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The flexural behavior model of bamboo reinforced concrete beams using a hose clamp

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Abstract. Bamboo can use at the simple concrete construction because of the tensile strength of its mechanical property. Meanwhile, a slippery surface of the bamboo caused cracks in the bamboo reinforced concrete beam (BRC) not to spread and yield slip failure between a bamboo bar and concrete. Load test at the BRC beam yield humble load capacity. This study aims to improve the capacity and behavior of BRC beam bending by giving waterproof coating, sand, and hose clamp installation. The beam test specimen with the size of 75x150x1100mm made as many as 26 pieces with the variety of reinforcement. The hose clamp used on the bamboo reinforcement varies with a distance of 0 cm, 15 cm, 20 cm, and 25 cm. The testing using a simple beam with two-point loading. The test results show that BRC beams have different bending behavior compared to the steel reinforced concrete beam (SRC).

1 Introduction

Bamboo can use as a substitute for steel reinforcement in concrete construction, especially for simple construction. The tensile strength of bamboo can reach 370 MPa [1]. Bamboo is much cheaper than steel reinforcement for the same level of strength. Bamboo is easy to obtain, easy to plant, can grow quickly, environmentally friendly, and as a renewable natural resource [2]. Bamboo for construction materials age at least 3-5 years old from the planting period [3] and can be harvested for several time without a need to plant again. Flexural strength of bamboo lamination is stronger if compare to concrete or other natural composite material [4]. The non-treated flexural bamboo reinforcement for reinforced concrete beams is recommended to use a safety factor of 1.2 [5]. Pillars, bridge framework, soil retaining wall in rural societies environment, and the research of reinforcement of peat soil under embankment are also using non-treated bamboo [6]. The slippery surface is the weakness of the bamboo bar. The roughness modifications such as giving notch and wire coil have done, but it hasn't been able to maximize the result.

Waterproof coating, sand coating, and adding a hose clamp on bamboo reinforcement is similar to the concept of deformed steel bars in concrete [7], namely the interaction of friction force, and the support style between steel bars and concrete. The stress and strain

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distribution analysis of flexural beam elements by Ghavami [1] is shown at different stages as in Fig. 1.

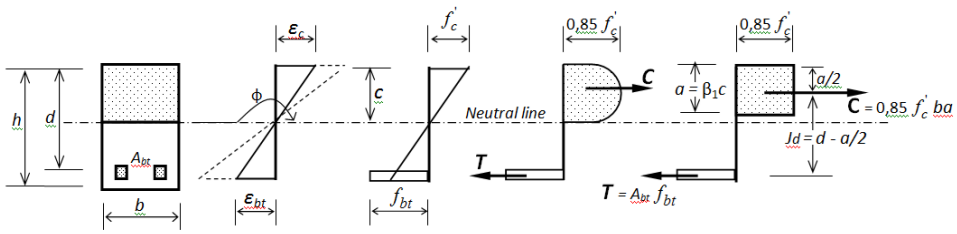


Fig. 1. Distribution of stress-strain cross section of bamboo reinforced concrete blocks [1].

The friction strength or bond stress, τ_b of the bamboo pullout test can be calculated using Eq. (1) [8]:

$$\tau_b = \frac{\mathrm{P}}{(2a+2b)L_a} (\mathrm{N/mm^2}) \quad (1)$$

with P is the pullout force, (2a + 2b) is the dimension of the bamboo cross-section, and L_a is the length of bamboo surface attachment.

2 Materials and methods

2.1 Bamboo

This research using bamboo petung (Dendrocalamus Asper) aged between 3-5 years [3] along 6 meters from the base of bamboo stems. Bamboo immersed in water to remove starch content for approximately 30 days [9]. Then bamboo is dried in free air for approximately 30 days [3, 4, 8-11]. Bamboo reinforcement size is 7x10mm², 10x10mm², and 15x15mm². The bamboo specimen size 15 mm thick with a length of 300 mm.

2.2 Hose clamp and Sikadur®-752

Fig. 2. Hose-clamp ring.

