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Application of Locally Available Bamboo as a Low Cost Reinforcing Material in Concrete

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Abstract: Bamboo could be used as a low cost alternative to reinforcing material in concrete due to its high tensile strength along the fiber direction. However, limited research has been conducted to learn how bamboo behaves so that it can be used as a reinforcement in concrete. In the present study, four types of locally available bamboo (i.e., Barak, Jewa, Yngoon, and Nola) were tested to determine the ultimate tensile strength. Bamboo reinforcing bars were prepared using a chisel, hammer, and large size of a sharp knife to make the same diameter compared to the steel reinforcement. The ultimate tensile strength test was conducted using a 400 kN capacity universal testing machine having a loading rate of 0.20 kN/sec. The pullout test was performed to evaluate the bond shear strength of concrete cylinders reinforced with bamboo bars for 100 to 200 mm bonding depth. Also, the flexural strength of bamboo reinforced concrete beams was measured using a third-point loading test setup. In the end, these results were compared with a low-grade mild steel reinforced concrete system. Results revealed that the Barak bamboo had a good performance in the tensile strength test among all types of tested bamboo. The bamboo reinforced concrete system had 2-2.5 times lower bond strength, and around 40% lower flexural strength compared to the steel reinforced system, respectively. Overall, the current study indicates the feasibility of using bamboo bars as the low-strength and low cost application for reinforcing materials in the less-important reinforced concrete structures.

Keywords: Bamboo bars, low cost application, tensile strength, bond shear strength, flexural strength

1. Introduction

Nowadays, the high cost and general shortage of reinforcing steel in many parts of the world (including Bangladesh) have led to increasing interest in the possible use of alternative locally available green materials for reinforced concrete. The bamboo (Bambusoideae as the scientific name) is one of the interesting renewable natural materials (evergreen perennial flowering plants), which is highly available in tropical countries, particularly in South Asia. Bamboo is characterized by a fast growth rate, short rotation age, high tensile strength, low price, and is easily available almost everywhere in the world (Hidalgo, 1995). Bamboo is more lightweight than wood, concrete, or steel; it has a substantial strength-to-weight ratio as an advantage, because of the hollowness of its cylindrical shape. In Bangladesh, bamboo is usually used for making different kinds of less important structures, such as low-cost village houses, trusses in temporary recreation structures, temporary defense and monitoring structures, watchtowers, framing and scaffolding for building, and different types of temporary waffle slabs and floors, etc.

However, one of the major problems associated with bamboo is that it attracts living organisms such as fungi and insects into it. In order to face this challenging situation, it is necessary to treat the bamboo-like seasoning or coating to protect it from the environment. In reinforced concrete, reinforcing steel is usually protected by a passive film obtained by the relatively higher alkaline environment of concrete pore solution. Therefore, it is also expected that the environmental degradation of bamboo bars may be avoided up to a certain period while used as the reinforcing material in the reinforced concrete from the viewpoint of sustainability, bamboo can reduce the high consumption of steel reinforcement during making the reinforced concrete, and CO_2 emissions during manufacturing of steel reinforcement. Furthermore, in the construction projects of reinforced concrete, the steel reinforcement significantly influences the price of the overall project. Therefore, bamboo may be used as the reinforcing material with the replacement of mild steel due to its low price and relatively higher availability for making the low-cost sustainable construction projects, i.e., low-cost buildings, low-cost footpaths or parking pavements, low-cost embankment, etc.

