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RESEARCH ARTICLE

ASSESSMENT OF INTERFACIAL BONDING STRENGTH OF BAMBOO AS REINFORCEMENT IN CONCRETE: A STATE-OF-THE-ART

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ABSTRACT

The rising cost of iron and steel production and its concomitant damage to the ecosystem has become a major challenge for estate developers and governments in many of the developing African nations' especially, Nigeria, as they struggle with infrastructure development and delivery to their citizens. To address this challenge, replacing steel with bamboo as reinforcement is considered. The paper reviewed previous studies on bamboo reinforced concrete technology with a view to reducing the over-dependence on steel, carbon emission challenges in the region and achieve better environment at reduced cost. The study revealed major challenges in the behaviour of bamboo at elevated temperatures or in fire conditions is unknown and the possible week bond likely to exist between the bamboo - concrete interface in a bamboo reinforced concrete composite.

Keywords: *Interfacial Bonding Strength; Bamboo; Reinforcement in Concrete*

Introduction

In recent years, the prices of steel have soared and has become unaffordable globally as a result of skyrocketing prices which in turn, is driven by the high cost of energy demand for its production. As a consequence, the currently, usage of steel is heavily limited. Steel production demands high fossil fuels consumption, so, the steel discharge in the construction of structures has been presented, showing the possibility of drastic reduction by researchers (Masakazu, T and Koichi, M 2012). Also, the environmental destruction such as air and water pollution has become a major challenge due to the rapid development and production of steel from ferrous materials. For developing economies such as Nigeria, it is important to keep infrastructure delivery at affordable cost by replacing sophisticated technologies with a reliable traditional construction method available locally. To this end, the bamboo materials is reviewed.

Statement of the Problem

Due to increase in the use of bamboo especially as reinforcement in concrete which is proven to have a great tensile strength (resistance to being pulled apart) than steel and it can withstand compression better than concrete, the bamboo has previously failed under load due to weak bond between the surface bamboo and concrete (Ghavami, 2005). It absorbs the water from the concrete and cause bamboo bars to expand inside the concrete. Upon the loss of moisture, the bamboo strips shrink and lose bond with the concrete matrix. The smooth condition of the bamboo surface is liable to reduce friction on bamboo – concrete interfaces which allows the bamboo to slip without developing a strong bond. Puri (2019) investigated bamboo and observed that the bamboo splints coming out from embedded mortar specimens failed due to their deterioration during curing. These findings require the modification of standard test guidelines. Several issues such as shrinkage, water absorption, species type, etc. affect the bamboo performance in cement composites. Raw bamboo absorb moisture from the concrete and also from the environment through pores and micro cracks in concrete. This results in swelling of bamboo inducing internal local stress degrading the surrounding concrete, shrinkage of bamboo also occurs with a reduction in moisture content leading to voids creation. Due to this continuous cycle of swelling and shrinkage of bamboo, the proper bond cannot be formed between bamboo and concrete and creates a serious limitation to its use as a reinforcement in place of steel. To achieve high surface bonding strength which will result in removal of these limitations, underscores the aim of this research.

Aim and Objectives

This research aims at investigating the interfacial bonding strength of bamboo as reinforcement in concrete.

Objectives:

1. To characterize the properties of bamboo
2. To determine the effect of moisture on bamboo in concrete surrounding
3. To examine the components of pull-out test in determining the bond strength of bamboo in concrete.
4. To determine bamboo treatment for the reduction of moisture penetration.

Research Questions

1. What are the characteristic properties of bamboo?
2. What is the effect of moisture on bamboo in concrete surrounding?
3. Does the component of pull-out test help in determining the bond strength of bamboo in concrete?
4. What is the bamboo treatment for the reduction of moisture penetration?