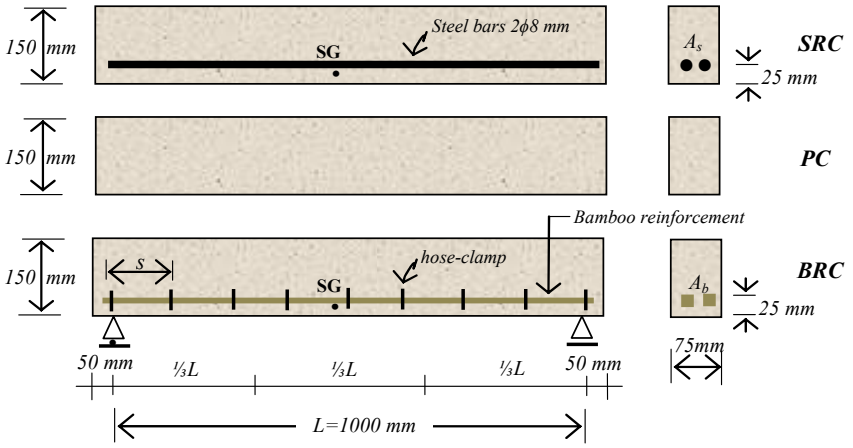
Fig. 3. Bamboo bars with waterproof and sand coating, and the hose clamp.

This research using waterproof coating Sikadur®-752 and ¾" stainless-steel hose clamp as shown in Fig. 2 [12, 13]. Hose clamp mounting distance varies between 0 cm, 15 cm, 20 cm, and 25 cm. Installation of a hose clamp on the bamboo reinforcement done after the first layer of waterproof coating is dry (Fig. 3). A second waterproof coating is performed for closing first stage waterproof defects and to adhere hose clamp more closely to the bamboo reinforcement, and it sprinkled with sand to become rough [8].

2.3 Test Method

The test material uses Portland pozzolana cement, sand, coarse aggregate, and water with a proportion of 1:1.81:2.82:0.52. The compressive strength test carried out using a 150x300mm of the concrete cylinder and The Universal Testing Machine (UTM) with 2000 kN capacity. A pullout test of the bamboo bar using UTM with 500 kN capacity.

The beam test specimen was made as many as 26 pieces with the size of 75x150x1100mm (Fig. 4), consist of 24 pieces of BRC beam, one piece of SRC beam, and one concrete beam without reinforcement (PC). Bamboo reinforcement is installed as tensile reinforcement with a variation of reinforcement area 140 mm^2, 200 mm^2, and 450 mm^2. The 8 mm steel bars used with an As = 100.48 mm^2 of reinforcement area.



Note: *SRC*= Steel Reinforced Concrete, *PC* = Plain Concrete, *BRC* = Bamboo Reinforced Concrete, SG = Strain Gauge, *s* = Distance of hose-clamp (Variation of *s* = 0 cm, 15 cm, 20 cm, and 25 cm), A_s = Area of steel reinforced (A_s = 100.48 mm^2), A_b = Area of bamboo reinforced (Variation of A_b = 140 mm^2 , 200 mm^2, and 450 mm^2).

Fig. 4. Detail and geometry of the bamboo reinforced concrete beam.

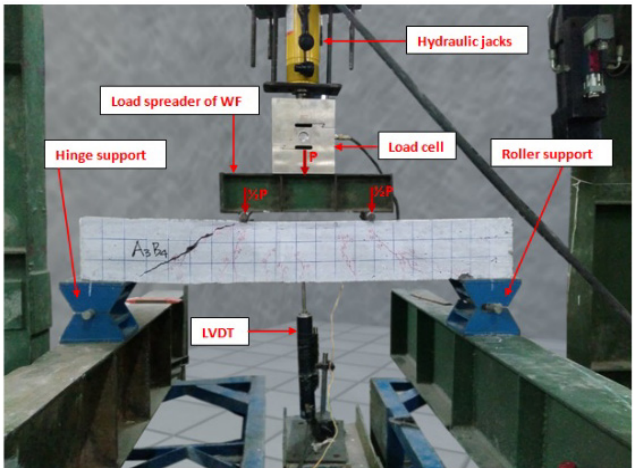


Fig. 5. The flexural test of bamboo reinforced concrete.