A limited number of research studies on indigenous bamboo have been found in the previous literature, where it has been utilized as a reinforcing material in reinforced concrete with the replacement of mild steel. Material engineers investigated how bamboo could be utilized as an engineering material, whereas structural engineers investigated how bamboo could be used as a structural material. The bamboo bars were tested to see how well they could withstand the bending induced by wind force (Sutnaun et al., 2005). Also, the bamboo bars were used as the reinforcing materials in the construction of water tanks (Chembi & Nimityongskul, 1989), lightweight concrete beams, impermeability treatment substances to prevent water absorption, as well as to improve the bonding strength between concrete and bamboo (Ghavami, 1995; Ghavami, 1995). In addition, the bamboo bars were used as reinforcement in the concrete slab (Kankam, 1986) and concrete beams (Sabbir et al., 2011). The results showed that the load-carrying capacity of lightweight concrete beam reinforced with bamboo bar increased up to 400% compared to that of the concrete beam made without bamboo reinforcement (Rahman et al., 2011). From another point of view, the carbon footprint for manufacturing a medium carbon steel is 2.2-2.8 kg CO_2/kg, while bamboo plants absorb CO_2. Although, there might be some carbon footprint for bamboo due to cutting and processing, this is significantly lower (0.25 kg CO_2/kg) compared to steel manufacturing (GharPedia, 2021). Moreover, the typical price of low-grade mild steel in Bangladesh is around 800-900 $/ton, while the price of bamboo bars is significantly lower compared to steel reinforcement. In Bangladesh, bamboo having a length of 10-12 m is usually sold per piece for 5-10 $ and the average weight of bamboo is 30-50 kg, thus; the total cost could be 130-180 $/ton (CEIC, Bangladesh wholesale prices: DH: Bamboo, accessed on November 25th, 2021) Therefore, if bamboo could be utilized as the reinforcing materials, a huge amount of money would be saved from the construction projects; especially for the relatively less important civil engineering structures. Considering the studies that have been carried out by various researchers, it has resulted in significant confidence in employing bamboo as a replacement for mild steel for low cost sustainable applications in Bangladesh.

The application of bamboo as the replacement for mild steel has been a research topic for the last two decades as bamboo has a very good tensile and flexural strength. Nevertheless, no organized research has been undertaken to recognize the underlying phenomenon of utilizing bamboo in civil engineering structures. In the present study, four types of locally available bamboo (i.e. Barak, Jewa, Nola, and Yngoon) were collected from the local market of Bangladesh. The ultimate tensile strength test was conducted with a universal testing machine (UTM) of 400 kN capacity. In order to measure the bond shear strength of concrete reinforced with bamboo bars, 100 mm × 200 mm size concrete cylinders were prepared. For this, both 100 mm and 200 mm of bonding depth were considered. In addition, for measuring the flexural capacity, 127 mm × 127 mm × 610 mm size of bamboo reinforced concrete beams were prepared. In the end, these results were compared with the steel-reinforced concrete beams made with parallel specifications to the bamboo-reinforced concrete beam.

2. Experimental Methods

2.1 Materials

The present study used crushed burnt clay brick as coarse aggregate, locally available Sylhet sand as fine aggregate, portland composite cement as binding material, and different types of locally available bamboos.

2.1.1 Fresh Brick Aggregate (FBA)

Fresh bricks were collected from the local market in Dhaka city. The collected bricks were broken into pieces manually to have a size of 19 mm downgraded, as shown in Figure 1(a). After sieving, the aggregates were washed precisely to remove dust, and dried in the laboratory to maintain the saturated surface dry (SSD) condition. The oven-dry (OD), SSD unit weight, and void content were calculated according to the ASTM C29 (ASTM 2010). The rodding method was used to calculate the unit weight. The specific gravity and absorption capacity of the brick aggregate was determined according to the ASTM C127 (ATM 2017), as reported in Table 1.

2.1.2 Fine Aggregate (FA)

Sylhet Sand, which was obtained from the rivers in the Sylhet district of Bangladesh, was used as the fine aggregate in the present study, as shown in Figure 1(b). Before the sieve analysis, all large particles and trash were removed using an ASTM No. 4 sieve (Islam & Siddique, 2017). The fineness modulus (FM) of sand was found to be 3.0 after the standard sieve analysis as per ASTM C136 (ASTM 2020). Table 1 displays the fundamental physical properties of sand.

2.1.3 Bamboos

In the present study, 4 types of locally available bamboos such as Barak (Bambusa balcooa Roxb), Jewa (Bambusa species), Nola (Melocanna baccifera), and Yngoon (Thyrsostachys species) were collected from the local market of Dhaka city. The diameter of those bamboos was between 50-75 mm, as shown in Figure 1(c). The internodal length of bamboos was approximately 300-450 mm. After collecting, all bamboo samples were dried under the sun in order to eliminate the initial moisture in it. Note that the bamboo cylindrical rods (splints) were prepared from the whole length of these collected bamboos using a chisel, hammer, and large size of a sharp knife.

2.1.4 Mild Steel

A 40 ksi yield strength (Grade 40 rebar) of the steel reinforcing bar having the size of 8 and 12 mm in diameter as the tie bar and the main bar, respectively, were collected from the local market, to compare the tensile properties of steel bars with bamboo bars in the reinforced concrete system.

