Investigation of bamboo as concrete reinforcement in the construction for low-cost housing industry

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Abstract. Concrete is the most consumed material, with three tonnes per year used for every person in the world. Twice as much concrete is used in construction as all other building materials combined. Concrete has excellent characteristic in compressive strength, but low in tensile strength. Steel commonly used in reinforcing material because of high tensile strength. The usage of steel as reinforcing material is limited because it is costly and also has an effect on air pollution during its manufacturing process. As an alternative to overcome this problem, bamboo material has been used as a replacement of reinforcement in concrete. Bamboo is a suitable material because it is a natural material, cheap and also available material. In this research, the performance of bamboos as an alternative material in reinforced concrete has been evaluated. Tensile strength test of bamboos has been performed to identify the yields stress of bamboos. From the test, result has shown that bamboo has a similar characteristic with steel and bamboo can be used as an alternative material for reinforcing concrete. However, the characteristic of bamboos showed high water absorption and low bonding strength between bamboo’s surface and concrete. In this research, a waterproofing agent has been used to minimize water absorption and increase the bonding strength. Flexural strength test of the bamboo singly reinforced beam with the size of 150 mm x 150 mm x 750 mm has been undertaken to determine the performance of bamboo as reinforcement. From the test, it has resulted that bamboo give good potential as an alternative material in concrete reinforcement for low-cost housing industry.

1. Introduction

Concrete is an extensively used construction material for its various advantages such as low cost, availability, fire resistance etc. But it cannot be used alone everywhere because of its low tensile strength. The plain concrete possesses a very low tensile strength, limited ductility, and little resistance to cracking. So, generally, steel is used to reinforce the concrete because steel has a high tensile strength to complement the low tensile strength of concrete. In construction, the use of steel is very costly and caused so much energy-consuming in its manufacturing process. Thus, a suitable material must be used to substitute steel in construction. The material must provide availability with a low cost, environmentally friendly and also less energy-consuming. Addressing all these problems, bamboo is
one of the suitable replacements of reinforcing bar in concrete for low-cost constructions. Bamboo is easily accessible as it is available in almost every tropical and subtropical region.

One of the characteristics that would make bamboo an excellent substitute to steel in reinforced concrete is its strength. The strength of bamboo is greater than many advantageous timber products, but it is quite less than the tensile strength of steel. Bamboo is natural, cheap, widely available and most importantly strong in both tension and compression. The tensile strength of bamboo is relatively high and can attain 370 MPa [1], which makes bamboo an attractive substitute to steel in tensile loading applications. This material can reduce the cost of construction and increases the strength of the buildings that would otherwise be unreinforced. This paper aims to study the characteristic of the bamboos for concrete reinforcement performance, investigate the characteristic yields stress of the bamboo and to compare the bamboo and steel reinforcement for low-cost housing industry.

2. Material
Below are the materials that have been used in this study:

2.1. Selection and preparation of bamboo
For the sample selection of bamboo, the brown colour of bamboo with longer and great diameter culms has been selected. Bamboo culms are cylindrical shells as shown in Figure 1, and are divided by nodes as solid transversal diaphragms. The strength distribution is more uniform at the bottom of bamboo than at the top or at the middle of it since it is subjected to maximum bending stress due to wind at the top portion of the culms [1]. Based on the previous studies [2], the following criteria have been measured in this research for the selection of bamboo culm for use as a reinforcement in the concrete structures:

i. The bamboo showing a brown colour with at least three years old is selected.
ii. The accessible biggest diameter of the culm is being selected.
iii. The whole culm of green bamboo is not being used.
iv. Avoid cutting the bamboo in spring or early summer because the bamboo is weaker due to increase in fibre and moisture content.

In this research, three years old bamboo plants of pronounced colour were selected. Samples (1 m each) were collected from the bottom of the plant having four or five nodes.

Bamboo sticks are generally more popular than whole culms in construction works. After cutting the bamboo plant, it should be allowed to dry and season for three to four weeks before using. For the sample preparation, bamboo has been allowed to dry for 30 days and split according to the suitable dimension. The bamboo culms can be split or cut by using hand knife and machines equipment’s. In this research, the dimension of 10 mm x 20 mm x 700 mm has been used for the sample preparation of the beam reinforcement. The thickness of the sample varies throughout its length since it is a natural material whose properties cannot be controlled strictly. For the tensile test, the diameter and length that have been used for the testing was 10 mm x 300 mm. The specimens for concrete reinforcement sample is shown in Figure 2.
2.2. Water-proof material
By referring to the previous study [3], the characteristic of bamboos showed high water absorption and low bonding strength between bamboo’s surface and concrete when used as a reinforcement in concrete. In order to prevent this problem, ‘Tack coat’ has been used to minimize the swelling of bamboo and to increase the bonding strength. The coated has been applied one day before the bamboos being used as a reinforcement in the beam sample.