Significance of the Study

This research is significant because its findings and accompanying recommendations shall be invaluable to categories of individuals, bodies, organizations (both government and non-governmental), organizations and the society in general:

i. The research will fill some gaps in the knowledge of the influences of bamboo as reinforcement bars in concrete and help strengthen the teachings of material selection, behavior and properties of materials in the built environment.
ii. It will be of importance to policy makers, legislature and decision makers at all levels of governance in Nigeria and in the local building authorities. Also, to manufacturers of building materials, entrepreneurs for wealth creation by venturing into production and identification of bamboo species needed as reinforcement in concrete. It is hoped that in the end, it will chart a course in lowering construction cost in Nigeria.
iii. It will be of utmost importance to the built environment by reducing the demand for iron and steel which in turn, will reduce the impact of steel production in the emission of gases contributing to global warming.
iv. Finally, it will be of importance to professional bodies in the built environment like the Nigeria Institute of Architects (NIA) among others in their development of codes of practices.

Literature

Bamboo is one of the fastest growing plants and has good viability. It has been used in constructions for thousands of years in Asia and other parts of the world and takes little energy to harvest and transport. It also has low manufacturing costs compared to steel and is therefore expected to be used widely in countries and regions that have no advanced manufacturing technology and construction techniques. The use of such renewable resources by the construction industry will help to achieve a more sustainable pattern of consumption of building materials. The research and investigations reported in International Network for Bamboo & Rattan (INBAR 2002), revealed the advantages of using bamboo as a construction material as: its ecological value, its competitive mechanical properties, and its social and economic value and low energy consumption.

However, bamboo itself, has an inherent shortcoming. The problem with bamboo as a reinforcing material in reinforced concrete structures is the weak surface bond between the bamboo and concrete. The assumption that the perfect bond exists in the design of bamboo-reinforced concrete becomes unrealistic due to the weak bamboo-concrete bond (Puri V. (2019).

Alireza, Mateusz, Ian and Dirk (2016), Pankaj and Debarati (2019) and Nindyawati and Baiq (2016) have all improved the bamboo–concrete bond, but it is unclear how these improvements can affect bamboo-reinforced concrete structures' behavior. Previous researchers have summarized that the structures failed under low loads due to poor bamboo–concrete bonds (Ghavami, 2005), which can be attributed to two factors. First, the bamboo strips absorb the water from the concrete and cause bamboo bars to expand within the concrete matrix. Upon loss of moisture, the strips shrink and lose contact with the concrete surface. Second, the smooth condition of the bamboo surface that can minimize friction allows the bamboo strips to slip without developing a strong bond.

Harish, Vamsi and Ramana (2012) carried out investigations on the Moso type of Bamboo to find out its tensile stress, compressive stress, modulus of elasticity, water absorption capacity, shear stress and bonding stress. They concluded that the nodes of the bamboo pose ductile behavior. They also found out that compressive strength of the bamboo is parallel to its tensile strength and the behavior is same as that of steel. Since bamboo absorbs water, it would have to be waterproofed.

Nithi and Nicholas (2011) focused on how to achieve the highest strength of bamboo reinforced concrete in their project titled Materials characterization of bamboo and analysis of bonding strength and internal strength as a structural member in reinforced concrete, presented at California Polytechnic State University, San Luis Obispo. Both concluded that the pull-out strength of bamboo is about 30% of steel but can be improve with coating and surface roughness or by wrapping or surface abrading the bamboo.

In Nigeria, bamboo is considered a suitable material for structural applications. The use of bamboo ranges from scaffolding, structural support, as reinforcement in thatched buildings and building of fences among others. Its acceptability has grown over the past few years due to its affordability (Ghavami, 2005)

The rural-urban migration of people from village areas to urban cities have resulted in huge housing shortage in cities. Such a huge population growth rate causes tremendous demand for housing leading to the exploitation of conventional natural resources such as iron ore required for producing steel reinforcement. Further, the production of these conventional materials is also detrimental to the environment due to the production of a large amount of greenhouse gases. Steel production causes an environmental impact by emitting gases such as Carbon monoxide (CO), Sulphur oxide (SO_X), Nitrogen oxide (NO_X), and Particulate matter (PM_2), primarily being the carbon dioxide gas. Apart from these it also produces wastewater contaminants, hazardous wastes and solid wastes which poses a threat to the environment. Further with increased demand, the costs of steel risen significantly over the years. This hinders its application for low-cost housing (Pacheco-Torgal, F. and Labrincha, J.A, 2013).

