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Experimental evaluation of bamboo reinforced concrete slab panels

Pankaj R. Mali *, D. Datta

Department of Applied Mechanics, Visvesvaraya National Institute of Technology, Nagpur 440010, India

HIGHLIGHTS

- Enhancement of bond strength at bamboo concrete interface.
- Application of newly developed bamboo reinforcement in RC slab panels.
- Improvement in flexural performance of slab panels with proposed bamboo reinforcement.

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ABSTRACT

Reinforced concrete structural members are primarily subjected to static gravity loads. The conventional steel reinforcement is used to provide additional tensile strength and energy absorption capacity to concrete members. But conventional M.S. (Mild steel) or HYSD (High Yielding Strength Deformed) bars are heavy in weight, costly, nonrenewable and un-ecofriendly material. Aiming to mitigate this concern a sustainable, renewable, ecofriendly material like bamboo has been used as substitute to steel in the present work. Bamboo-concrete Bond behaviour was first studied through a series of pull-out tests. Bond strength investigation has resulted in a unique bamboo strip profile along with a surface treatment the combination of which exhibited maximum bond strength under uniaxial loading. This new bamboo strip is further used as main reinforcement in concrete slab panels. Feasibility and effectiveness of this unique bamboo profile used as reinforcement was investigated through experimental testing of concrete slab panels. A total 15 concrete slab panels were fabricated and tested as per Eurocode EN-1448-5 (2006). The effect of total replacement of main steel reinforcement by bamboo on the flexural behaviour of slabs in terms of load-deformation characteristics, energy absorption capacity, crack patterns and failure modes have been studied. Test results show that there is improvement in the load carrying and deformation capacity when proposed bamboo strip is used as reinforcement in concrete slab panels as compared to that of PCC (Plain Cement Concrete) and RCC (Reinforced Cement Concrete) slabs. Interestingly the structural behaviour of slabs using newly developed bamboo reinforcement has shown significant improvement in flexural performance and it was marginally better than the RC slabs having M.S. bars as main reinforcement.

1. Introduction

The reinforcing of concrete structures has been studied by using fibrous reinforcement materials. These fibrous reinforcements include synthetic and natural fiber. Besides synthetic fibers other materials such as steel, glass and carbon in fibrous form have been used as concrete reinforcement along with concrete. Although these conventional materials provide significant improvement in properties of concrete they are obtained from nonrenewable and unsustainable sources which makes them a costly building material. Considering the limitations of these synthetic fibers the focus has been to use renewable and sustainable material. These are natural fibers which contains lignocellulosic materials in their composition. There are many such materials exist in the nature which have the potential to be used in concrete and make concrete structures more sustainable and ecofriendly. One such fiber which belongs to Grass family is bamboo [1].

Conventional RC structures are made up of steel and concrete. This form of structures is built because of their ability to withstand high loads, ease in construction, durability, etc. Over the period of time especially, in last two decades, there is a tremendous increase in demand for housing and infrastructure and the majority of them is RC structures. To meet this requirement, the production rate of cement and steel are boosted and now reaching to the point of

* Corresponding author.
E-mail addresses: pankaj04.m@gmail.com (P.R. Mali), debaratidatta@apm.vnit.ac.in (D. Datta).

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saturation. The scenario in developing countries is not so favorable as the demand for this conventional material kept on increasing but the amount of material is limited. Moreover, the level of destruction caused to the atmosphere is enormous. The amount of CO_2 released in the atmosphere is about 50 times higher in steel and cement production compared to bamboo which consumes 1-tonne of CO_2 during its growth [2,3]. Being the fastest growing renewable, eco-friendly material, it could be a proper and a sustainable alternative to conventional steel reinforcement.

There are more than 1200 species of bamboo currently noted around the globe [3]. The availability of bamboo species depends upon the locality, type of soil, climatic condition, water, etc. Interestingly the availability of bamboo is very high in regions adjacent to developing countries. Also, in small villages of these countries bamboo is being used extensively as a building material from long past.

The traditional method of selecting engineering materials is no longer solely based on strength, efficiency and cost, but additional consideration must be given to the performance of the material, not only in terms of structural capacity but also in terms of the environment. Bamboo in its natural form is a highly efficient material. With these additional parameters under consideration, bamboo quickly becomes a potential reinforcing material for structural use [3].

From technical perspective bamboo is a fast-growing grass. It has high strength to weight ratio (about six times higher compared to steel) compared to reinforcing steel; it reaches its optimum strength in 3–4 years and attains complete maturity in 5 years. Like a steel bar it can support both tension and compression parallel to fibers, whereas many other materials cannot withstand against compression loading. However, being an organic material, durability of the material is a drawback for bamboo [4].

