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BOND-SLIP IMPROVEMENT OF BAMBOO REINFORCEMENT IN CONCRETE BEAM USING HOSE CLAMPS

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Abstract

Failed of bond-slip interaction between bamboo reinforcement and concrete are main factors of flexural failure at bamboo's reinforced concrete beams. To increase bond-slip interaction between surface of bamboo reinforcement and concrete has been done using coating treatments with water-resistant material, the addition of hooks, wire rope wrapping, and others. With the treatments, concrete beams with bamboo reinforcement able to increase capacity, but the pattern still shows slip failure. The aim of this research is to improve bond-slip interaction between bamboo reinforcement and concrete to reform the flexural behavior pattern of concrete beam using a hose clamp. This research used bamboo petung (Dendrocalamus asper) 2-3 years. Dimension of bamboo reinforcement is 15 mm x 15 mm. Dimension of concrete beam is 120 mm x 200 mm x 2100 mm, with percentage of tensile reinforcement (ρ) about 4.68% and compression reinforcement (ρ ') about 1.875%. Shear strength reinforcement using steel bar with diametre of 6 mm. Four beam specimens casted with four different treatment, i.e: normal reinforcement, reinforcement with hose clamp, reinforcement with water-resistant coating, and reinforcement with water-resistant coating and hose clamp. Beam tests performed using four-point load. The test results showed flexural capacity, ductility, and stiffness of the beam with bamboo reinforcement which coated by water-resistant material and hose clamp has increased compared to the other beam. All beams shows crack and collapse by slip failure, but beams with bamboo reinforcement which were coated by water-resistant materials and hose clamp has many spread crack before it collapses

Keywords: *Bamboo reinforced concrete, hose clamp, bond-slip interaction, flexural capacity.*

INTRODUCTION

Bamboo can be used as alternative of reinforcement in concrete structure because of several advantages. Tensile strength of bamboo can reach 370 MPa (Ghavami, 2005) and even up to 417 MPa (Morisco, 2005). As concrete reinforcement, bamboo should be treated, i.e soaked, dried, or coated with a waterproof coating, and sprinkled with dry sand. Bamboo bar can be coated with an adhesive waterproof layer such as: Araldite, Tapecrete P-151, Anti Corr RC, and Sikadur 32 Gel (Agarwal et al, 2014); Araldite layer, Epoxy Resin, and Coal Tar (Siddhpura et al., 2013); epoxy layer and fine sand coating (Kumar et al., 2014); paint and fine sand coating (Nindyawati et al, 2013); and asphalt layer and sand (Bhonde et al., 2014)

Although treatments has been done, concrete bond with bamboo not as good as concrete with steel. Load test of bamboo beam reinforcement with no treatments shows that there only one or two lines crack and then bamboo straight slip detached from the concrete. After adhesive strength of bamboo enhanced with paint layers and sand, bending crack is increasing at bamboo beam and it has increasing load capacity. Lack of bond slip at bamboo can be seen from test results of some

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researchers that only reach 35% of capacity, if tensile strength of bamboo is full (Khare et al., 2005; Terai et al., 2011). If adhesion is enhanced, it is expected that flexural capacity of bamboo beam can be increased.

Rudeness modification research of bamboo reinforcement has done with notch treatments (Budi S., 2013) and additional hooks (Lestari et al., 2015). This method can increase beam capacity, but still many shortcomings, such as notch process can weaken bamboo reinforcement. Concept of using hose clamp on bamboo reinforcement is same with concept of using deformed steel reinforcement at concrete, where this concept is happened at interaction of frictional force and pivot force between concrete and reinforcement. In order to increase bond-slip of bamboo reinforcement in concrete beams, this study will use hose clamp ring at bamboo reinforcement which installed after the first waterproof coating.

MATERIALS AND METHODS

Materials

Bamboo

This research using “petung” bamboo (Dendrocalamus asper) 2-3 years. The bamboo trunk which is used as concrete reinforcement along 3-6 meters taken from the base. Bamboo divided or cut according to size plan and then soaked to issue a starch content (Morisco, 2005) about one month. After soaking, bamboo was dried or aerate for approximately one month. Then bamboo is coated by a water-resistant coating to minimise swelling.