2.3. Steel bar
High yield steel deformed (HYSD) were used in this study in order to identify the performance of standard reinforcement used in concrete and to make a comparison with the bamboo reinforcement.

2.4. Concrete
The concrete to be used in the beams was made using Ordinary Portland Cement, sand as the fine aggregate and stone chips as coarse aggregate with a maximum size of 20 mm. The concrete mix proportion (cement: fine aggregate: coarse aggregate) was 1:2:4 with 0.5 water cement ratio used in this study.

3. Methodology

3.1. Mechanical properties of bamboo
Mechanical properties are important to identify the characteristic strength of bamboo. All the characteristic values were used in the design calculation. Based on the previous study [4], the equation and design procedure can be used to design bamboo reinforced concrete if all mechanical properties values were substitute in the reinforcement calculation. The mechanical properties have been determined in this study by conducting few tests such as tensile test, compressive test and pull-out test.

3.1.1. Tensile test of bamboo stick. Bamboo sample with 300 mm length was selected for the tensile test. The tensile tests were conducted for several samples on the specimen having no nodes at the center across its length. During the tension test of bamboos reinforcement, an effort was prepared to prevent the failure at the grip by covering the end of the specimen by galvanized wire. Appropriate gripping is a significant factor in the tensile test to get the accurate result. According to [5], in order to solve this gripping problem between surface of bamboos and machine, galvanized wires (2 mm diameter) were wringed spirally at the both ends of the specimens. The use of galvanized wires spiral around the ends of bamboos specimens has been presented in Figure 3.

Figure 2. Samples of bamboo used in concrete reinforcement.
3.1.2. Compressive strength test of bamboo. For the compressive strength test, the sample bamboo with hollow culms of 150 mm were prepared with a different type of sample specimen was selected. One of the sample specimens having a node and the other one without nodes was prepared as shown in Figure 4. The dimension of each sample was measured and was placed in the UTM machine. From the ultimate load graph, the compressive strength was determined.

![Figure 3](image1.png)

**Figure 3.** Galvanized wire spiral around the ends of bamboo specimens.

![Figure 4](image2.png)

**Figure 4.** Bamboo samples in compressive strength test.

3.1.3. Pull-out test. Pull-out test has been performed using the UTM machine to identify the bonding strength between bamboo surface and concrete. Three different type of samples such a coated bamboo, uncoated bamboo and steel have been tested. The test has been conducted according to [6] with the length of bonding in concrete is 150 mm. The schematic diagram is shown in Figure 5. The bond stress is determined from the ultimate load by using the formula of bond stress (unit are in N/mm²):

\[ Z_{bd} = \frac{P}{\pi d L_b} \]  

(1)

Where:
- \( Z_{bd} \) = bond stress
- \( P \) = ultimate load at failure
- \( d \) = diameter of specimen
- \( L_b \) = lengths of bonding
3.2. Beam specimen
In this research, the standard EUROCODE 2: design of concrete structures – part 1-1: General Rules and Rules for Building [7] has been referred to design concrete by using bamboo reinforcement and steel reinforcement. The load for the concrete sample has been assumed 25 kN/m (including permanent and variable load). The mechanical properties have been changed for bamboo reinforcements design which involved the values of characteristic strength of bamboo ($f_{yk}$) and the safety factor of the material. The characteristic strength of bamboo ($f_{yk}$) is 168.31 N/mm$^2$ (from the tensile test). By referring to [8], the safety factor for the bamboo material is 1.5 or 2. In this study, the factor of safety 2.0 has been used.

The size of bamboo reinforcement that has been used for concrete beam sample is 10 mm x 20 mm and the steel bar reinforcement was 12 mm diameter. In this research, three types of beam were produced namely bamboo reinforcement (BR2) with two pieces of bamboo reinforced, bamboo reinforcement (BR6) with six pieces of bamboo reinforced and steel reinforcement (SR). The dimension of beam is shown in Figure 6. The beams specimen has been designed for singly supported to determine the feasibility of the bamboo reinforced in concrete reinforcement. The strength of the beams is being determined by conducting the flexural test.