Many researchers have carried out their experimentation on the feasibility of using bamboo as alternative reinforcement in structural concrete. The use of raw bamboo either full culm or in the form of splints (A strip of bamboo culm) has three major disadvantages. The first one is the durability of bamboo strips over a considerable period of time inside structural concrete leading to weakening and splitting of bamboo fibers due to water absorption. The second is chemical decomposition of bamboo due to alkaline nature of aqueous concrete. The third is the loss of bonding between bamboo and concrete due to inadequate chemical and mechanical action at the interface. The above issues have been addressed by many researchers. A few important works have been discussed below to study the structural behavior of bamboo reinforced concrete (BRC) members. In 2016, [5] have investigated impact behaviour of BRC simply supported one-way slabs (300 mm x 300 mm) under impact loading. The concrete used for casting slab panels consist of rice husk in 5% and 10% proportion (with respect to Ordinary Portland Cement complying to ASTM type I). The effect of bamboo diameter and slab thickness on impact strength of slab panels were studied during the experimentation. It is reported that there exists a linear relationship for first and ultimate crack strength with respect to bamboo diameter and slab thickness in both type of concrete mix. The impact strength of these BRC slabs compared to conventional RCC slabs (control specimens) needs further investigation. [6] in 2013 investigated the performance of BRC slab panels subjected to impact loading. In this work, they have used oil palm shells (OPS) as substitute to conventional aggregate inside concrete mix with OPS to cement ratio as 0.45 and 0.6. The impact strength for first crack was mainly influenced by bamboo diameter but it is even more sensitive to slab thickness.

Several researches had been carried out specifically on use of bamboo strip as main reinforcement in slab panels. For instance, [7] in 2017 have examined the flexural performance of BRC slabs with Styrofoam as infill panel which is a type of expanded polystyrene (EPS). EPS is a recyclable and ecofriendly material. It was reported that slabs casted with the combination of bamboo reinforcement and EPS infill panel becomes light in weight by 27%, with 6% decrease in load carrying capacity. The bond slip strength of the bamboo reinforcement could have been improved more by incorporating additional mechanical action at bamboo concrete interface. This might have helped in enhancing load-deformation behaviour of BRC slabs. [8] in 2016 has investigated the flexural behaviour of bamboo based ferrocement slab panels. They have used bamboo strip skeletal as reinforcement in one-way slabs along with chicken wire mesh. The effect of replacement of cement by fly ash and with variation in thickness of slab has been studied. The results of slabs tested under monotonically increasing uniformly distributed flexural load show that the first crack load and ultimate loads were similar in both type of slabs. The contribution of bamboo strips with respect to mortar and wire mesh of the theoretical ultimate capacity of slab was about three times higher corresponding to the experimental ultimate load capacity. [9] in 2001 used *babudua* bamboo bars (*Thalia Geniculata*) as main reinforcement in one-way slabs. There was significant improvement in both flexural and shear strength of slabs relative to the theoretically predicted results. These slabs have exhibited high ductile behaviour and produced large deflections prior to failure. [10] in 2003 also used *babudua T. Geniculata* bamboo bars as main reinforcement in two-way slabs which are supported on all four sides. This time this author has tested the slabs under monotonic as well as cyclic loading and it was observed that there was significant improvement in flexural strength and punching shear strength of these slabs than those of theoretically predicted values under both type of loading conditions. *Babudua* bamboo reinforcement in concrete slab has provided adequate stiffness against deflection. [11] in 2015 have investigated the effect of bamboo reinforcement on flexural behaviour of slab panels under centrally uniformly distributed load. They reported that the slabs have performed better when bamboo and steel reinforcement are used together, compared to steel reinforcement samples (control specimens) as well as bamboo reinforcement samples (bamboo alone). [12] in 2014 tested BRC slabs under concentrated uniformly distributed load. The design moment was found less than the experimental ultimate moment. It is reported that this behaviour of BRC slabs was very similar to the conventional RCC slabs and hence working stress method can be used to design BRC elements. [13] in 2013 have used bamboo splints as reinforcing material in bamboo reinforced concrete wall panels (BRCWP). The bamboo reinforcement cage was prepared as per the guidelines of NBC India (2016), part-6. The bamboo splints of width 20 mm and thickness around 8–15 mm have been used with simple varnish coating and sand blasting. The wall panels are then tested under uniformly distributed eccentric loading from top and bottom ends resembling a two action of load. The effect of aspect ratio (AR: 1.6–2) and thickness ratio (TR: 12.5–15) on ultimate load and deformations at predefined locations have been observed during the experimentation. While slenderness ratio and grade of concrete were kept constant. It was reported that ultimate load of BRCWP increases with increase in TR and it decreases with increase in AR. An equation was proposed based on the observation to predict the ultimate load of BRCWP. The previous research work shows that bamboo has the required potential to be used as main reinforcement in structural concrete. Such BRC members can be more durable if the bamboo concrete bond behaviour is taken care. The efficiency of the proposed bamboo strip profile along with the surface treatment has been explored experimentally in the present study.

In the present work, feasibility and performance of slab panels using bamboo strips as main reinforcement has been investigated experimentally. Fifteen slabs were tested which include three