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Use of Bamboo as Reinforcement Material

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ABSTRACT

Access to hygienic sanitation facilities remains a major challenge in developing nations, particularly in rural areas, slums, and temporary settlements. Conventional toilets require permanent construction, high costs, and long installation time, making them unsuitable for rapid deployment. This paper presents the design and development of a ferrocement detachable toilet unit as a cost-effective, durable, and portable sanitation solution. The unit is fabricated using thin ferrocement panels reinforced with wire mesh, which are lightweight yet strong. The system is designed for easy assembly, disassembly, and relocation, making it highly suitable for construction sites, disaster relief camps, and rural sanitation programs. The study highlights the design methodology, material selection, structural performance, cost-effectiveness, and future applications of this innovation.

Keywords: *Ferrocement, Sanitation, Portable Toilets, Detachable Units.*

1. INTRODUCTION

Use of Bamboo as Reinforcement Material. In recent years, there has been a growing interest in sustainable and eco-friendly alternatives to conventional construction materials. One such promising material is bamboo, a fast-growing and renewable natural resource. Traditionally used in construction across many parts of Asia, Africa, and Latin America, bamboo is now being explored as a reinforcement material in concrete structures, offering an environmentally friendly substitute for steel reinforcement. Bamboo possesses several mechanical properties that make it suitable for structural applications. It has a high strengthto-weight ratio, good flexibility, and excellent tensile strength, which makes it comparable to mild steel in certain applications. Moreover, its natural abundance, low cost, and carbon-sequestering properties make it an attractive material for green building initiatives. However, the use of bamboo as a reinforcement material also presents challenges, such as its susceptibility to moisture, decay, and insect attacks, as well as variability in strength due to natural growth conditions. To overcome these issues, treatment methods and protective coatings are being researched and developed to enhance bamboo's durability and compatibility with concrete. This shift toward sustainable construction practices positions bamboo not only as a traditional building material but also as a modern alternative to steel reinforcement, especially in low-cost housing and rural infrastructure in developing regions.

2. LITERATURE REVIEW

Bamboo has been widely studied as a sustainable alternative to steel reinforcement in concrete structures. A recent systematic literature review conducted in 2025 analyzed approximately 48 research papers along with relevant Indian Standard codes to evaluate the feasibility of bamboo as a structural reinforcement material. The study identified several commonly investigated bamboo species, including *Bambusa balcooa*, *Bambusa vulgaris*, and *Dendrocalamus asper*. These species are preferred due to their availability, mechanical strength, and suitability for structural applications. The review reported that bamboo exhibits an average tensile strength of about 118.58 MPa and an average modulus of elasticity of approximately 15.53 GPa when used in concrete reinforcement. Additionally, the use of bamboo instead of steel reinforcement can lead to significant economic and environmental benefits, including an estimated cost reduction of about 36.78% and lower carbon emissions due to the renewable nature of bamboo.

Several experimental studies have investigated the mechanical behaviour of bamboo reinforced concrete in structural members such as beams, columns, and joints. Research on bamboo reinforced concrete beams (BRCB) has shown promising load-bearing capacity when subjected to flexural loads. Concrete beams reinforced with longitudinal bamboo poles have demonstrated structural behaviour comparable to certain steel-reinforced concrete beams under controlled conditions.

Flexural behaviour studies also indicate that bamboo bars can be used as both main reinforcement and shear reinforcement (stirrups). In such cases, parameters such as load–deflection relationships and failure patterns can be predicted using conventional section analysis, provided that the lower modulus of elasticity and possible bond-slip characteristics of bamboo are considered in the design.

Studies on columns and beam-column joints have also highlighted the potential advantages of bamboo reinforcement. The use of treated bamboo in beam- column joints has been found to improve bond strength and structural performance. For example, applying coatings such as epoxy or other protective treatments helps enhance bonding between bamboo and concrete. Furthermore, research has shown that bamboo columns containing natural nodes (knots) exhibit higher strength and stiffness compared to smooth or non-knotted bamboo elements, as the nodes act as natural reinforcement points.

Despite its advantages, durability remains one of the major challenges associated with bamboo reinforcement. Bamboo has a natural tendency to absorb moisture from the concrete mixture and surrounding environment, which can cause swelling, shrinkage, fungal attacks, insect infestation, and long- term degradation. These factors may reduce the bond strength between bamboo and concrete and can eventually lead to structural failure if not properly treated. To address these issues, several treatment methods have been studied, including chemical treatments such as borax-boric acid solutions and alkali treatments. In addition, surface coatings such as epoxy resin, Sikadur gel, and waterproof protective coatings are commonly applied to improve moisture resistance and durability.