2.1.5 Cement and Water

The portland composite cement (CEM II/B-M) was used in the current investigation for all relevant tests meeting the requirements of the specifications of BDS EN 197-1: 2003 (BDS cement 2003). The physical and chemical properties of cement are presented in Table 2. The setting time was determined according to the standard specification of ASTM C191 (ASTM 2019). The normal consistency of cement was measured as per ASTM C187 (ASTM 2016). However, normal tap water was used in all types of concrete mixes in the present research.

Figure 1

Materials Used in the Current Study (a) Crushed Brick as Coarse Aggregate, (b) River Sand as Fine Aggregate, (c) Different Bamboos

(a) (b) (c)

Table 1

Properties of Different Types of Aggregate

Name of properties	Fresh brick aggregate	Fine aggregate
Bulk Specific Gravity (OD)	1.83	2.26
Bulk Specific Gravity (SSD)	2.10	2.40
Apparent Specific Gravity	2.34	2.53
Unit Weight (OD) (kg/m^3)	1000.00	1573.00
Unit Weight (SSD) (kg/m^3)	1120.00	1666.00
Absorption Capacity (%)	17.00	2.10
Void Content (%)	40.00	26.28
Fineness modulus (FM)	6.18	3.00

Table 2

Chemical Properties of Portland Composite Cement Obtained From the Manufacturer and Physical Properties in the Laboratory

Properties of cement		Value
Chemical composition	Clinker (%)	72-79
	Fly ash, slag, limestone (%)	21-28
	Gypsum (%)	0-5
Initial setting time (mins)		110.00
Final setting time (mins)		290.00
Normal consistency (%)		28.25
Specific gravity (g/cm^3)		3.00

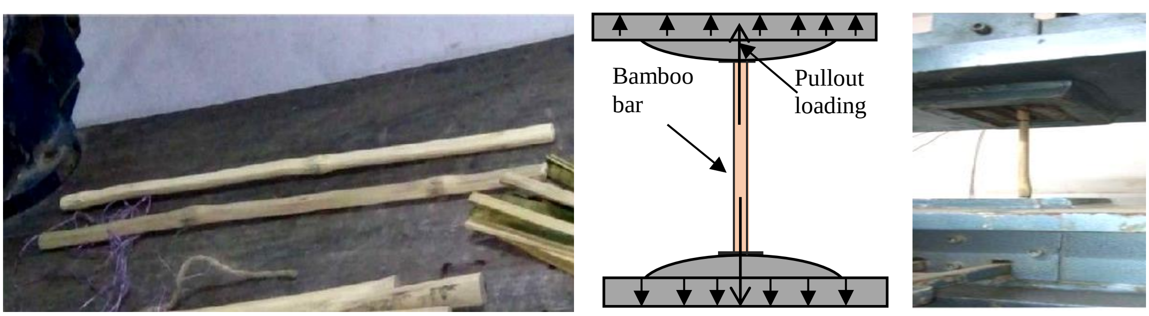
2.2 Test Setup

An experimental test setup was done for determining the ultimate tensile strength of bamboo bars, bond shear strength between the concrete & bamboo reinforcing bars, and flexural capacity of bamboo reinforced beams.

2.2.1 Ultimate Tensile Strength

Collected bamboos were prepared to have a cylindrical rod using a chisel, hammer, and large size of a sharp knife, as shown in Figure 2(a). The diameter and length of the cylindrical bamboo rod were 12 ± 1 mm, and 610 ± 2 mm, respectively. Each specimen contained at least 1 knot, and any imperfection like fracture, void, and decay was eliminated. Samples were prepared with a careful visual inspection and any undulation was edged off. The mechanism with a schematic diagram and a simple test setup that was used for measuring the ultimate tensile strength of bamboo bars has been shown in Figures 2(b) and 2(c), respectively. A 100 kN capacity of a universal testing machine (UTM) was used for running the test with a loading rate of 0.20 kN/sec. The ultimate tensile strength was calculated from the ultimate load capacity divided by the cross-sectional area of the test specimen making an average of 3 samples.