Bamboo is one such sustainable building material which has higher than six times the strength to weight ratio comparable with steel (Ghavami, 2005). The amount of CO_2 emission in the atmosphere in case of bamboo is 50 times less as compared to steel and cement. Furthermore, bamboo consumes around 1 tonne of carbon dioxide during its growth phase (Xiao, Yang & Shan 2013), (Sharma, Gatoo, Bock, Mulligan & Ramage 2014). However, there are different issues such as properties variation across species, bond strength development in concrete, treatment processes involved in the application of bamboo in the form of reinforcement in concrete.

The proposition of its widespread use as a sustainable alternative to steel in reinforced concrete structures, poses key questions to architects, builders, engineers and researchers with regards to its bonding strength, as well as constructability and sustainability issues, (INBAR, 2002). This research therefore assesses the interfacial bonding strength of bamboo as reinforcement in concrete for use in building construction to reduce steel-carbon issues, cost issues and promote green construction.

Global Concepts on Bamboo as Reinforcement in Concrete

Earlier studies indicate that the use of bamboo as a reinforcement in concrete structures dates back a century in Southeast Asia (Chow, 1914). Early experimental studies on bamboo-reinforced concrete were conducted at Massachusetts Institute of Technology by (Chow, 1914), in Germany by (Datta, 1936), Italy by (Simone, 1939), the United States by (Glenn, 1950), (Smith and Saucier, 1964) and Colombia by (Hidalgo, 1974). These studies used either bamboo bars (whole-culms of small diameter) or splints (semi-round strips). Much early interest in bamboo-reinforced concrete was attributed to the US Navy and their interest in rapid re-construction in Southeast Asia following the Second World War. Research conducted by Glenn (1950) on bamboo-reinforced concrete, financed by the US War Production Board, included mechanical tests and the construction of experimental buildings. Glenn produced a set of conclusions from the test results obtained, as well as design and construction principles for the use of bamboo canes and splints as reinforcement in concrete. Glen, 1950 observations include:

I. High deflection, low ductility and early brittle failure of the bamboo reinforced concrete beams under load;
II. Reduced ultimate load capacity when compared to steel-reinforced elements;
III. Bonding issues associated with excessive cracking and swelling of bamboo fibres; and
IV. The need for using asphalt emulsions.

Glenn (1950) advised use of a bamboo tensile stress of 34 - 41 Mega Pascal (MPa) based on maximum stress values of 55 - 69 MPa for concrete beams with 3 - 4% bamboo reinforcement. Finally, Glenn is recommended an allowable bamboo tensile stress between 20 and 28 MPa for reinforced elements in order to keep the deflection of the beam below 1/360 of the span.

A closer look at the situation suggests that as the world population is increasing, so is the increase in the demanding for construction materials for shelter and other infrastructure. This incremental demand for materials equally and directly affects the prices of material with a corresponding pressure on the immediate environment. To this end, Pacheco-Torgal and Labrincha (2013), expressed that the importance of environmentally sustainable and costeffective materials can best be understood by the fact that construction industry consumes up to 50% of all raw materials.

Although bamboo prices may vary wildly across regions, it is still much cheaper compared to steel. The drivers of this variation include amongst others as haulage costs, the bamboo quality, culm sizes and specie. For instance, in Laos, the cost of raw bamboo can be as low as $12 per ton (World Agroforestry Centre, 2006) whereas in Nigeria, it is less than $8 per ton depending on the haulage distance and handling. Major opinion in favour of bamboo use as reinforcement in concrete is, its sustainability and low carbon footprint relative to steel. Ferrous minerals, the principal raw material for steel, is one of the most abundant earth minerals. For extraction to be considered economically viable, the ore has to contain up to 25% iron. With discoveries of new deposits with higher iron content and advances in iron and steel technology, possibility for higher yield may result. For example, electric arc furnaces are replacing the less efficient basic oxygen furnaces (USGS, 2019).