Water-resistant coating

The water-resistant coating “Sikadur®-752” use as water-resistant coating as in research of Agarwal et al. (2014). Sikadur®-752 is a solvent-free, consist of two component super low viscosity-liquid, based on high strength epoxy resins. Especially for injected into cavities and cracks in concrete, increasing the bond strength and restoring its structural integrity.

Hose clamp

This research is using hose clamp ring at bamboo reinforcement to improve bond between bamboo and concrete reinforcement. Hose clamp ring size is ¾“ made in Taiwan as shown in figure 1a.

a. Hose clamp

b. Test setup

c. Bamboo speciment

Figure 1. Hose clamp, bamboo speciment and tension test setup.

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Experimental Program

The following tools are used for the experiment: 2000 kN compression machine of concrete test for compression strength test of concrete, 500 kN Universal Testing Machine (UTM) for bamboo tension test and pullout test. The loading frame with hydraulic jacks and load cells are using for flexural strength test. Several specimens for each type of test is shown in Table 1.

Table 1. Objects test speciment

Type of testing	Number of specimens
Concrete compression strength testing	14
Tension testing of bamboo	6
Pullout test	15
Beam flexural test	4

Concrete compression strength testing

Material for normal concrete was cement, sand, coarse aggregate, and water. Sand and coarse aggregat was taken from Malang. Specimen test was cylinders with 150 mm diametre and 300 mm height. Concrete cylinder covered with gunny sack for 28 days. Specimens were weighed before test. The specimens were placed in compression testing machine. The load is applied to concrete in gradual increments until the specimen failure. Compression stress is determined at ultimate load.

Tension testing of bamboo

Bamboo specimens with length of 300 mm use as shown in figure 1c. The procedure of tension test for bamboo is same as for steel. Load and elongation readings for specimen which placed in UTM are recorded.

Pull out tests specimen

The dimension of Bamboo reinforcement are 15mm x 15mm x 400mm. Concrete cylinders of 150 mm diametre and 300 mm length are used for test. Bamboo reinforcement were inserted at the center of concrete cylinders with 200 mm depth when casted. Speciment were tested after 28 days curing. Several treatment has made to measure their performance in improving the interaction bond-slip strength between bamboo and concrete. Total 15 cylinders are casted for the comparison purpose, which includes three cylinders for each different treatment, i.e., bamboo reinforcement with (a) normal reinforcement, (b) hose clamp with span 100 mm, (c) Sikadur®-752, (d) Sikadur®-752 and hose clamp with span 100 mm, and (e) Sikadur®-752 and hose clamp with span 50 mm. The typical sectional detail and pull out test setup is shown in figure 2.

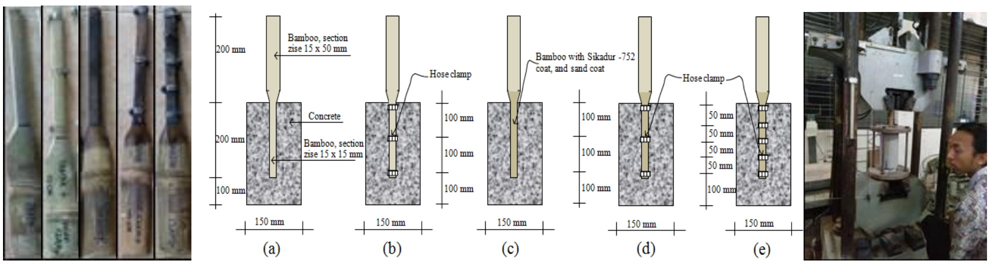

Figure 2. Typical sectional detail of pull out tests and test setup

Speciment bond stress (τ_b) is calculated using equation (Agarwal et al., 2014):

$$\tau_b = \frac{F}{SL} \quad \text{(N/mm}^2\text{)} \qquad (1)$$

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where F is pulling out load, S is perimeter of bamboo reinforcement and L is length of bonded interface. Bamboo reinforcement can be detached from concrete because of split in the longitudinal direction when the high frictional adhesion or high defence. When bamboo reinforcement could be pulled out and leave a hole in the concrete, it means low adhesion or small friction.