The flexural test is carried out using a two-point loading method on simple beam [14]. External load divided into two points with spaced ⅓ L from the beam support with a WF load spreader. The strain gauge mounts on the bamboo bar at ½ L from the beam support.

Deflection is detected using LVDT (Linear Variable Displacement Transducers) at a ½ L distance from the beam support. External load provided using hydraulic jack and 200 kN load cell. Deflection control becomes the controller after beam reaches its ultimate load. The settings of the applied test equipment and load scheme shown in Fig. 5.

2.4 Verification by finite element method

Numerical verification is done using the finite element method with the Fortran PowerStation 4.0 program. The load that caused the initial crack is calculated using elastic theory (linear analysis) with the transformation cross-section. For linear analysis, the material data included is the modulus of elasticity (E) and the poisons ratio (υ). Triangular elements are using to model plane stress elements in two directions of primary displacements (u, v) at each point so that the element has six degrees of freedom. The discrete form of the beam with the triangular element shown in Fig. 6.

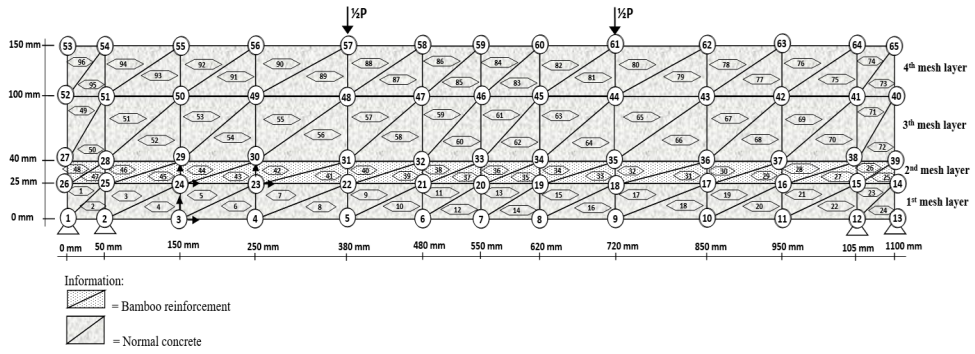


Fig. 6. Finite element idealization of BRC beam.

3 Results and discussion

3.1 Pull out tests results

From pull-out test results, bamboo reinforcement with a coating of Sikadur®-752, sand, and hose clamp embedded in concrete cylinders showed an increase of bond stresses of 240% and 214% compared to untreated bamboo, with hose-clamp spacing respectively 15 cm and 20 cm. For untreated bamboo reinforcement with hose clamp distance of 10 cm, the bond stress increased 8%. While bamboo reinforcement with Sikadur®-752 coating and sand without hose clamp increased by 150% as shown in Fig. 7.

The specimen which treated using a waterproof and sand coating and hose clamp shows the bond collapse patterns and concrete cone failure and bamboo node failure as shown in Fig. 8b and Fig. 8c. This shows the Sikadur®-752 adhesive effect and the hose clamp installation work well, and the concrete still attaches to the bamboo reinforcement. The specimen with sand and Sikadur®-752 coating shows bond-slip failure but still has an excellent high adhesive strength. While the specimen with only hose clamp shows bond-slip failure almost the same as bamboo reinforcement without treatment as shown in Fig. 8a. The test results show that waterproof and sand coating is necessary before the hose clamp installation.

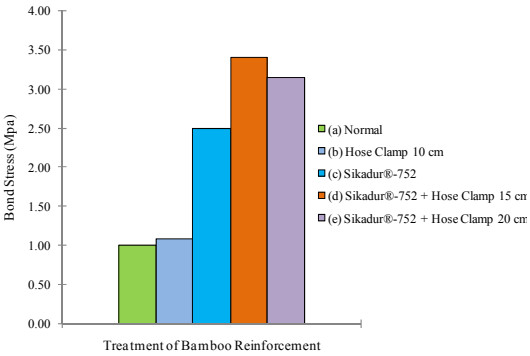


Fig. 7. Variation of the bamboo bond stress.