Nonetheless, as the most iron-rich deposits are depleted, the prices of steel and the energy required to process it will also increase. This informs that steel and its production processes will have increasingly worse environmental credentials.

In addition, the global demand for iron and steel production is increasing. It rose from 274 million tonnes in 1950 to 1554 million tonnes in 2005. According to the U.S. Geological Survey (USGS, 2015), Iron ore production in 2014 was 3220 million tonnes, Yellishetty, Ranjith and Tharumarajah, (2010) estimated that the currently viable worldwide reserves of 230 billion tonnes would last for about 50 years and that the global annual carbon dioxide (CO_2) emissions from various manufacturing steel plants will be 3169 million tonnes by 2020. In addition to the high environmental cost of mining and processing iron ore, its haulage generates significant emissions. Some of the top steel-producing countries like Japan has no iron reserves of its own while Brazil exports 90% of its mined iron ore.

Bamboo is rapidly renewable and has a low carbon footprint. Bamboo is harvested ideally at the age of three to four years while wood takes decades to mature. Bamboo improves the climate through photosynthesis (photosynthesis produces Oxygen and consumes CO2) (Khatib, 2009), and sequesters more carbon per hectare relative to trees (Lobovikov, Schoene and Yping, 2012). Researchers have suggested that subsidising the cultivation of bamboo can help in greater carbon sequestration (Wu, Liu, Zhu, and Shen, 2015).

Khatib (2009) opined that cultivating bamboo can have additional localized benefits. For example, the root system of bamboo is highly invaluable in erosion and flooding prevent.

Concepts on Bamboo as Reinforcement in Concrete in Nigeria

Bamboo utilisation in Nigeria include its use for fencing, scaffolding and other temporary works. Its culms are used for temporary support for suspended floor construction (referred to as decking in Nigeria). In rural area where bamboo is mostly used especially in Cross River and Akwa Ibom states, bamboo is used to give body and reinforce clay wall construction in mud house building, where the bamboo culms are used as frames to provide skeleton for the building (RMRDC, 2004).

Figure 1: Bamboo used as scaffolding and a roofing element and structural base in mud house.

Bamboo is a biodegradable plant with great renewable and sustainability potentials to produce a different end product (Akwade, Akinlabi, 2016). Nigeria has high possibilities in bamboo cultivation since the nation has a reasonable landscape with a total land area of 923,763 km^2. From literature, it is notable that Nigeria's climatic condition is suitable for bamboo cultivation. However, there is no policy for the commercialization of the harvested bamboo, (Hassan and Ayodeji, 2019). For successful bamboo cultivation, the nation needs to put in place enough available land for the bamboo farming process, superior technology, and create a suitable marketing medium since bamboo products are locally and internationally sought. (Selvan &Tripathi, 2017).

According to Hassan (2019), the bamboo industry can earn Nigeria economic over $22 billion annually" if the Nigerian government gives useful attention to its cultivation. Studies on bamboo transformation into multiple products, bamboo cultivation in Nigeria can generate a lot more to the national economy, (Partey, et al., 2017). On the backdrop bamboo transformation into varied products, it is considered as an excellent source of income. It has excellent market potential for both domestic and export in the micro-enterprise and livelihood for the rural communities (Nurdiah, 2016).

Ogunwusi and Onwualu (2011) carried out an inventory of bamboo accessibility and exploitation in Nigeria. They used partial essential survey and field inventory visits. Their results show that the act of bamboo farming and production is more concentrated in the middle belt region and the southern part of Nigeria. Bamboo has little or no dominance with about 10% of the natural vegetation in these twelve states in Nigeria, which are: Adamawa, Gombe, Bauchi, Borno, Kano, Katsina, Kaduna, Kebbi, Sokoto, Jigawa, Yobe, and Zamfara states. The availability of a bamboo plant in Taraba, Abuja, Niger, and Plateau State is small when compared to the middle belt and southern region with 3–5.9% (Ghavami, 2005).