Figure 2
Sample Preparation and Test Setup for Bamboo Bars, (a) Preparation of Cylindrical Bamboo Bars, (b) Schematic Diagram of Tensile Strength Test, (c) Bamboo Bars in UTM



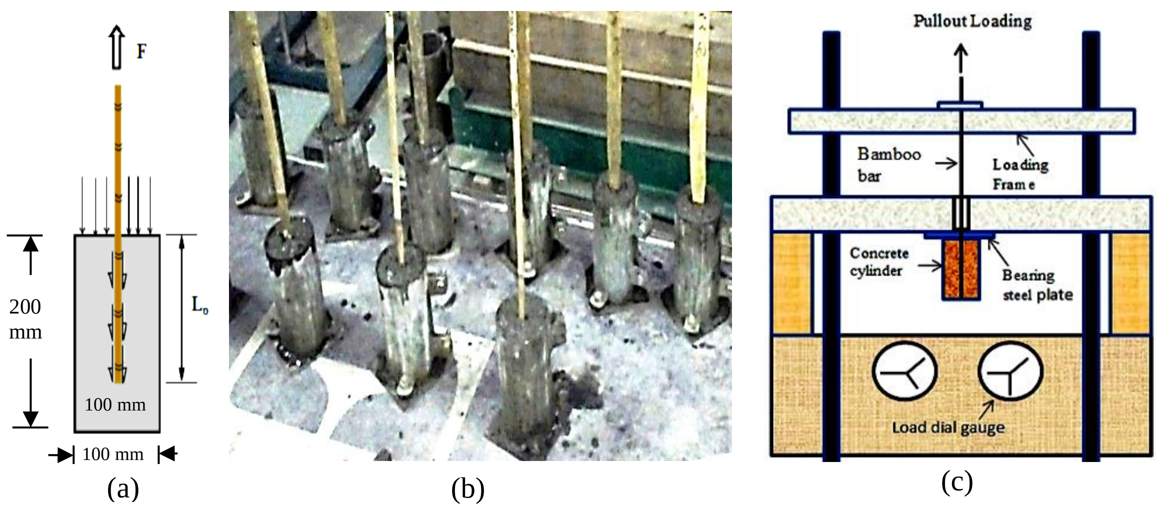
(a) (b) (c)

2.2.2 Bond Shear Strength

The primary mechanism of bond strength is a frictional force which typically comes from the interfaces between concrete and reinforcing bars as shown in Figure 3(a). The bond shear strength of concrete reinforced with bamboo bars was measured using a pullout test method in the present study for all 4 types of bamboo bars. The diameter of bamboo bars was 12 ± 1 mm. In order to understand the effect of bond length, both 100 mm and 200 mm of bonding depths were considered for all cases. For this, concrete cylinders with 100 mm in diameter and 200 mm in height were prepared and the bamboo reinforcing bars were placed at the center in the concrete cylinders based on their bonding depth. The water-to-cement ratio (w/c) for all concrete samples was 0.42, and a sand-to-total aggregate ratio (s/a) was also 0.42. The cement content was 390 kg/m^3, and no chemical admixture was used. The mixing of concrete was done as per ASTM C192 (ASTM 2015). The casting of concrete with bamboo reinforced bars has been shown in Figure 3(b). The pullout test of bamboo reinforced concrete samples was conducted at 28 days of curing age by a universal testing machine (UTM) of 400 kN capacity with a loading rate of 0.20 kN/sec according to ASTM C900 (ASTM 2020). The schematic diagram of pullout loading was similar to the previous test setup conducted by the author (Islam, 2019), has been shown in Figure 3(c). However, the same dimensional (12 mm) steel reinforced concrete cylinder was also prepared to compare the results made with the bamboo reinforced beam.

Figure 3

Bond Shear Strength Test Setup (A) Mechanism of Bond Strength, (B) Casting of Concrete with Bamboo Reinforced Bars, (C) Schematic Diagram of Pullout Test (Islam, 2019)



2.2.3 Flexural Strength

In order to determine the flexural capacity of the bamboo reinforced concrete beam, the Barak (*Bambusa balcooa Roxb)* bamboo was selected among 4 types of bamboo due to its relatively higher tensile strength compared to others. The preparation of bamboo reinforcing bars was similar to the specimen preparation for the ultimate tensile strength. The diameter of the cylindrical bamboo rod as the main reinforcing and tie bars was approximately 12 ± 1 mm, and 8 ± 1 mm, respectively. The size of the bamboo reinforcing materials has been presented in Table 3. The cage for bamboo reinforced beam before the concrete casting has been shown in Figure 4(a).