Figure 5. Schematic diagram of specimen [6].
According to [4], the placement of bamboo should not be placed fewer than 40 mm from the face of the concrete surface. The suitable spacing between bamboo strips must not be fewer than the maximum size of coarse aggregate. This is important to make sure the honeycomb will not occur during the casting of the concrete. The bamboo strips have been strongly tight with galvanized wire before casting process. Figure 7 showed the placement of bamboo before concrete casting.

**Figure 6.** Dimensions of sample beam.

3.2.1. Compressive strength test (concrete cube). The concrete that has been used in the beams was made by using Ordinary Portland Cement (OPC), sand as the fine aggregate and stones chips as coarse aggregate with a maximum size of 20 mm. The cubes dimension is 150 mm x 150 mm x 150 mm. After casting the concrete cubes, the concrete was demoulded after 24 hours and were placed for curing for 28 days. Three cubes were tested at the age of 7 days and three cubes were tested at the age of 28 days.

3.2.2. Flexural test for concrete beam. The beam was carefully placed under the testing machine and support was placed at the measured location of 150 mm inside from each end. Figure 8 illustrates the test setup. The deflection of the beam at mid-span was measured at regular interval of loading. From the flexural test, the performance of reinforcement has been identified for the three types of specimens.
4. Results and discussion
Below are the result and discussion for this study.

4.1. Tensile test of bamboo stick
The tensile strength test was conducted using Universal Testing Machine (UTM). Specimen was positioned in the machine and tensile load was applied until break. The tensile tests were conducted for several samples which having no nodes at the center across its length. The result for tensile test can be seen from the Table 1. From the result, the average stress is 169.27 MPa has been taken for the three samples of bamboo specimen.

Table 1. Tensile stress of bamboo specimen.

| Sample | Area (mm²) | Ultimate load (kN) | Stress (MPa) |
|--------|------------|--------------------|--------------|
| 1      | 200.00     | 34.03              | 170.17       |
| 2      | 200.00     | 32.04              | 160.20       |
| 3      | 200.00     | 35.49              | 177.45       |
| Average|            |                    | 169.27       |

4.2. Compressive strength test of bamboo
The first type of specimen contains central nodes and the second types of specimen is without nodes. The failure of bamboos was observed and from the result, it can be seen that the stress value obtained for specimen without nodes is greater compared to the specimen with central nodes. The average compressive stress of bamboos is 39.90 MPa. The results of the compressive test can be seen in Table 2.

Table 2. Result of compressive strength test for bamboo specimen.

| Sample | Maximum load (N) | Compressive strength (MPa) |
|--------|------------------|----------------------------|
| 1      | 79.87            | 34.86                      |
| 2      | 102.92           | 44.93                      |
| Average|                  | 39.90                      |
4.3. Pull-out test of bamboo sticks and steel
Pull-out failure occurred due to the shear strength between the bamboo and concrete. From Table 3, it shows that the bond stress of coated bamboo and uncoated bamboo are nearly the same. It is observed that the bond stress of bamboo is 4.2 times less than steel.

| Sample | Length of bonding (mm) | Bond stress of coated bamboo (MPa) | Bond stress of uncoated bamboo (MPa) | Bond stress of HYSD bar (MPa) |
|--------|------------------------|-----------------------------------|-------------------------------------|-----------------------------|
| 1      | 150.00                 | 2.17                              | 1.95                                | 5.86                        |
| 2      | 150.00                 | 1.95                              | 1.85                                | 6.39                        |
| 3      | 150.00                 | 1.88                              | 1.81                                | 6.20                        |
| Average|                        | 2.00                              | 1.87                                | 6.15                        |

4.4. Compressive strength test (concrete cube)
Compressive test was conducted to determine the compressive strength of the cement concrete cubes of grades M20. The same mixed designed has been used as would normally be used with steel reinforced concrete. The results obtained for compressive test are shown in Table 4.

| Sample | Days | Load (N) | Compressive strength (MPa) | Average (MPa) |
|--------|------|----------|----------------------------|---------------|
| 1      | 7    | 597.85   | 26.57                      |               |
| 2      | 7    | 574.12   | 25.52                      | 25.61         |
| 3      | 7    | 556.84   | 24.75                      |               |
| 4      | 28   | 765.59   | 34.03                      | 32.95         |
| 5      | 28   | 753.55   | 33.49                      |               |
| 6      | 28   | 705.12   | 31.34                      |               |

Target mean strength of concrete has been calculated in this research based on the study by [9]. Considering the inherent variability of concrete strength during production it is necessary to design the mix to have a target mean strength which is greater than characteristic strength by a suitable margin. The formula used to calculate target mean strength:

\[ f_t = f_{ck} + k \times S \]  \hspace{1cm} (2)