Beam flexural test

This research used bamboo petung (Dendrocalamus asper) 2-3 years. Dimension of bamboo reinforcement is 15 mm x 15 mm x length of bamboo. Dimension of concrete beam is 120 mm x 200 mm x 2100 mm, with tensile reinforcement (ρ) about 4.68% and compression reinforcement (ρ') about 1.875%. Reinforcement for shear strength using steel reinforcement with 6 mm diametre. Four beam specimens were casted with four different treatment of bamboo reinforcement, i.e. : (B1) normal reinforcement, (B2) with hose clamp, (B3) with water-resistant coating, and (B4) with water-resistant coating and hose clamp as shown in Figure 3. Table 2 show the dimensions and cross section of sample beams. The resulting concrete is poured in cylindrical moulds of 150 mm diameter and 300 mm height. After casted, concrete beams are kept in wet place and de-moulded at 24 hours age. Beams were tested after 28 days treatment. Specimens tested at loading frame with capacity of 150 kN and load cell with capacity of 100 kN. During the loading test, load (P) was measured by load cell. Speciment displacements externally measured by displacement transducers instrument at the bottom of specimens. Beam tests performed using four-point load as shown in Figure 4.

Table 2. Dimension and cross section of beam specimen

Beam Specimens	Longitudinal Reinforcement		Stirrup at		Using Hose Clamp	
	Upper	Lower	Position of shear field	Position of no shear field	Upper	Lower
(B1) Normal	2□15x15	5□15x15	Ø 6 - 5	Ø 6 - 20		-
(B2) Hose Clamp	2□15x15	5□15x15	Ø 6 - 5	Ø 6 - 20	_	Ø ¾" - 10
(B3) Sikadur®-752	2□15x15	5□15x15	Ø 6 - 5	Ø 6 - 20		-
(B4) Sikadur®-752 + Hose Clamp	2□15x15	5□15x15	Ø 6 - 5	Ø 6 - 20		Ø ¾" - 10

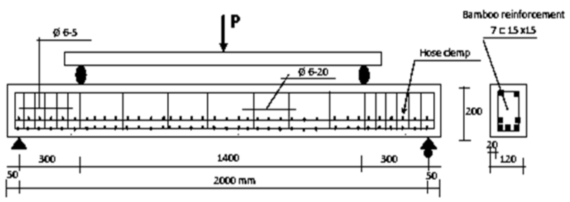

Figure 3. Details of beam specimens

Figure 4. Four-point loading test set up for beam

RESULT AND DISCUSSION

Concrete compression strength test

Compressive strength test was performed according to ASTM C 39 at 28 days using Universal Testing Machine with a constant loading rate. In order to ensure uniform loading on the cylinder, each

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Specimen was capped with sulfur. Average compression stress of normal concrete was 31.31 MPa and average weight concrete silinder in the study was 122.78 N.

Tensile testing of bamboo

Tensile test is conducted to understand the ultimate strength and elasticity parameters of the bamboo reinforcement. Test procedure for bamboo reinforcement is same as for steel. Total six specimens are tested for this purpose. Bamboo is more vulnerable for failure at the nodes. All six samples considered for the study were having one node. The physical dimensions of samples and corresponding test results are given in Table 3. Measurement of width and thickness done at six different location on the speciment and their average value is considered as strength estimation. From Table 3, average tensile strength is 126.68 N/mm^2. The average strain value is 0.0074. The modulus of elasticity is 17118.92 MPa.

Table 3. Details of tensile test results

Specimens	Length (mm)	Width (mm)	Thickness (mm)	Area (mm2)	Ultimate load (kN)	Failure stress (MPa)
1	300	16	14	224	38	169.64
2	300	15	15	225	20	88.89
3	300	14	14	196	28	142.86
4	300	15	13	195	30	153.85
5	300	16	12	192	18	93.75
6	300	15	12	180	20	111.11
Average =						126.68

Pull out tests results

The Pull-out test for bamboo reinforcement with layer of sikadur 752 and hose clamp ring embeded in concrete cylinders shows that the increasing the adhesion stress about 364% to 411% of the bamboo without treatment with the distance of hose clamp about 100 mm and 50 mm in a row. While the failure patterns shows the bond failure, concrete cone failure and bamboo failure of nodes as shown in Figure 5b and Figure 5c. It shows that influence of hose clamp installation on bamboo reinforcement are work well and the bamboo reinforcement still attached to the concrete.