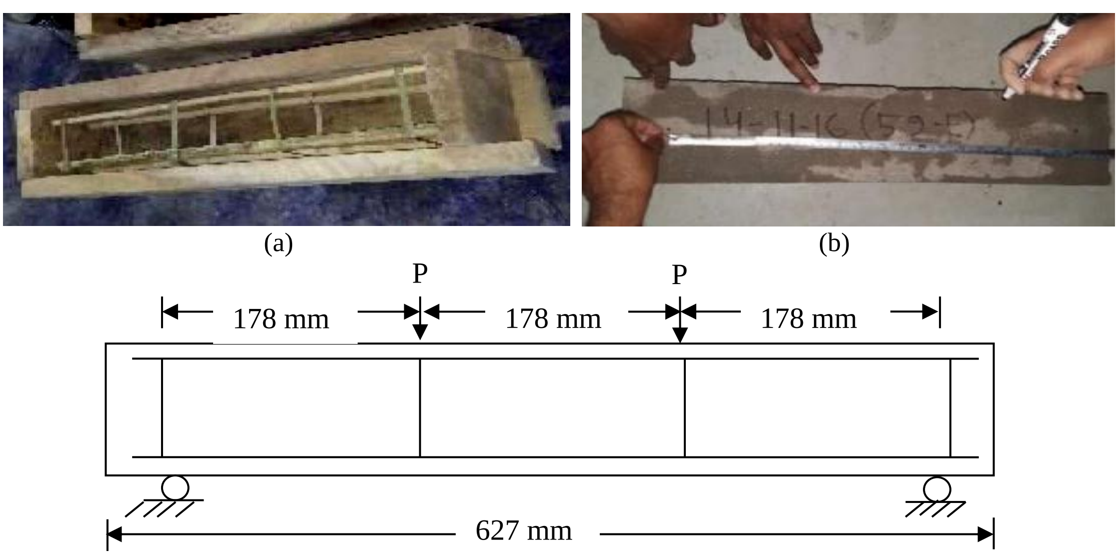
The concrete mixing composition was similar to the concrete prepared for the bond shear strength, i.e. w/c ratio was 0.42, s/a ratio was 0.42, and the cement content was 390 kg/m^3 without any chemical admixtures. The dimension of the beam was 127 mm × 127 mm × 610 mm, as listed in Table 3. After casting of concrete, the beam was unmolded at 24 hours, as shown in Figure 4(b), and underwater curing was done until it tested for a flexure capacity at 7, 14, 21, and 28 days. However, the same dimensional steel reinforced concrete beam was also made to compare the results made with the bamboo reinforced beam. The specification of reinforcing materials and beams has been provided in Table 3.

The flexural strength of concrete made with bamboo and steel reinforced beams was done using a third point loading as per ASTM C78 (ASTM 2018). In this method, the load was applied to the concrete beam specimen using a universal testing machine (UTM). The loading rate was controlled by using a controlling regulator. The testing was performed with the help of technical assistants to control the whole process with an initial trial test. The load was applied at a very slow rate, and an initial load of about 5 kN was applied and then slowly increased until failure. A deflection measuring gauge was installed at the mid-point of the beam to measure the maximum deflection at the mid-point (half of the length) of the beam. The test set up for the third point loading of both bamboo and steel reinforced beam has been shown in Figure 4(c).

Table 3
Properties of Bamboo and Steel Reinforced Concrete Beams

Types of beam	Width (mm)	Height (mm)	Length (mm)	No. of main bar	Dia. of main bar (mm)	Dia. of tie bar (mm)	No. of tie bar
Bamboo reinforced	127	127	610	4	12	~ 8	4
Steel reinforced	127	127	610	4	12	8	4

Figure 4
Flexural Strength Test Setup (A) Formwork of Bamboo Reinforced Beam, (B) Bamboo Reinforced Beam after Casting of Concrete, (C) Third Point Loading Test Setup



(c)

3. Results and Discussions

In the present study, the ultimate tensile strength of bamboo reinforced bars, bond shear strength of concrete cylinders, as well as the flexural capacity of the bamboo reinforced beam were measured. Finally, these results were compared with a steel reinforced concrete system (i.e., concrete cylinder and beam).

