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Bond-behavior study of newly developed bamboo-composite reinforcement in concrete

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HIGHLIGHTS

- Application of newly developed bamboo-composite material in concrete.
- Bamboo composite material can serve as reinforcement in concrete.
- Bamboo-composite reinforcement can develop adequate bonding with concrete matrix.
- Epoxy-based coating with sand particles could provide extra protection.
- The new bamboo-composite reinforcement could replace steel reinforcement.

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ABSTRACT

Bamboo is a rapid growing, affordable and available natural resource in many developing countries. It is potentially superior to timber and to construction steel in terms of its weight to strength ratio. A new technology has been developed in this research to preserve the mechanical properties of bamboo and to enhance physical characteristics through composite action for application in structural concrete. The goal of present work is to investigate the bonding properties of a newly developed bamboo-composite reinforcement in concrete through pull-out testing. Various coatings are applied to determine bonding behavior between concrete and newly developed bamboo-composite reinforcement. The results of this study demonstrate that bamboo-composite reinforcement without coating develops adequate bonding with the concrete matrix. However an epoxy based coating with sand particles could provide extra protection without loss of bond strength.

1. Introduction

Today, the world is facing the highest population growth rate it has ever experienced. With it, enormous urbanization rates are reported, especially in developing territories. To satisfy the immense demand for construction materials, the traditional understanding on how to build shelter and infrastructure is no longer sufficient. Either materials are finite or they are not available in the locations where they are needed. For instance only two out of 54 African nations produce steel in notable quantities. Using steel as reinforcement has disadvantages. High costs of production, lack of renewability and corrosion in concrete are disadvantages that are usually associated with using steel reinforcement. New strategies favor cultivating required materials instead of mining them. Proposals are emerging to replace steel with renewable, low-cost and sustainable forms of reinforcement that can be found locally. Organic materials such as jute, sisal, coconut coir and date palm are among some of the alternatives that have been used to replace steel. However, the tensile capacity of these materials is often too low when compared with steel [1–4].

Among possible alternative materials, bamboo is an organic alternative which grows in the tropical zones, an area that coincides closely with the developing countries where the highest rates of urbanization and population growth can be found. Bamboo is gaining attention as an alternative for steel since most developing countries could benefit economically by its use in construction. It could strengthen local value chains, bring jobs and trade as well

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as lower dependency on international markets through meeting construction demands locally. From technical perspective, bamboo is a fast growing grass, which can grow up to one meter a day and can reach its maximum strength in 3 years. Some species of bamboo have shown tensile capacities of more than 400 MPa and single bamboo fibres can reach a tensile strength as high as 1000 MPa [5–8].

Several studies have been carried out on the use of raw bamboo as reinforcing material to replace conventional steel. In 1950, Glenn conducted research into using natural raw bamboo as reinforcement in concrete structures [9]. Using small diameter culms and bamboo splits, he demonstrated that although the application is feasible in principle, there were disadvantages regarding insect and fungus attacks, shrinking and swelling.

Ghavami has undertaken more recent work in this field. He completed a series of mechanical tests on several species of bamboo in order to find the most appropriate for use as reinforcement in lightweight concrete beams [10,11]. Concrete beams with raw bamboo as reinforcement showed an increase in the ultimate-load behavior compared to beams reinforced with steel bars [11]. Nevertheless, the long-term durability of bamboo in concrete beams was not studied.

Terai and Mianmi studied use of raw bamboo as reinforcement in concrete beams and columns [12]. They found a similar fracture behavior to steel-reinforced-concrete beams and columns. Although several other studies involved use of natural raw bamboo to replace steel reinforcement in concrete walls, beams and slabs none addressed the challenges related to durability of raw bamboo reinforcement [13,14].

Lima Junior et al. used bamboo culms filled with concrete as structural column. The ultimate load capacity of the column was 50% lower than that of a column made only with bamboo culm [15]. Long-term durability and bonding behavior of the culm in the concrete matrix were not discussed.