For specimens without hose clamp ring, the collapse bond-slip failure are shown in Figure 5a. However, in a few cases, bamboo samples have broken during the slippage despite of fact that tensile strength of bamboo sample is much higher than the maximum bond stress which obtained between bamboo reinforcement and concrete. This due non-alignment of the samples in testing machine leading to unnecessary eccentricity. Details of 15 cylinder test and the results are shown in Table 4.

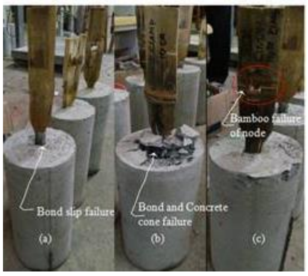

Figure 5. Modes failure of pull out test

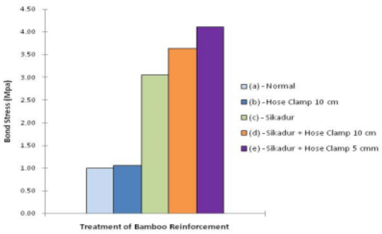

Figure 6. Variation of Bond stress of Bamboo reinforcement

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Beam flexural test

Flexural analysis of bamboo's reinforced concrete beam in this study refers to the research of Ghavami (2005). The balance between the compressive force on the concrete (C) with a tensile force (T) must be fulfilled. Tensile on bamboo reinforcement (T) is obtained by multiplying the stresses by juxtaposition (Pull out test results) with an area of shear reinforcement, because based on the research of bamboo reinforced concrete beam collapse caused by the loss of bond between bamboo and concrete. Flexural test results and calculations on bamboo reinforced concrete beams can be shown in Table 5.

Table 4. Details of pull out test results

No	Treatment	Bamboo width (mm)	Bamboo thickness (mm)	Depth (mm)	Contact area per unit height (mm)	Pull out load (kN)	Bond stress (MPa)	Average Bond Stress (MPa)	Modes of Failure
1	(a) Normal	15	15	200	60	12	1.00	1.00	Bond slip failure
2			15		60	12	1.00		
3			10		50	10	1.00		
4	(b) Hose clamp	15	15	200	60	12	1.00	1.06	Bond slip failure
5			15		60	13	1.08		
6			10		50	11	1.10		
7	(c) Sikadur®-752	15	15	200	60	40	3.33	3.06	Bond slip failure
8			15		60	33	2.75		
9			15		60	37	3.08		
10	(d) Sikadur®-752 + Hose clamp 10 cm	15	15	200	60	42	3.50	3.64	Bamboo failure of node
11			15		60	44	3.67		
12			15		60	45	3.75		Bond and Concrete cone failure
13	(e) Sikadur®-752 + Hose clamp 5 cm	15	15	200	60	49	4.08	4.11	Bamboo failure of node
14			15		60	49	4.08		
15			15		60	50	4.17		Bond and Concrete cone failure

Table 5. Comparison of flexural test results and theoretical calculations

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. Specimens	Theoretical calculations		Flexural test results			Bond stress flexural beam (μ) (MPa)	Bond stress pull out test (u) (Mpa)
	First crack load (kN)	Ultimete load (kN)	First crack load (kN)	Failure load (kN)	Deflection at failure (mm)		
B1-Normal	21.64	78.32	16.00	60.00	28.57	0.75	1.00
B2-Hose clamp 10 cm	21.64	82.54	16.50	52.50	29.60	0.66	1.06
B3- Sikadur®-752	21.64	183.60	20.00	98.30	33.26	1.62	3.06
B4- Sikadur®-752 + Hose clamp 10 cm	21.64	198.57	19.50	86.50	28.24	1.57	3.64

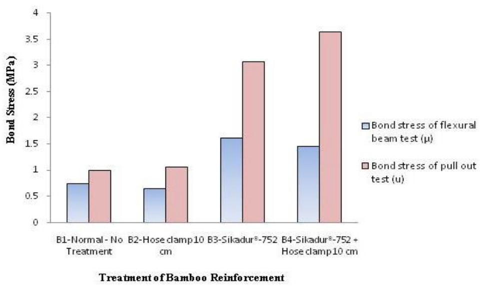

Figure 7. The comparison graph of bond stress of pull out test and flexural beam test

