Performance of Bamboo and Steel Reinforced Concrete under Flexural Strength

P E H Ab.Rahman¹, N J A Malek², Mohd Hanizan Bin Bahari ³ and R Hassan⁴

¹ MSc student, Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia
² SEGi University Kota Damansara, Petaling Jaya, Malaysia
³ Kolej Kemahiran Tinggi MARA Pasir Mas, Lebuhraya Lubok Jong, Pasir Mas Kelantan, Malaysia
⁴ Engineered Wood Product (EW⁵) Research Group, Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia

Abstract. As well known, concrete and steel are widely used in construction industry due to its strength and durability. The usage of these materials is threatening the environment as steel and concrete are non-renewable sources and the productions were consuming largest energy in construction industry. In order to overcome this problem some studies were conducted by different researchers in replacing steel with bamboo in structural components such as beam, column, slab and others. Therefore, in this study, the usage of bamboo as the replacement for steel reinforcement in concrete covering slab is tested. The flexural strength of bamboo reinforced concrete covering slab for 100 mm x 50 mm and 100 mm x 100 mm meshing were tested under four-point load. The result of comparison of flexural strength between steel reinforcement and bamboo meshing shows that the steel reinforcements have more flexural strength than bamboo meshing with percentage difference of 40.95% for 100 mm by 100 mm meshing opening and 62.37% for the 100 mm x 50 mm meshing opening size. From the experiment, it shows that slab cover with steel reinforcement has higher bending strength that the bamboo reinforced. The brittle behaviour of bamboo cannot compete with steel with higher elasticity.

1. Introduction
In the civil construction industry, concrete and steel are widely used due to its strength and durability. Although concrete strong and durable, it still need reinforcement to strengthened the concrete and to prevent cracking. Steel is non-renewable sources which is a threat to the construction industry. The commonly used reinforcement materials are steel, fibre and many others. As well known, steel is not easy to find due to lack of resources and need skilled labour to handle them. Reinforcement is needed in a concrete structure as it is weak in compression and bending.

As steel is a non-renewable sources and becoming more limited, the prices are starting to increase. Therefore, the usage of natural and renewable bamboo would reduce this problem. Other than expensive, the production of steel could harm the environment. As stated by Bujnan (2011)[1], hazardous emission from steel were obviously potentially to be a harmful acidification. Therefore, in order to minimize the usage of steel in structure, some studies were carried out to replace the steel reinforcement with bamboo.

Bamboo is a natural vegetation and available at most places. Due it availability, the bamboo is much cheaper than steel thus can provide lower cost construction. Before bamboo can be used as
construction material, it needs to be protected from several conditions such as temperature, moisture and pests. Therefore, treatment is needed to preserve the bamboo.

Previously, there were many studies regarding the usage of bamboo to replace steel reinforcement (Pozo et al., 2017[2]; Wang et al., 2017[3]; Teychenne et al., 1988[4]; Gupta, 2007[5]; David, 2005[6]; Bujnan, 2011[1]; Janssen, 1987[7]; Alireza et al., 2014[8]; Sevalia et al., 2013[9]; Guo et al., 2013[10]; Ghavami, 2005[11]; Mansur et al., 1983[12]; Maruthupandian et al., 2016[13]; Terai et al., 2012[14]; Schneider et al., 2014[15]; Pawar, 2014[16]; Yu, 2007[17]; Jung, 2006[18]). For example, a study by Khan, 2014 [19] reported on the usage of bamboo reinforcement in beam. The author used several types of cross sectional area of bamboo as reinforcement and compared them with the steel reinforcement in beam. In extension to their research, this study is conducted to test bamboo meshing as steel replacement function to reinforced concrete covering slab.

2. Literature Review

Bamboo has been used for centuries in the construction of low-cost rural housing in developing countries (Mansur et al, 1983)[12]. Countries such as Asia, South America and Africa used bamboo for thousands years ago as furnishings, buildings and bridges. More new industrial material have been invented from bamboo as needs for people in daily life Bamboo contains cellulose, lignin and hemicellulose which is same with trees (Yu, 2007)[17]. Bamboo only need 5 years to grow therefore it was a renewable sources of short cycle (Guo et al, 2013)[10]. Bamboo fiber has become an ecological viable substitute for wood fiber and presents great potential for various applications in the polymer composites industry (Wang, 2017)[3]. A study that conducted by Ghavami (2005)[11] which studied the capability of bamboo to absorb water on several species. The water absorption by the bamboo could cause cracks in cured concrete. Other than water absorption, the bond between concrete and treated bamboo is higher than the bond between concrete and steel or untreated bamboo.