Where:
- \( f_t \) = target of Strength
- \( f_{ck} \) = characteristic strength of concrete
- \( k \) = a constant depending upon the definition of characteristic strength
- \( S \) = standard deviation of the particular mix

In this research, the value of \( k \) that has been used is equal to 1.65 where not more than 5% of the test results were expected to fall below the characteristic strength. Table 5 and 6 show the value of constant (\( k \)) and standard deviation (\( S \)). From the formula, concrete strength on 28 days was targeted
at 26.6 MPa as shown in Equation (3). From the result of compressive test for concrete cubes on 28 days (Table 4) showed the value of 32.95 MPa which is more than the target strength.

\[ f_t = 20 + 1.65(4.0) = 26.6 \text{ MPa} \]  

(3)

| Percentage of result below the characteristic strength | 20 | 10 | 5 | 2.5 | 1 |
|-------------------------------------------------------|----|----|---|-----|---|
| Constant (k)                                          | 0.84 | 1.28 | 1.65 | 1.96 | 2.33 |

Table 5. Value of statistical constant (k) [9].

| Grade of concrete | M10 | M15 | M20 | M25 | M30 | M35 | M40 | M45 |
|-------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Standard deviation assumed (N/mm²)                    | 3.0 | 3.5 | 4.0 | 4.0 | 5.0 | 5.0 | 5.0 | 5.0 |

Table 6. Assumed standard deviation (S) [9]

4.5. Flexural test for concrete beam

In this research, flexural test has been conducted for three beam specimens i.e. steel reinforced (SR), two strips bamboo reinforced (BR2) and six strips bamboo reinforced (BR6). Figure 9 shows the comparison strength between the three types of specimen. Based on the graph, three type of specimens have shown the different value of strength. Steel reinforcement (SR) has shown the highest value of strength with the ultimate load of 69.15 kN (for 7 days) and 110.37 kN (for 28 days) compared to bamboo reinforcement with six’s strip (BR6) and bamboo reinforcement with two strips (BR2). For BR2 specimens, the maximum load for 7 days is 51.8 kN and 76.80 kN for 28 days. This shows that the BR2 beam can carry the load based on the design load of 25 kN/m. BR6 beam shows the ultimate load of 62.13 kN (for 7 days) and 85.83 kN (for 28 days). Flexural test has been conducted for three samples for each day that means three samples for 7 days and three samples for 28 days.

![Figure 9. Strength comparison between SR, BR6 and BR2.](image)

For the steel reinforcement beam (SR), the failure pattern of the beam specimen showed a ductile failure. The first crack started at the central of the beam. The shear crack developed at the bottom of
the beam element and transmitted towards the central portion of the beam. The crack widened with the increase of the load from the flexural test. The failure pattern of the SR beam reinforced can be seen in Figure 10. For BR2 beam, crack also started at the central of the beam. The crack developed at the bottom in tension zone of the beam element. The crack propagated vertically toward the top of the beam. This proved that the beam was able to undertake shear load but weak to undertake the flexural load. The crushing of the concrete also took place at the top of the beam. The beam failed in ductile failure. The failures pattern of the beam is shown in Figure 11. BR6 beam also failed in ductile failure similar with SR beam. The shear crack generated at the bottom of the beam element and propagated towards the central portion of the beam as can be seen in Figure 12. The crack widened with the increase of the load from the flexural test.

Some parameters during casting and preparation of sample also affect the strength of beam specimen especially in compaction. Honeycomb was found in concrete specimen and this is one of the parameters that affect the strength of the beam specimen. Another major factor that can be related with the strength of bamboo reinforcement is the characteristic of the material. Bamboo is a material that has high water absorption. Bonding strength between bamboo surface and concrete also affect the strength of the concrete. From the pull-out test, it can be seen that the bonding stress of steel is higher than bamboo.

5. Conclusion
This study provides bamboo as a potential reinforcement in concrete. From the flexural test of bamboo reinforced beam, it has been seen that using bamboo as reinforcement in concrete can increases the load carrying capacity of the beam. From the tensile test, it shows that bamboos have similar behaviour like steel which consist the elastic characteristic. As bamboo is eco-friendly material, limiting the use of steel can reduce the carbon dioxide emissions. In the green building concept, the use of bamboo reinforced concrete may be recommendable. Further study must focus on how to improve the bonding strength between bamboos and concrete. Water absorption of bamboo is very high and waterproofing agent is recommended to minimize the water absorption during concrete casting in order to improve the bonding strength between concrete and bamboo. The study should be
focusing on how to minimize the water absorption and improve the bonding strength by using suitable waterproofing agent.

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