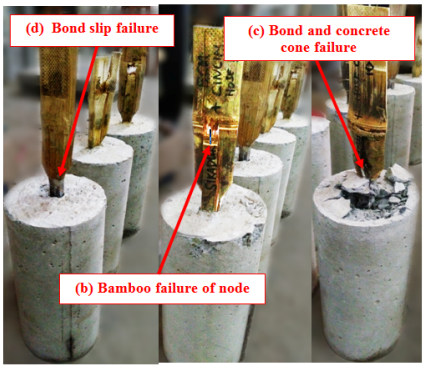


Fig. 8. The failure mode of the pullout test.

3.2 Flexural beam test

3.2.1 The capacity of the bamboo reinforced concrete beam

Fig. 9 shows the average ultimate load of BRC beam with hose clamp reaches 90% more than theoretical calculation. This is one of the problem solutions of the low capacity of bamboo reinforced concrete beams. Earlier researchers concluded that the bending capacity of bamboo reinforced concrete beams only reached 56% of its capacity if full bamboo tensile strength [15], reaching only 29% to 39% of the steel reinforced concrete beam capacity with the same dimensions and breadth area [16], and just reached 35% of steel reinforced concrete beams at the same level of strength [17, 18].

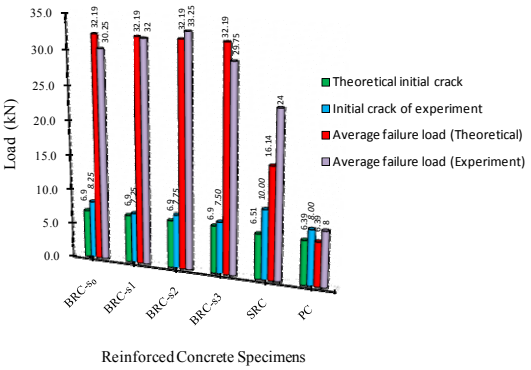


Fig. 9. Comparison of BRC beam ultimate loads.

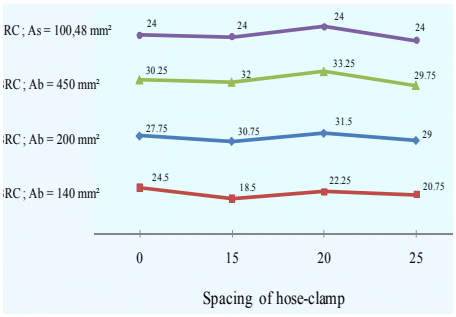


Fig. 10. The ultimate load of BRC beams based on reinforcement area variation and hose clamp distance.

Fig. 10 shows the ultimate load of BRC beam with hose clamp is higher up to 38.5% compared to SRC beam with area 100.48 mm^2. BRC beams with 1.78% bamboo reinforcement area have surpassed the strength of SRC beams with a steel reinforcement area of 0.89% up to 38.54%. The greater bamboo reinforcement area ratio will increase the capacity of the BRC beam in a linear trend. Variation of hose clamp usage on BRC beams can increase load capacity up to 35.71% compared to BRC beams without hose clamp. Optimum hose clamp installation occurs on BRC beams with a 20 cm distance with an

ultimate load of 33.25 kN. The largest ultimate load capacity achieves by BRC beam with reinforcement ratio (ρ) 4% or reinforcement area 450 mm^2 with a hose-clamp distance 20 cm. BRC beam load capacity with bamboo reinforcement ratio (ρ) 4% and hose clamp distance 0 cm, 15 cm, 20 cm, and 25 cm increase respectively 26.04%, 33.33%, 38.54%, and 23.96% compare to SRC beam with reinforcement ratio steel 0.89%.

3.2.2 The load-deflection relationship.

Fig. 11 and Fig. 13 illustrate the load-deflection relationship and the stress-strain relationship of the BRC beam and the SRC beam. In the SRC load-deflection diagram, load-deflection connections are trilinear, i.e.: (i) the pre-crack area, (ii) the post-crack area, and (iii) the crack area (post-serviceability).