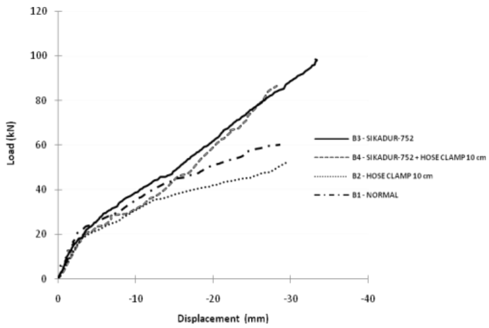

Figure 8. Load-deflection curve for beams under four-point loading test

Comparison of bond stress of pull out test and flexural beam test

The bond-stress of pull-out test (u) is greater than flexural stress of bond-beam test (μ). From Figure 7 and Table 5, it shows that the value of the bond-stress for specimens of bamboo reinforcement-Normal B1 and B2-Hose clamp with distance of 100 mm is lower than the speciment reinforcement with layers of water-resistant bamboo-Sikadur®-752 B3 and B4-Sikadur®-752+ hose clamp with distance of 100 mm. However beams with bamboo reinforcement of Sikadur®-752 + hose clamp with distance of 100 mm tend to be more rigid, it is caused by the installation of a less optimum hose clamp.

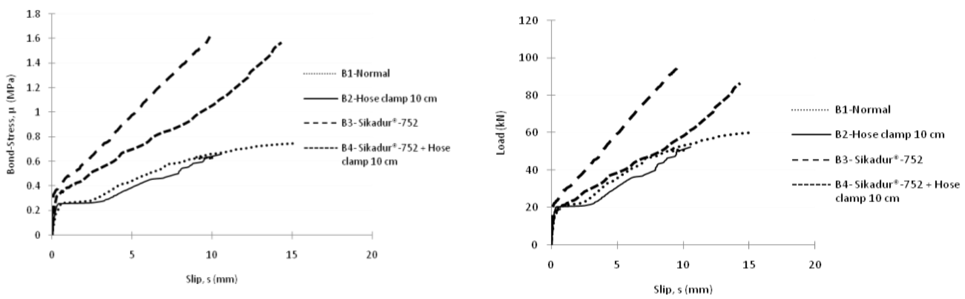

Figure 9. Bond stress–slip relationships and Load–slip relationships of bamboo reinforced concrete beam speciments

Bond-slip of bamboo reinforcement

In general, Load-slip relationship is characterised by small slippage at initial loading stage, then followed by rapid increase when load reaches the maximum support load. At initial loading stages, there were the well bonding performance are observed in these four beams, and their load–slip curves almost linear. At this stage, chemical adhesion between concrete and bamboo reinforcement governs bond mechanism, and slippage is avoided. After lost chemical bond, the friction between the concrete and bamboo reinforcement takes effect. With load increase, bond–slip between bamboo reinforcement and concrete develops, friction diminishes and contact surface is damaged, and when applied load reaches maximum support load, sudden decay is recorded. The peak loads for both beam B1 and B2 attained quickly and at comparatively low slip values and their maximum support loads are 60 kN and 52.50 kN respectively. This is due reinforcement of bamboo which has properties hygroskopis and slippery surface.While for beams B3 and B4 with bamboo reinforcement layered of water-resistant reinforcement Sikadur®-752 and bamboo with layered of water-resistant Sikadur®-752 + hose clamp, showing bond-slip behavior better. B3 and B4 beams exhibits better bond–slip behaviour. A well bonding performance with very little slippage is recorded till around 98.30 kN dan 86.50 kN, and the load–slip curves are almost linear as shown in figure 9. Achievement of maximum load beams B3 and B4 is much larger than achievement of maximum load beams B1 and B2. It can shown that bamboo reinforcement surface condition is very important to bond–slip behaviour between bamboo and the surrounding concrete.

CONCLUSIONS

Calculation of the bond-stress reinforcement of bamboo based on direct bond pull-out test is greater than bond-stress reinforcement that occurs on the beam. The bamboo reinforcement's surface condition is very important in the bond-slip behavior between bamboo reinforcement and the surrounding concrete. Installation of hose clamp can increase stiffness and bond-slip bamboo reinforcement, but the not optimum installation in hose clamp, can decrease ductility of bamboo's reinforced concrete beam. All beams shows cracks and collapse due to failure of slip, but concrete beam with bamboo reinforcement which coated by water-resistant material and hose clamp has many spread crack before collapses.

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