Experimental analysis on the performance of concrete beam due to the effect of knitted bamboo reinforcement ratio

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Abstract. Bamboo is an abundant material in Indonesia which has been previously studied as a construction material and reinforcement. The performance of concrete beam with knitted bamboo reinforcement are studied, especially on the flexural strength and crack behaviour. Three concrete beams with the dimension of 15 x 25 x 160 cm and three slices of bamboo in each knit are investigated. The outer skin surface of this knit is soaked NaOH with sikadur and sand as coating material. The results found that the flexural strength of concrete beam for the first and second model was 3.56 MPa and 6.15 MPa, respectively. Pure bending crack occurred on all concrete beam models.

1. Introduction
Bamboo is an abundant material in Indonesia, as a tropical climate country. The selection of bamboo as a building material already studied because of its advantages, such as high tensile strength and relatively low price than steel [1]. Previous research on the using of bamboo as a construction material and reinforcement has been studied [2]. From this study, it has been suggested that the use of bamboo strips as reinforcement in column should not be for the purpose of imparting compressive strength but rather than to induce elasticity in the cross section, which in turn guide against sudden failure.

Furthermore, the application of bamboo as a knit reinforcement already applied at the concrete wall in resisting lateral load [3] and embedded into concrete beam which is compared to the plain bamboo reinforcement [4]. The result shows that it contributes on the increasing of friction force between reinforcement and concrete as compared with plain bamboo reinforcement.

2. Experimental methods
The present experimental study examined the behavior of concrete beam with variation of knitted bamboo reinforcement subjected to three-point bending load [5]. Three concrete beams were investigated with the details on structural model and test set-up in the following section.

2.1. Structural modelling
The dimension was 15 x 25 x 160 cm, represent the width x height x length of the RC beam with concrete covers of 30 mm. The target compressive strength was 20 MPa. The knitted bamboo reinforcements with the dimension of 4 mm x 4 mm were applied in each beam as shown in Figure 2. Each knit contained three slices of bamboo with outer skin surface which were soaked with NaOH, with the pattern
in Figure 1 [4]. The coating material consist of sikadur and sand were used in order to reduce the shrinkage and to provide the skin friction of bamboo, respectively.

Figure 1. Knit pattern, (a) modeling of knit pattern which was refer to (b) [4], (c) knit pattern with sikadur and sand coating [4]

Figure 2. Two different variation of knitted bamboo reinforcement (unit: mm)
2.2. Pull-out test of knit bamboo reinforcement
The tensile strength of knit bamboo reinforcement was experimentally tested previously with pull-out test method [4]. Based on this paper, it can be suggested that the first variation of knit bars applied in this research had the greatest average number of the tensile stress. Furthermore, this type of knit model could improve the bonding stress between bamboo and concrete due to its improvement to the friction force between bamboo reinforcement and concrete. In addition, prior research determined the tensile strength of this material was 216 MPa [6], which was slightly lower than the tensile strength of undeformed steel bar.

2.3. Compressive strength test of cylinder concrete
The total of six cylinder concrete test specimens for the first model was examined previously by compressive strength machine, with the averaged result of 29.34 MPa, as shown in Table 1. From this result, it can be noted that the third mixing has the smallest results which is possible due to inconsistency compaction process. While the averaged compressive strength for the second model was 27.5 MPa. According to these results, it can be seen that the compressive strength for each model exceed the target strength of 20 MPa.

| Specimens | Compressive Strength (MPa) | Averaged Compressive Strength (MPa) |
|-----------|---------------------------|-----------------------------------|
| 1A        | 31.31                     |                                   |
| 1B        | 30.18                     |                                   |
| 2A        | 28.87                     |                                   |
| 2B        | 32.22                     |                                   |
| 3A        | 28.87                     |                                   |
| 3B        | 24.57                     | 29.34                             |

2.4. The flexural strength test for RC beam
The flexural strength for every beam was tested by using three-point bending load method depicted in Figure 3. In order to examine the maximum deflection of this structural model, LVDT was located under the mid-part of beam. In addition, crack was observed throughout loading produced by hydraulic jack and transferred using spreader beam. The flexural strength was calculated by equation (1).

![Figure 3. Bending test set-up in laboratory [6]]
\[ \sigma_{\text{max}} = \frac{P_L}{b h^2} \]  
(1)

where

- \( P \) = the maximum load (N)
- \( L \) = length of the beam (mm)
- \( b \) = width of the beam (mm)
- \( h \) = height of the beam (mm)

3. Results and discussions

3.1. The maximum load

The maximum load of reinforced concrete beam specimen was calculated theoretically with the moment capacity of the tested beam. In addition, the result would be compared to the experimental data. The theoretical calculation for the first model is presented below, shown in Figure 4. According to this analysis, it could be seen that the maximum theoretical load about 19.64 kN. While the experimental data are shown in Figure 5. It is depicted that the averaged maximum load is 22.23 kN, which is 13.18% larger than theoretical calculation. In addition, the averaged result is 46.09 kN which is twice larger than the previous model. This condition is due to difference on knit bamboo reinforcement modelling and width of beam.

**Figure 4. Structural model**

Dimension of the RC beam:

- Length of the beam (L) = 150 cm
- Width of the beam (b) = 15 cm
- Height of the beam (h) = 25 cm
- \( C = T \)
- \( 0.85 f'c.b.a \) = \( As.fy \)
- \( a = \frac{As.fy}{0.85f'c.b} \)
The 2nd International Conference on Green Civil and Environmental Engineering  
IOP Conf. Series: Materials Science and Engineering 669 (2019) 012043    doi:10.1088/1757-899X/669/1/012043

\[ \frac{96 \times 216.076}{0.85 \times 29.34 \times 150} = 5.55 \text{ mm} \]

\[ M_n = \text{As.fy.}(d-a/2) \]

\[ = 96 \times 216.076 \times (220 - 5.546/2) = 450.6 \text{ kgm} \]

\[ M_n = \frac{1}{2} P.L_1 \]

\[ P = 2002.67 \text{ kg} = 19.64 \text{ kN} \]

**Figure 5.** The maximum experimental load for the first model

### 3.2. Load vs deflection curve

Deflection of the tested beams were observed during the bending test analysis, depicted in Figure 7. According to the experimental results, it could be determined that the maximum deflection for the first model occurs in the third beam model with the value of 4.23 mm. The average data will be equal to 4.00 mm. Moreover, the experimental deflection result for the second model is 2.22 mm, which is smaller than the first model. It indicates that knit bamboo reinforcement capable to restrain the tensile force due to external load.

**Figure 6.** The flexural strength of RC beam for the first model

### 3.3. Crack propagation

Each specimen has a similar crack behaviour, which propagates firstly around middle of the beam as a pure bending area. Then, collapse occur immediately after increasing load of 100 kg with the maximum crack width of 6 mm for the first and second specimen, and 2 mm for the third specimen. Experimental results of the crack propagation can be seen in Figures 8 and 9 for the first and second model, respectively.
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Figure 7. Load vs deflection curve for the first model

Figure 8. Crack propagation of the concrete beam for the first model
4. Conclusions
In this work, the knit bamboo was used as the reinforcement of concrete beam. Based on the experimental observation, the following can be deduced:

- The average flexural strength of the first model and second model were 3.56 MPa and 6.15 MPa, which are larger than theoretical calculation.
- The crack behaviour for the first and second model could be categorized as pure bending crack. The concrete beam collapsed directly after increasing load on the first crack.

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