The difficulty associated with durability of raw bamboo is that it absorbs water from the surrounding environment through fine cracks in concrete. This results in swelling of the bamboo. Swelling occurs when there is sufficient time for water to reach the bamboo before the concrete cures. It is then absorbed by the bamboo microstructure, which induces an expansion of the bamboo reinforcement and promotes internal local stress in the concrete surrounding the bamboo. Over a long period of time, the consequences are brittle splitting failure in concrete can result in sudden collapse. Fig. 1 shows the swelling problems associated with using raw bamboo in concrete.

In addition to water absorption of raw bamboo, chemical decomposition of the bamboo fibres, accelerated by the alkaline environment of the concrete matrix, is another reason for the loss of mechanical properties of raw bamboo over time. Pacheco-Torgal & Jalali reviewed the works on natural fibre degradation in cementitious matrix and concluded that chemical decomposition is due to the high alkaline environment which dissolves the lignin and hemicellulose phases, thus weakening the fibre structure [16].

To overcome these issues, researchers investigated methods to control the mechanical properties and physical behavior of bamboo. One of these methods was treatment of raw bamboo with various types of coating. This method has been investigated for many years by many researchers, from the early stages of research into use of raw bamboo in construction [17–21].

Coatings such as water-based paints or bitumen were used to prevent the water ingress to bamboo reinforcement in concrete. Unfortunately, such coatings only last for the first few years of service. They are sensitive to damage due to improper handling. Studies on the long-term durability and feasibility of such coatings are not available.

Bonding between bamboo and concrete is another important factor, especially when there is loading on the concrete member. The bond between reinforcement bars and concrete matrix is developed principally through main mechanisms; adhesion to the concrete matrix; development of residual compressive stress due to concrete shrinkage at the interface of reinforcement and concrete; and friction due to surface roughness of reinforcement bars. Bonding establishes a shear resistance at the concrete matrix interface with reinforcement. Ghavami studied bonding properties of treated and untreated raw bamboo splits in concrete [11]. The study showed that a two-component epoxy resin coating enhances the bonding of raw bamboo reinforcement up to 5 times compared with uncoated bamboo and steel.

To overcome the problems related to the use of raw bamboo reinforcement, such as swelling and chemical decomposition, a new class of materials, called natural fibre composites is under development. Advantages of natural fibre composites over their traditional synthetic fibre composites include their abundance, renewability, and low production costs. This research focuses on the application of newly developed bamboo-fibre-reinforced composite materials to replace conventional steel reinforcement in structural concrete.

In this study, bamboo fibres are first obtained by processing entire bamboo culms. The fibres are then added to a two-component epoxy resin system and then pressed into high tensile strength composite materials using a hot-press fabrication technology. The process yields a bamboo composite material which is densely compressed. The newly developed bamboo-composite materials are cut into different sizes for the use in concrete as reinforcement.

Preliminary physical and mechanical tests have been carried out to evaluate the suitability of bamboo-composite materials for concrete reinforcement. The key factor for implementation is the bonding of reinforcement bars to concrete. Adequate bonding between bamboo-composite reinforcements and the concrete matrix ensures a stable load transfer between the two materials.

To understand the bonding behavior of the newly developed bamboo-composite reinforcement in concrete, series of pull-out tests were carried out to find a suitable technique to enhance the bonding between concrete matrix and bamboo-composite reinforcement.

Several types of coating were applied on the surface of the bamboo-composite reinforcements to investigate bonding behavior with concrete matrix. The coatings and their chemical composition are discussed in experimental procedures. Normal

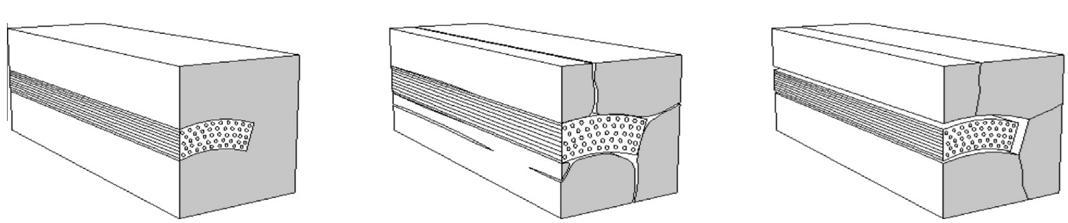

Fig. 1. Swelling of raw bamboo reinforcement in concrete and the micro cracks followed by the expansion of raw bamboo.