Influence of bamboo in concrete and beam applications

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Abstract. Bamboo is known as one of the quick growing plant due to its unique rhizome-dependent system. Its fiber owns the lowest density in comparison with the other natural fibers. The bamboo fibers can be used as innovative fibers in concrete. It can increase the strength of the concrete and improve the ductility of concrete. This study investigates the influence of different percentages of bamboo fiber in concrete through the compressive strength results. There are three different percentages of bamboo fibers to be incorporated in the concrete. A demonstration of utilising the bamboo as the steel reinforcement replacement is also presented in this study. From this study, an optimum percentage of 0.5% of incorporation of bamboo fiber as an addition in the concrete mix provides the highest compressive strength. From the three point load test, the concrete beam specimen cast with the addition of bamboo fibers yielded the prominent outcome. The findings of this study proved that the bambooos have a good potential for its application in the concrete application.

1. Introduction

There are many types of natural fibers that have been employed in the studies related to material engineering such as bamboo [1-2], kenaf [3-4], and coconut fibers [5-6]. There are numerous benefits of utilising the natural fibres in construction. Among the main benefits are that they are sustainable material, low density, low cost, non-toxicity, renewable and biodegradable instantly [7-8]. In this study, bamboo fibers are employed to investigate their influence in enhancing the concrete properties. The bamboo fiber is selected in this study compared to other natural fibers due to abundant and fast growing nature of bamboo plants especially in Malaysia [9].

Ahmad et al. [1] has demonstrated that the modulus of elasticity increased with the addition of the bamboo fiber in the concrete structural beam. The flexural strength of the bamboo reinforced beam presented in the study increased almost doubled compared to a conventional beam without reinforcement. Thus, the author remarked that bamboo fibers could be used as replacement in concrete which save the expensive concrete of 10000 cm$^3$ per 1 m$^3$ of concrete. In the other similar study by Kavitha et al. [2], it is concluded that the addition of bamboo fibers in concrete has caused the concrete to be very resistive in flexure. The inclusion of bamboo splints in concrete beams has also increased the load carrying capacity in beams but not proportionately [10].

In this study, three different percentages of bamboo fibers are incorporated into the concrete to investigate their influence to the concrete compressive strengths as compared to the conventional concrete. Then, an optimal percentage is suggested in the subsequent study in demonstrating the beam bending in determining the ultimate load in beams of three different configurations. The details of the beam configurations are provided in subsection 3.2. The failure modes are also observed in this study.
2. Methodology
As the bamboo is a good water absorber material, hence the bamboo fibers used in this study is treated to avoid them to absorb the water from the concrete mixture in the later stage. In addition, the process also conducted to avoid deterioration of bamboo in concrete for long term usage. After the bamboo has been treated, they were utilized in the preparation of the concrete cube specimens of size 100 mm x 100 mm x 100 mm and concrete beam specimens of size 500 mm x 100 mm x 100 mm.

The percentages of bamboo fiber as the addition material in the concrete were employed at 0.5%, 1% and 1.5%. Similar adoption can be referred to Brindha et al. [7]. From the results of the compressive strength, an optimal percentage of bamboo fiber that provides the highest value would be applied for the concrete beam specimen preparations, which applied the bamboo as the reinforcement replacement. The bamboos as the conventional steel replacement were placed at 1 inch from the beam soffit.

2.1 Preparation of bamboo fibers
In this study, type of the bamboo used was Buluh Betung. The bamboo fibers were collected from a handicraft shop in Bukit Mertajam, Pulau Pinang. This study utilised two different conditions of bamboo; i.e. hair and stick. To prepare the raw bamboo into the hair type, the bamboo was squashed into a sloppy state. Subsequently, they were cut into 3 cm length. In the other hand, the bamboo was cut into a stick shape with a similar dimension of 140 mm in length, 25 mm width, and 7 mm thickness. A rectangular stick shape bamboo was used in this study as it provided a larger surface area that allows loadings to be transferred effectively in the beam. Four sticks were prepared as the conventional steel reinforcement.

2.2 Method of treatment for bamboo
As mentioned earlier, the bamboo has to be treated to prevent long term deterioration as it is a natural fiber that could biodegradable. In this study, a method called “leaching bamboo” was applied. It is a traditional preservation method of bamboo. The bamboo fibers were first immersed into water as depicted in Figure 1. The weight of the fibers was recorded before and after the treatment process. During the immersion process, the starch content is leached out, hence durability is increased. In addition, the treatment is also to prevent the fibers from absorbing the water meant for the hydration process in the concrete mix that affect the concrete strengths.