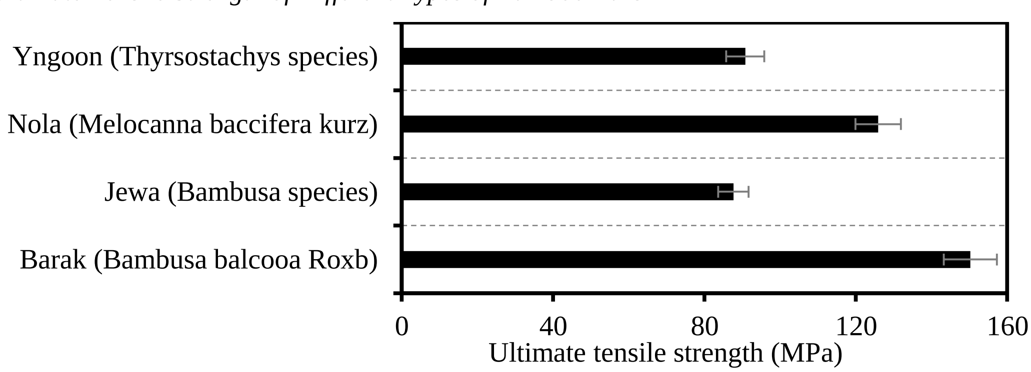
3.1 Ultimate Tensile Strength

Figure 5 illustrates the ultimate tensile strength of all bamboo reinforcing bars. As can be seen, the Barak (*Bambusa balcooa Roxb*) bamboo had the highest tensile strength among all types of bamboo. In contrast, the Nola (*Melocanna baccifera kurz*) bamboo bar obtained about 16% lower tensile strength compared to the Barak bamboo bar. On the other hand, Yngoon (*Thyrsostachys species*) and Jewa (*Bambusa species*) obtained almost similar tensile strength, which was around 40-42% lower compared to the Barak bamboo bar. The typical ultimate tensile strength of a 40 grade mild steel is 413 Mpa, which is around 2.75 to 4.55 times higher than that of the bamboo bars. However, the possible reason for the relatively higher tensile strength of the Barak bamboo bar was due to the fiber density, and perhaps, the lower number of knots.

3.2 Bond Shear Strength

Figure 6 demonstrates the bond shear strength of steel and 4 types of bamboo reinforced bars for 100 and 200 mm of bonding depth. According to the results, it can be seen that steel reinforced bars had the maximum bond shear strength for both 100 and 200 mm of bonding depth. In contrast, the bamboo reinforced bars exhibited around 2-2.5 times lower bond shear strength compared to the steel reinforced systems. Among 4 types of bamboo reinforced system, it was observed that the Barak bamboo reinforced concrete obtained the highest bond shear strength for both 100 and 200 mm of bonding depth. For 100 mm of bonding depth, Jewa, Nola, and Yngoon obtained around 15%, 22%, and 15% lower bond shear strength, respectively, compared to the Barak bamboo bar reinforced concrete.

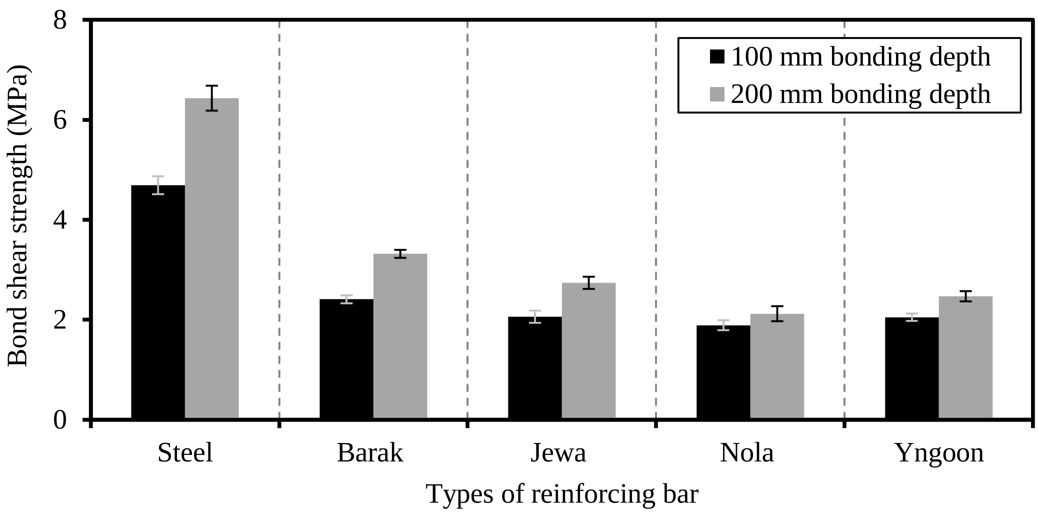
Figure 5
Ultimate Tensile Strength of Different Types of Bamboo Bars