Atanda, (2015) research on sustainable material as a substitute for construction materials in Nigeria examined the significance of bamboo and its properties. His findings show that bamboo is fit as a substitute for timber and steel in the construction industry considering its excellent mechanical properties, such as weight to strength ratio, high durability, and cognitive flexibility when used as a construction material. That study also opined that Nigeria has much bamboo in over twenty different states. Figure 2 shows of the authour's delineations of states in Nigeria with abundance of bamboo.

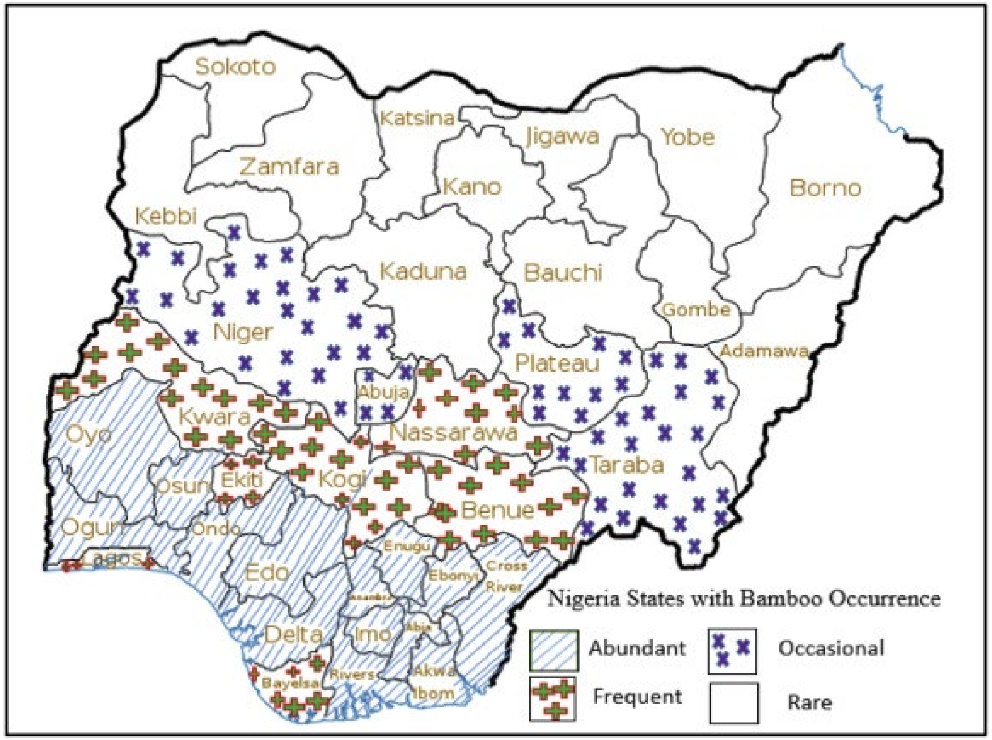

Figure 2. The Nigeria map, showing the rate of bamboo abundance in nature.

Bamboo has been and is still being used in varieties of applications in Nigeria such as recreation for the construction of various musical instruments, defense, housing and construction. In addition to the fact that bamboo can be used in the arts, it is also used for ornaments. The market for bamboo shoots has grown rapidly in the last years. In fact, the Nigeria scaffolding markets is widely dominated by Gmelina and bamboo as most widely used for construction with the latter preferred for its straightness and abundant availability.