For the bamboo stick, they were treated differently in this study due to the reason that they would become fragile if they were immersed in water. A thin coating was applied using the spray paint to the bamboo sticks (Refer Figure 2). Thick coating should be avoided to prevent weak bonding with concrete and act as lubrication surface for the composite materials in concrete. Similar procedure was reported by Terai et al. [11]. The use of this method will reduce the swelling when the bamboo in contact with concrete. Without coating, bamboo will swell before the concrete has achieved high strength, thus weaken the strength of concrete.

![Figure 1. Water absorption treatment](image1)

![Figure 2. Coated bamboo sticks](image2)
2.3 Concrete mix design and materials
There were a total of 36 concrete cube specimens and 4 concrete beam specimens were prepared, including the control specimens. Grade 40 of Ordinary Portland cement is used. A combination of water and cement will form a binder. The water binder ratio was kept at 0.425 in this study. Clean water is used to ensure no external substance to affect the concrete strengths. Clean water also responsible in hydration process that will leads to hardening of concrete. The free water content in this study is designed at 170 kg/m$^3$. The slump value targeted was in the range of 30 cm to 60 cm. Table 1 tabulates the mix proportion employed for all the raw materials, while Table 2 presents the percentage addition of bamboo fiber in concrete.

| No. | Materials      | Amount (kg/m$^3$) |
|-----|----------------|-------------------|
| 1   | Cement         | 400               |
| 2   | Fine aggregate | 610               |
| 3   | Coarse aggregate | 1288             |
| 4   | Water          | 170               |

In the preparation of concrete beam specimens, the crushed coarse aggregates were used with the maximum size of 40 mm. Crushed type improves strength due to the interlocking properties of angular particles, while rounded improves the flow ability due to less internal friction. The coarse aggregate content from the concrete mix design was obtained at 1288 kg/m$^3$. A ratio of 1:1.5:3 was utilised, which summed up to 235 kg for 10 mm, 350 kg for 20 mm and 705 kg for 40 mm, nearest to 1 m$^3$ mixture. Meanwhile, the uncrushed fine aggregates used together in the mixture acts as important role in turn down of separation. Table 3 presents the physical properties of the fine aggregates.

| No. | Addition of bamboo fiber (%) | Amount based on cement (kg/m$^3$) |
|-----|-------------------------------|----------------------------------|
| 1   | 0.5                           | 2                                |
| 2   | 1.0                           | 4                                |
| 3   | 1.5                           | 6                                |

The four concrete beams specimens were distinguished by the type of reinforcements used and either using the conventional concrete mixture or concrete mixture with the addition of bamboo fibers.

2.4 Testing
Various standard codes recommend concrete cylinder or concrete cube as the standard specimen for the test. The compressive strength in this study was performed according to British Standard (BS 1881-116:1983). Three concrete cubes were utilised to test for the compressive strength for each testing and the average strength was calculated. Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending. A three point load test was employed in this study according to BS 1881-Part1:1983.
3. Results and Discussions

3.1 Compressive Strength

The concrete cubes were cured by fully submerged in clean water and tested at 7, 14, and 28 days. The results of compressive strength are tabulated in Table 4, while Figure 3 provides evidence of relationship of the compressive strength and the concrete age.

Table 4. Compressive strength results of utilizing different percentage of bamboo fibers addition

| No. | Concrete sample     | Compressive strength (N/mm$^2$) |
|-----|---------------------|---------------------------------|
|     |                     | 7 Days | 14 Days | 28 Days |
| 1   | Control concrete    | 18.31  | 45.69   | 60.58   |
| 2   | 0.5% Bamboo concrete| 47.33  | 58.33   | 61.09   |
| 3   | 1.0% Bamboo concrete| 43.93  | 52.58   | 58.38   |
| 4   | 1.5% Bamboo concrete| 38.66  | 52.22   | 57.33   |

Figure 3. Relationship of average compressive strength and concrete age

From Table 4 and Figure 3, the specimens that incorporated 0.5% addition of bamboo fibers in the mix had resulted to the highest average compressive strength as compared to other mixtures. The highest average compressive strength recorded was 61.09 N/mm$^2$. Although specimens with 1.0% and 1.5% addition of bamboo fibers registered higher average compressive strengths in the early age of concrete as compared to the control specimens (refer to Table 4), but at the age of concrete maturity (at 28 days), the average compressive strength for the control specimens surpassed both the average compressive strengths for the specimens of 1.0% and 1.5% addition of bamboo fibers. This finding may be due to bond failure between the two materials as the grips between two interfaces are lost as reported in Akeju [10].
3.2 Ultimate load in beam subjected to flexural bending

Based on the results obtained in subsection 3.1, an optimal percentage of addition of bamboo fibers was determined. Subsequently, four concrete beams were prepared. These four concrete beams were distinguished by first: the control beam cast with conventional concrete and steel reinforcements; second: concrete beam cast with conventional concrete with bamboo reinforcements; third: concrete beam cast with 0.5% addition of bamboo fibers with steel reinforcements; and finally fourth: concrete beam cast with 0.5% addition of bamboo fibers with bamboo reinforcements. All the beams were tested for its ultimate load using the three points loading beam test. Ultimate load is the yield point when maximum loading applied onto beam before the beam fails.