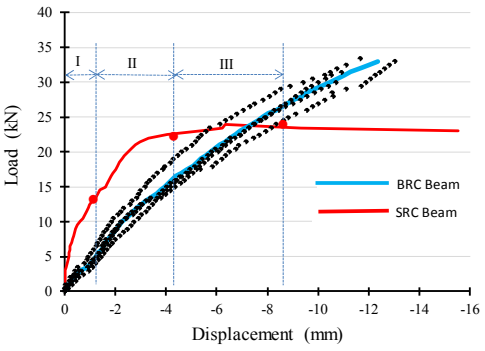


Fig. 11. The behavior of load-deflection BRC beam and SRC beam.

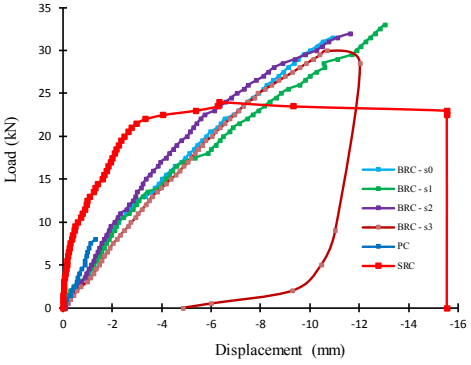


Fig. 12. BRC beam load-deflection diagram.

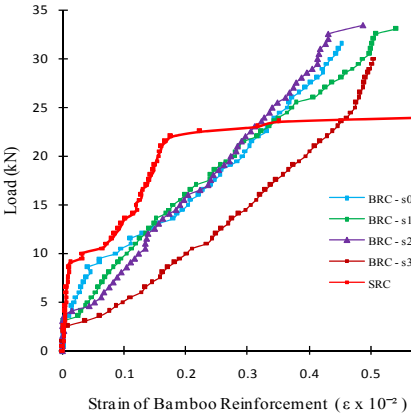


Fig. 13. Load-strain correlation of BRC beam.

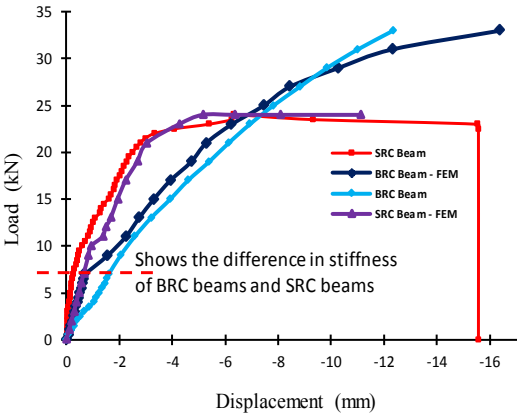


Fig. 14. The behavior of load-deflection relation of BRC beam and SRC beam with finite element method.

While the load-deflection diagram of BRC beam shows only the pre-crack or elastic region. The post-crack area until the crack area (post-serviceability) tends to be linear. The BRC beam load-deflection diagram has a much higher deflection compared to SRC beam before failure, indicating higher energy absorption and ductility. BRC beam after reaching ultimate load or after crack level, if the load releases, the deflection almost return to zero as shown

in Fig. 12. As an example of the BRC-s3 beam deflection behavior in Fig. 12. While the SRC beam, after ultimate load, the deflection diagram will increase without load increment until collapse occurs.

In Fig. 14, if the horizontal line is portraying the point where the initial crack occurs the BRC beam, it will explain that the stiffness of the BRC beam is lower when compared to the stiffness of the SRC beam. The average value of BRC beam stiffness is lower to 75% than the SRC beam. This is the weakness of BRC beams that need to be examined in further studies. The diagram shows that the decreased stiffness after the initial crack following the loading stages of each mesh layer is very influential on the results of the analysis performed. The modulus of elasticity of concrete on BRC beam was reduced from 26,324.76 MPa before cracking to 6581.20 MPa after collapsed [19].

3.2.3 Load-deflection correlation model of bamboo reinforced concrete beams

Table 1. Load-displacement relationship calculation data.