Bond behaviour between bamboo and concrete has also been investigated through pull-out tests. These studies generally show that bamboo exhibits lower bond strength with concrete compared to steel reinforcement or fiber reinforced polymer (FRP) bars. However, researchers have found that certain surface modifications, including grooving the bamboo surface, applying protective coatings, wrapping bamboo with wires, or adding mechanical textures, can significantly improve the bond performance between bamboo and concrete.

3. METHODOLOGY

3.1 Objective of the Study

The objective of this study is to evaluate the mechanical performance and structural feasibility of using treated bamboo as reinforcement in concrete structural members such as beams, slabs, or columns. The study aims to investigate whether bamboo can act as a viable alternative to conventional steel reinforcement by analyzing its strength, bonding behaviour, and durability within concrete. Furthermore, the performance of bamboo reinforced concrete is compared with conventional steel reinforced concrete under similar loading and environmental conditions to assess its suitability for sustainable and low-cost construction.

3.2 Materials Selection and Procurement

The selection of suitable materials plays an important role in ensuring the reliability of bamboo reinforced concrete. Locally available bamboo species such as *Bambusa balcooa* and *Dendrocalamus strictus* are selected for this study because of their relatively high strength and availability. Mature bamboo culms with an age of approximately 3 to 5 years are chosen to ensure adequate mechanical properties. The selected bamboo should have a consistent outer diameter, wall thickness, and minimal defects such as cracks or insect damage. Before use, the physical properties of bamboo including length, outer diameter, wall thickness, and moisture content are recorded.

For the preparation of concrete, Ordinary Portland Cement (OPC) of grade 43 or 53 is used as the binding material. Fine aggregate consists of clean river sand conforming to the requirements of Indian Standard IS 383. Coarse aggregate of nominal size 20 am is used to provide adequate strength and stability to the concrete mix. Potable water free from harmful impurities is used for both mixing and curing of concrete to ensure proper hydration of cement and durability of the concrete structure.

3.3 Bamboo Treatment Process

Untreated bamboo tends to degrade rapidly when embedded in concrete due to moisture absorption, biological attack, and dimensional changes. Therefore, proper treatment of bamboo is necessary to improve its durability and bonding characteristics with concrete.

3.3.1 Surface Preparation

The bamboo culms are first cut into the required sizes according to the design of the structural member, such as longitudinal bars for beams and stirrups for shear reinforcement. The outer waxy layer present on the bamboo surface is carefully removed to enhance bonding with the surrounding concrete. The surface is then smoothed and cleaned to remove dust and impurities.

3.3.2 Preservative Treatment

After surface preparation, bamboo is subjected to chemical treatment to increase its resistance to biological degradation and improve bonding characteristics. One common method is soaking the bamboo in a borax–boric acid solution in a ratio of 3:2 for a period of 7 to 14 days. This treatment helps protect the bamboo against insect and fungal attacks. Alternatively, an alkaline treatment using a sodium hydroxide (NaOH) solution with a concentration of about 1–2% for approximately 24 hours can be applied. This process reduces the starch content present in bamboo, thereby minimizing the risk of insect attack and improving surface roughness for better adhesion with concrete.

3.3.3 Surface Coating

After chemical treatment, a protective coating is applied to the bamboo surface to reduce water absorption from the concrete mix and surrounding environment. Coating materials such as epoxy resin, bitumen, or polyurethane are commonly used for this purpose. To further enhance the bond strength between bamboo and concrete, the treated bamboo may be wrapped with sand or jute fibers before applying the coating. Finally, the treated bamboo is air-dried for about 7 to 14 days until the moisture content reduces to approximately below 20%, ensuring dimensional stability and better performance when used as reinforcement in concrete.

3.4 Design of Bamboo Reinforced Beam

The design of the bamboo reinforced concrete beam is carried out by considering the mechanical properties of bamboo and conventional reinforced concrete design principles. Since the modulus of elasticity and tensile strength of bamboo are lower than steel, appropriate modifications are made during the design process. The bamboo bars are used as longitudinal reinforcement in the tension zone of the beam, while smaller bamboo pieces or split bamboo strips are used as stirrups for shear reinforcement.

The beam dimensions are selected based on laboratory testing convenience, commonly around 100 mm × 150 mm cross-section with a length of about 700–1000 mm. The bamboo reinforcement is arranged in a similar configuration to steel reinforcement, maintaining adequate concrete cover to protect the bamboo from moisture exposure and environmental effects. Proper spacing between reinforcement bars is maintained to ensure uniform concrete placement and proper bonding.