Figure 4 illustrates the results of the ultimate loads recorded for the different types of beam. The highest ultimate load is recorded at 36.62 kN for beam specimen cast with 0.5% addition of bamboo fibers with steel reinforcements, follows by 33.57 kN as in control beam. The lowest ultimate load was recorded in beam specimen cast with conventional concrete with bamboo reinforcements. The result obtained in this study demonstrates that with the incorporation of bamboo fibers in concrete, it has enhanced the properties of the concrete mix. Similar finding is also found in Ahmad [1] whereby the flexural strength test results on the in beams utilising bamboo as reinforcement was higher than control beam.

![Ultimate Loading](image)

**Figure 4.** Ultimate loading for different configurations of beams

3.3 Failure Modes

Failure modes in the beam specimens were observed and analysed based on the crack patterns developed upon beam failure. Figures 5 to 8 show failure modes observed in all the beam specimens investigated in this study. The crack propagations were observed carefully with the aid of a flashlight. The failure mode occurred in the control beam was observed as shear crack (Refer to Figure 5). The initial crack started at near support when load was recorded at 28.61 kN. When the load was at 33.57 kN, a significant cracking sound was produced which indicated that the beam has started to fail.

Figure 6 depicts a flexural-shear failure for concrete beam specimen cast with conventional concrete and bamboo reinforcement. The initial crack that occurred at near mid span was small and had a width about crack 0.5 mm. The load that caused this initial crack was 9.39 kN. At load of 15.64 kN, a significant cracking sound was registered.

The initial crack for concrete beam specimen cast with 0.5% addition of bamboo fibers with steel reinforcement was observed to take place near the beam support. The initial crack was observed to be
very small which registered about 0.1 mm crack width. The cracks propagated from the initial crack to the loading location (at mid span). Figure 7 illustrates the failure mode recorded at failure for this beam. The significant cracking sound was recorded when load at 36.62 kN which indicated that the beam has entered its final stage before failure took place. Upon failure, this beam demonstrated a shear crack mode.

Figure 8 presents the concrete beam specimen cast with 0.5% addition of bamboo fibers with bamboo reinforcement. The initial crack occurred at the soffit of the beam and the width was approximately 0.3 mm. The load registered for the initial crack was 9.16 kN. The cracks were constantly observed to propagate along the beam. The significant cracking sound was recorded when the load achieved 15.83 kN. The final failure mode observed in this beam was a flexural failure.

4. Conclusions
This study aims to study on the influence of addition of bamboo fibers to the concrete compressive and flexural strengths. A range of 0.5% to 1.5% of bamboo fibers as an addition into the concrete mix was employed in this study. Based on findings of the study, it can be concluded that:

(i) The addition of 0.5% of bamboo fibers in the concrete mix provided the highest compressive strengths. The compressive strength obtained for specimens utilising 0.5% of bamboo fibers was 61.1 kN at 28 days. It evidences that the bamboo has the properties to enhance the concrete properties with the correct amount of usage in the concrete application.
(ii) Both concrete beam specimens utilising bamboo reinforcements as the main reinforcements provided a relatively low value of the ultimate load upon failure. The ultimate loads recorded in both the beam specimens were less than half of the ultimate load of the control beam specimen. Thus, from this finding, bamboo is not suggested to be applied as the reinforcement replacement for structural application. It may be considered for non-structural application using bamboo.

(iii) Concrete beam cast with 0.5% addition of bamboo fibers with steel reinforcements withstand highest load during the flexural test. A maximum load of 36.6 kN was recorded in the test. This value was higher than the ultimate load recorded from the beam specimen of control specimen which utilised the conventional concrete in the beam. This finding shows evidence that with the addition of bamboo fibers in the concrete can provide higher strength, hence would improve the structural deflection when in application.

(iv) Flexural failures were observed in the beam specimens employing the bamboo as the reinforcements. Hence, it is suggested that shear links are applied in this configuration to increase the beam’s capacity if it is to be used in the structural application.

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