Specimens/ code	Sample no	Theoretical calculations		Flexural test results				
		First crack load (kN)	Ultimate load (kN)	First crack load, P_{cr}(kN)	Service load, $P_{service}$ (kN)	Failure load, $P_{ultimate}$ (kN)	Deflection at failure (mm)	P_{cr}/ $P_{ultimate}$ (%)
(a) BRC-s0/ A3B1	1	6.87	32.19	8.50	18.90	31.5	10.92	26.98
	2			8.00	17.40	29	11.9	27.59
(b) BRC-s1/ A3B2	1	6.87	32.19	7.00	18.60	31	13.02	22.58
	2			7.50	19.80	33	12.18	22.73
(c) BRC-s2/ A3B3	1	6.87	32.19	8.00	20.10	33.25	14.69	23.88
	2			7.50	19.80	33	9.32	22.73
(d) BRC-s3/ A3B4	1	6.87	32.19	7.50	17.70	29.5	7.61	25.42
	2			7.50	18.00	30	10.69	25.00
Mean values (*Ru*)				7.69	18.79	31.31	11.29	24.61
Standard deviation (σ)				0.46		1.73		1.97

A load-deflection pattern of BRC and SRC beams are influenced by the mechanical properties of the reinforcement. The stress-strain characteristics of bamboo do not have a long starting yielding point. This causes the service load limit point is difficult to determine. The service load range limits are determined at the base of ASTM E2126 [20] i.e. by drawing a vertical line through the line encounter of 0.4 Pultimit with a horizontal line of 0.8 Pultimit. BRC beam load-deflection diagram analysis shows the average P service load of 18.79 kN or about 60% of Pultimate. While the value of the elastic boundary point range is calculated using the Eq. 2:

$$P_{cr}/P_{ultimate} = R_u - 2.3(\sigma) \quad (2)$$

$$P_{cr}/P_{ultimate} = R_u - 2.3(\sigma) = 20.07\% \approx 20\%.$$

Table 1 shows that the lowest elastic point of 22.58% occurs on the BRC-s1 beam, the highest of 27.59% occurring on the BRC-s0 beam. The average of the elastic limit point is 24.61% of the ultimate load. The elastic boundary value is 20% of the ultimate load. The elastic point limit on the SRC beam is 41.67% of the ultimate load. The service load range is 60% of the ultimate load. The idealization of the BRC beam load-deflection model shown in Fig. 15.

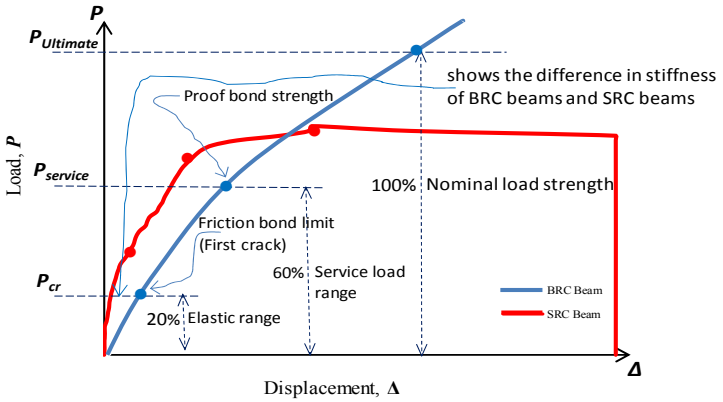


Fig. 15. The idealization of the load-displacement relationship model of BRC beam.

4 Conclusions

Installation of hose clamps, waterproof coatings, and sandblasting on reinforcement of BRC beams as slip brackets between bamboo reinforcement and concrete can increase the capacity of BRC beams, but still, have much lower stiffness than SRC beam stiffness. The reduction of elastic constants in each blocking layer is applying to analyze the load-deflection relationship of BRC beams. The result of the analysis shows that the load-deflection analysis model is quite close to the experimental results.

In the load-deflection diagram model of SRC beam, the relationship is trilinear, i.e. i) the pre-crack area, ii) the post-crack area, and iii) the crack area (post-serviceability). While on the BRC beam shows only the pre-crack or elastic region. The post-crack area until the crack area (post-serviceability) tends to be linear.

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