Conversely, Jewa, Nola, and Yngoon obtained around 18%, 36%, and 26%, lower bond shear strength, respectively, for 200 mm of bonding depth compared to the Barak bamboo bar reinforced concrete. It was found that the higher the bond length, the greater the bond shear strength because of the larger surface area at the interface. Vijay and Ishwar (2019), also measured the bond shear strength of bamboo reinforced bars and found a consistent result with the present study. However, the possible reasons for the relatively lower bond shear strength of bamboo reinforced bars were splitting and grip failure (Sabbir et al. 2011); further information will be provided in the failure pattern section.

Figure 6

Bond Shear Strength of Concrete Reinforced with Steel and Bamboo Bars



3.3 Flexural Capacity

The flexural capacity of steel and bamboo reinforced brick aggregate concrete beam for up to 28 days is shown in Figure 7. As can be seen, the flexural capacity of steel reinforced beam as the force was increased with the increasing age and reached a value of 119 ± 0.9 kN at 28 days. In contrast, the bamboo reinforced beam obtained a flexural capacity of 69.5 ± 0.71 kN, which is around 40% lower compared to the steel reinforced beam. Figure 8 illustrates the load vs mid-point deflection of both bamboo and steel reinforced beams at 28 days. It was observed that the steel reinforced beam had a maximum deflection of 8.02 mm at failure, while the bamboo reinforced beam had a maximum deflection of 10.1 mm at failure, which was around 26% higher deflection compared to the steel reinforced beam. The possible reason for relatively lower flexural capacity and higher deflection of the bamboo reinforced beam was due to the lower tensile strength and rupture strain taken capacity of bamboo bars. Therefore, the bamboo reinforced beams may be suitable for using as the substitution of the steel reinforced beams in the less important and low-strength applications.

Figure 7

Flexural Capacity of Bamboo Reinforced Beam as the Forces for Up to 28 Days

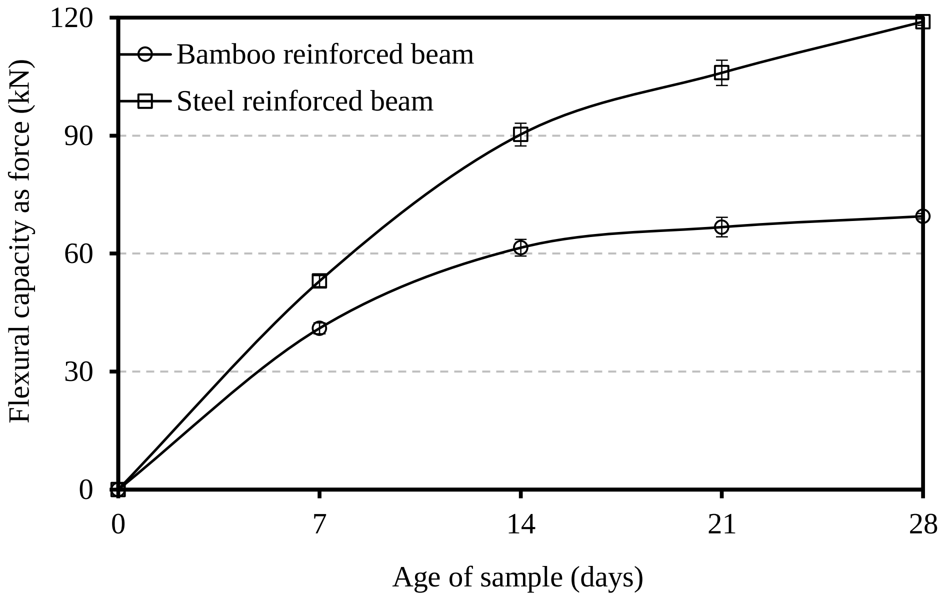
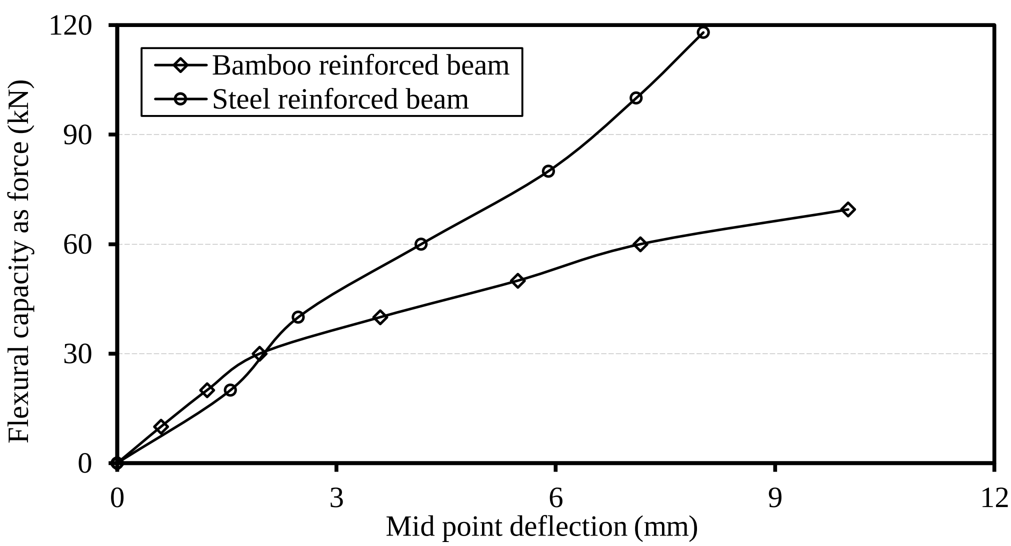