Issues in Bamboo as Reinforcement in Concrete

The previous sections discussed a number of key issues regarding the performance of bamboo-reinforced concrete. However, there are other practical issues that also hinder its use in conventional construction. They include:

i. The weakness of bamboo perpendicular to the fibres makes hollow bars prone to crushing or splitting during transportation, handling and erection. Like GFRP bars (which are also highly anisotropic), bamboo bars must be handled with additional care not required for steel bars (Correal, 2016).
ii. As illustrated in the portal frame example, bamboo-reinforced concrete will have congested bar details. This congestion, and the variability in bamboo bars, leads to the recommendation that, in order to facilitate adequate consolidation of the concrete, bamboo bars should be placed with a spacing of at least 3 bar diameters. This limit may result in sections being larger than is strictly required to satisfy strength design considerations.
iii. Like GFRP bars, bamboo bars will 'float' in concrete. This requires bars to be tied in place to resist uplift. With the larger number of bars present, this may be a cumbersome requirement.
iv. In addition to through-thickness treatment for protection from insect and fungal attack, pre-treatment of bamboo with special coatings to enhance bond and/or the use of waterproof membranes in ground-supported slabs are laborious and require expensive and complex application systems. This is counter to claims that bamboo-reinforced concrete is a sustainable, local and low cost alterative in developing regions.
v. Unlike steel, that when properly confined can be relied upon to contribute as 'compression reinforcement', the poor transverse properties of bamboo make it ill-suited for use in compression zones, including columns. Similarly, ACI 440.1R-15 does not permit GFRP bars to contribute to compression capacity.

vi. Bamboo is known to creep under the effects of sustained loads. Whereas the creep of steel reinforcement is negligible [indeed, compression steel is used to mitigate effects of concrete creep (ACI 318), creep of bamboo is comparable to that of timber (Gottron, Harries, Xu, 2014), limiting the sustained tensile force that can be practically resisted.

Summary

Due to some challenges related to the utilization of wood, such as long growth cycles and severe deforestation, the utilization of bamboo resources has attracted wide attention globally. Bamboo is characterized by remarkable strength and elasticity properties, minimal maintenance requirements, and a fast growth cycle, as it can reach maturity within three to five years. Moreover, bamboo is attractive as a sustainable resource owing to its excellent regeneration ability and high crop yield. A single cultivation of bamboo can remain in existent for several years, and the plants can regenerate new shoots shortly after harvest. Hence, the cultivation, management, trade, and utilisation of eco-friendly bamboo resources have become of great importance. However, the applicability and the viability of bamboo as a reinforcement in concrete has been worked out through number of test and systematic examination of research. The procedure intended to establish the quality and performance which includes dimension study, density, moisture content, shrinkage, water absorption, compression, shear, bending test and tensile strength test. In this research, the emphasis is on assessment of interfacial bonding strength as reinforcement in concrete.

Gap

Despite all these inherent and wonderful qualities bamboo, some gaps still await to be filled in the knowledge and discourse of bamboo as a reinforcing member in construction as follows:
The behaviour of bamboo at elevated temperatures or in fire conditions is unknown. Correal (2016) reports that bamboo properties degrade above 50 °C. Youssefian and Rahbar (2015) report the glass transition temperatures of lignin and hemicellulose (the primary components of the bamboo matrix) to range from 97 to 171 °C and 140 to 180 °C, respectively. It is likely that the behaviour of bamboo reinforcement under fire conditions is inferior to that of steel. There is no known research on the fire performance of bamboo reinforced concrete.
There are no known research addressing methods of splicing or the behaviour of splices in bamboo reinforcing bars. Like steel, bamboo bars are practically limited to about 6 m in length; thus, splicing will be necessary in many structures. There is no known research addressing the anchorage (beyond bond development) of bamboo in concrete. Whereas steel bars are easily bent and GFRP bars may be bent during their manufacture, it is not believed to be practical to bend bamboo bars in a manner appropriate to provide anchorage in concrete. Thus, the only practical anchorage for bamboo bars is straight bar development. Furthermore, it is not believed to be practical to produce bar end anchors for bamboo reinforcing bars.

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