm dia) 130 MPa (over 20 mm dia)	(100 – 400) [9] MPa
6	Bending Strength	0.66*yield stress	(70–300) [9] MPa
7	Factor of Safety (F.O.S)	1.15–Structural member for limit state of collapse	For safe working stresses of bamboo [8] 4–Extreme fiber stress in beams 4.5–Modulus of elasticity 3.5–Maximum compressive stress parallel to fibers
8.	Ratio of tensile strength (N/m^2) to specific weight (N/m^3)	5326	Six times greater than steel [4]

Guinness Book of world records [5]. Bamboo has a great economical advantage as it reaches to its full growth in few months [4] and is abundantly available in tropical and sub-tropical regions of the world. Production of every ton of bamboo consumes about a ton of atmospheric CO_2 in addition of releasing fresh oxygen in the atmosphere [6]. Bamboo is found to be about 50 times more energy efficient as compared to steel in terms of energy required to produce them [4]. Bamboo is pliable, lightweight, has excellent tensile strength and has a very good weight to strength ratio which makes it highly useful against high velocity winds and earthquakes. Table 1, discusses the comparison between steel and bamboo properties.

2.1. Bamboo in the construction

Performance of bamboo as a construction material was studied as early as 1914 by Prof. H.K. Chow [10]. In that study small diameter bamboo and bamboo splits were used as reinforcement material for concrete applications. However, elaborative research started only after 1950's with research projects on bamboo as reinforcement in concrete. The issues such as debonding of concrete, water absorption, fungus attacks, and coefficient of thermal expansion were predominant and not much further research was carried out. Later in 1995, Prof. K. Ghavami again started a number of mechanical tests using bamboo as reinforcement in concrete [11]. It was observed that bamboo considerably increased the load bearing capacity of the composite. Also, many researchers across the world have proven that bamboo can be considered as an alternative to steel as a tension element [4,6,9–13,15,16] due to its excellent tensile strength as compared to its weight.

2.2. Bamboo in walls

Walls usually occupy the largest area of a building and require large amount of construction material. Traditionally bricks are used in walls which increases the dead load of a building considerably and also further affect the seismic performance of the building. However, bricks increase the wall cost considerably and also causes land degradation by consuming the top fertile soil. When bamboos are cut into tiny strip and are woven, it enhances its tensile strength which makes it suitable for wall panels [4]. These bamboo strips based wall panels can provide an alternative to traditional brick walls.

Over the period of time, bamboo based walls are used in the rural regions where mud plaster is often used over a bamboo based grid. However, these walls are not durable for regions having heavy rainfall. Over the last few decades, researchers have proposed different improvements for such walls and have achieved significant performance of such structures. Dash et al. [14] have shown a scientific approach of constructing a bamboo reinforced concrete house which involves the bamboo frames made up with bamboo strips weaved inside and joined together with nuts and bolts and then plastered using cement mortar. However, such type of housing concept is not suitable for multi-storey structures.

Bamboo based walling system was developed by Vengala et al. [15] which was made from bamboo grids, bamboo columns and a steel wire mesh. It was concluded that such type of walls can sustain the most severe conditions likely to be experienced during the life span of the structure. Design of different types of bamboo based wall panels was discussed by Paudel [16] such as Quincha walls with bamboo poles, Grid wall system etc. The strengths, weaknesses, opportunities and threats of promoting bamboo for housing were also discussed. It was observed that bamboo is an excellent building material suitable for different economic groups as it offers a range of building options. Bamboo walls provide good thermal comfort compared to modern concrete as discussed by Dash et al. [14]. Indian Plywood Industries Research and Training Institute (IPIRTI) have developed a two story house using bamboo at Bangalore. The house has split bamboo grid and wire mesh plastered with cement mortar as walls and bamboo columns providing the support and the ceiling was made up of light bamboo mat used with corrugated sheets. These types of houses are suitable for earthquake prone areas as discussed in the study. Widyowijatnoko [17] developed a low cost house using prefabricated bamboo reinforced components consisting of bamboo reinforced concrete partition wall panel of size 4×30×110 (cm^3), bamboo reinforced formwork panel, bamboo reinforced door-window frame and steel reinforced concrete tie beam. Study observed that the properties of bamboo are excellent as compared to that of steel. It was also observed that the bamboo reinforcement improves the tensile strength of prefabricated panels [17].

3. Development of a prefabricated bamboo reinforced wall panel

Residential multi-storey buildings usually have the ceiling height at 3000–3600 mm. Frame structures are usually preferred for such structures with walls acting as partition walls that are built at a later stage. Thus to test the feasibility of proposed alternative partition wall a 50 mm thick prefabricated panel 2440 mm long, 300 mm wide has been developed. The sizes of such prefabricated panels can be varied based on the requirements.