Figure 8

Load vs Mid-Point Deflection of Bamboo and Steel Reinforced Beam at 28 Days



3.4 Failure Pattern

Figure 9 illustrates the fracture surface of different specimens for all tests. The knot failure of bamboo bars was mostly observed during the ultimate tensile strength test, as shown in Figure 9(a). Both grip and knot failure was observed for the bond shear strength test, as shown in Figure 9(b). A similar type of failure was observed by Sabbir et al. (2011). The similar pure flexural failure was observed for the bamboo reinforced beam during the rupture of the third point loading.

Figure 9
Fracture surface (a) knot failure of bamboo bar, (b) grip and knot failure of bamboo bars during shear bond test, (c) flexural failure of bamboo reinforced beam under third point loading test

(a) (b) (c)

4. Conclusion

The current study concludes that—

1. The bamboo bars used in the present study had around 2.75 to 4.55 times lower tensile strength compared to the Grade 40 steel reinforcing bar. Barak bamboo bar obtained the highest tensile strength. Nola, Yngoon, and Jewa obtained 16%, 40%, and 42% lower ultimate tensile strength compared to the Barak bamboo bar, respectively.
2. Steel reinforced concrete had around 2-2.5 times higher bond shear strength compared to that of the bamboo reinforced concrete (i.e., Barak, Nola, Jewa, and Yngoon) for both 100 and 200 mm of bonding depth. However, the Barak bamboo bar had a good performance in the bond shear strength as it obtained around 15-25%, and 20-55% higher bond shear strength at 100 mm, and 200 mm bonding depth, respectively, compared to other bamboo bars (Nola, Jewa, and Yngoon).
3. The Barak bamboo bar reinforced concrete had around 40% lower flexural capacity and around 26% higher mid-point deflection at failure compared to the steel beam reinforced concrete at 28 days.
4. The typical price for a low grade mild steel is around 800-900 $/ton, while the cost for bamboo is 130-180 $/ton in Bangladesh; which is significantly lower compared to steel reinforcement. Furthermore, the findings of this study indicate that bamboo bars can be employed as reinforcing materials in low-strength applications. Therefore, it is recommended to utilize bamboo as the reinforcement in the

relatively low-strength and less-important reinforced concrete structures such as low-cost village houses, temporary defense and monitoring structures, watchtowers, etc. However, further study is required with a full-scale experimental investigation for the bamboo reinforced concrete building or large structures, and it is not recommended where human life safety is a concern.

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