3.5 Casting of Specimens

After preparing the reinforcement cage using treated bamboo bars and stirrups, the beam moulds are prepared using steel or wooden formwork. The moulds are cleaned and lightly oiled to facilitate easy removal after casting. The bamboo reinforcement cage is then placed inside the mould with proper cover blocks to maintain the required concrete cover. Concrete is prepared according to the selected mix proportion, typically using a standard mix such as M20 grade concrete. The concrete is poured into the mould in layers and compacted properly using a tamping rod or mechanical vibrator to eliminate air voids and ensure uniform distribution of materials. The surface of the beam is finished smoothly, and the specimens are kept undisturbed for approximately 24 hours before demoulding.

3.6 Curing Process

After 24 hours of casting, the beam specimens are carefully removed from the moulds and transferred to a curing tank containing clean water. The specimens are cured for a period of 7 to 28 days to allow proper hydration of cement and to achieve the desired strength. Continuous curing is important to improve the strength and durability of concrete as well as to ensure good bonding between the bamboo reinforcement and the surrounding concrete. During curing, the specimens are kept fully submerged in water to maintain consistent moisture conditions.

3.7 Testing Procedure (Flexural Test / Load Test)

After the curing period is completed, the bamboo reinforced concrete beams are tested for flexural strength using a Universal Testing Machine (UTM) or a beam testing setup. The beam is placed on two supports to create a simply supported condition, and load is applied at the center or at two points depending on the selected testing method. The load is applied gradually until the beam fails. During the test, observations such as first crack load, ultimate load, crack pattern, and deflection are recorded. The load- deflection behavior of the bamboo reinforced beam is analyzed and compared with conventional reinforced concrete beams to evaluate its structural performance.

3.8 Data Analysis

The data obtained from the flexural tests are analyzed to determine the structural behavior of bamboo reinforced concrete beams. Parameters such as ultimate load carrying capacity, flexural strength, and deflection characteristics are calculated and recorded. The results are presented in the form of tables and graphs to clearly understand the performance of bamboo reinforcement. The experimental results are then compared with conventional steel reinforced concrete beams to assess the feasibility of using bamboo as an alternative reinforcement material. Based on the analysis, conclusions are drawn regarding the strength, durability, and practical applicability of bamboo reinforced concrete in sustainable construction.

4. APPLICATION

Portable sanitation systems have a wide range of practical applications in different environments where permanent sanitation facilities are not available. At construction sites, these units can be used to provide temporary sanitation facilities for workers, ensuring better hygiene and health conditions during the project duration. In disaster relief camps established after natural disasters such as floods, earthquakes, or cyclones, portable sanitation units can be rapidly deployed to provide immediate sanitation support to affected populations.

These systems are also highly beneficial in rural villages where infrastructure development is limited and access to proper sanitation facilities is often inadequate. In urban slums, portable community toilets can help reduce open defecation and improve public health conditions. Additionally, highway rest stops can benefit from easy-to-install sanitation facilities that provide travelers with convenient and hygienic toilet services without requiring complex construction.

5. FUTURE SCOPE

The concept of portable sanitation systems has significant potential for further development and improvement. In the future, these systems can be integrated with bio-digester tanks to enable eco- friendly waste treatment and reduce environmental pollution. The addition of solar-powered lighting and ventilation fans can improve usability, especially in areas with limited electricity supply.

Furthermore, smart monitoring systems can be incorporated to track usage levels, water availability, and maintenance requirements, which would help ensure proper functioning and timely servicing. With support from government agencies and non- governmental organizations, large-scale mass production and deployment of these portable sanitation systems can significantly improve sanitation access in underserved communities and disaster-prone regions.

6. CONCLUSION

This study highlights the potential of bamboo as a sustainable and cost-effective alternative to conventional steel reinforcement in concrete structures. The investigation focused on the selection of suitable bamboo species, proper treatment methods, and the design and testing of bamboo reinforced concrete beams. The results from various studies indicate that bamboo possesses good tensile strength and adequate mechanical properties that make it suitable for use as reinforcement in certain structural applications, particularly in low-cost and rural construction.

The treatment of bamboo using chemical preservatives and protective coatings plays a crucial role in improving its durability, resistance to moisture, and bonding with concrete. Properly treated bamboo reinforcement can enhance the performance of concrete members by providing sufficient load- carrying capacity under flexural loads. Although bamboo generally has lower bond strength and modulus of elasticity compared to steel, appropriate surface modifications and design considerations can significantly improve its structural performance. Overall, bamboo reinforced concrete presents an environmentally friendly and economical solution, especially in regions where bamboo is readily available and construction resources are limited. With further research, improved treatment techniques, and standardized design guidelines, bamboo reinforcement has the potential to become a viable material for sustainable construction practices in the future.

7. RESULT

Curing age	Approximate strength (MPa/N/mm^2)	% of 28-day of strength
7 Days	~13.53 MPa	65% - 70%
14 Days	~19.63 MPa	85% - 90%
28 Days	~26.46 MPa	99% - 100%

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