2.1. Bamboo as steel reinforcement replacement

Steel is often used as reinforcement for any concrete structure. But it have several disadvantages such as corrosion and costly. Other than that, it needs high energy in the production and it releases CO2 during the production which is not environmental friendly. Ho et al. (2012)[20] stated, composites material is more efficient. Maruthupandian et al. (2016)[13] concluded that bamboo could replace steel as reinforcement as the tensile strength of bamboo is quite high. Even the deflection of both slab with different reinforcement was merely equal. Besides that, the pull-out test conducted to compare between steel and bamboo bonding with concrete proved that bamboo bond strength is higher than steel (Terai, Minami, 2012)[14]. This prove that bamboo is capable to replace steel as reinforcement. Schneider et al. (2014)[15] conducted a pull-out test to measure the bond between bamboo and concrete and the effects of waterproofing and bond strength. From the pull-out test, it concluded that the treated bamboo has larger bond strength than untreated bamboo.

3. Methodology

3.1. Specimen Preparation

For this study, 24 numbers of specimens designed as covering slabs were prepared and tested on the flexural test. Out of the 24 numbers covering slabs, 12 specimens are steel reinforced covering slabs as the control specimens and another 12 specimens are bamboo-mesh reinforced. The size of the covering slab that casted was in 300 mm x 600 mm x 50 mm in dimension. Each concrete covering slab was tested on the flexural strength using the bending test. Firstly for the steel meshing preparation, R6 steel rod were used. The rod were first cut, then were welded according to the required spacing. As for the bamboo meshing, the bamboo were cut into 6 mm width. Then it was cut into the length and tighten using coconut coir rope according to the required spacing as shown in Fig. 1. Before the reinforcement were arranged in the formwork, strain gauges were installed respectively according to the type of reinforcement (steel and bamboo).
3.2. Experimental Setup

As for the formwork, firstly for the compression test, standard steel mold size of 100 mm x 100 mm x 100 mm was used. As for precautions steps, the molds were cleaned and greased so that the concrete will not stick to them. The nuts and bolts were fully tightened.

As for flexural test, the mold was made of timber formwork in a size of 600 mm x 300 mm x 50 mm. The formwork must be strong to withstand vibration during concrete compaction. The formwork must have no leakage to avoid water loss and honey combing. The steel and bamboo meshing were prepared as designed.

After the strain gauges were installed, the meshing were installed in the mold. Block spacer or tofu were installed before the meshing is placed. The tofu thickness must be the same as the designed cover that is 25 mm. the block spacer were made from sand cement and water.

Next, the concrete were mixed using the concrete mixing machine. The cement, water, fine and course aggregate weight according to the designed mix as stated in Table 3.1. For the covering slabs, the formworks were removed after 24 hours. As for compression test or cube test, six cubes were prepared and tested for 7 days and 28 days.

The slabs were cured using wet fabrics and placed at an open space so that it will exposed to sunlight and rain. After 28 days, the slab undergoes bending test using Universal Testing Machine (UTM). The cubes were placed into a pool of water for the process of curing. After a week (7 days), three cubes were tested for compression test. Then it were repeated for 28 days.

Table 1. Concrete Mix Design for Concrete with grade 25 N/mm² (Appendix 1)

| Per trial mix of 1m³ | Cement (kg) | Water (kg) | Fine Aggregates (kg) | Coarse Aggregates (kg) |
|---------------------|-------------|------------|----------------------|------------------------|
| Controlled Mix and specimen | 205 | 410 | 621 | 1104 845 |
3.2.1. Strain Gauge

The strain gauges were installed in order to measure the strain of the steel reinforcement, bamboo reinforcement and the concrete itself. Three types of different strain gauges were used for each type of material. The strain gauges were properly mounted onto a smooth surface and it was wrapped using cellophane tape to prevent it from damage due to water.

Figure 2. Steel Reinforcement with Strain Gauge Installed.

3.2.2. Linear Variable Differential Transformer

The function of LVDT is to provide small displacement output. It produces electrical output which allows it to produce displacement with good resolution. The LVDT will be placed at the mid span of the slab. The formulas that going to be involved in the analysis are modulus of rupture, maximum bending strain and modulus of elasticity.

Figure 3. Four-point bending test

Figure 4. LVDT Location
Table 2. Formulas modulus of rupture (MOR), max bending strain and modulus elasticity (MOE).

|                      | Formula                                      |
|----------------------|----------------------------------------------|
| Modulus of rupture, $\sigma_f$ (MPa) | $\sigma_f = \frac{3P(L-Li)}{2BD^2}$          |
| Max bending strain, $\varepsilon_f$ (mm)  | $\varepsilon_f = \frac{6\delta D}{(L-Li)^2}$ |
| Modulus of elasticity, $\varepsilon_f$ (MPa) | $\varepsilon_f = \frac{\sigma_f}{E_f}$       |

4. Results and Discussion

This study was carried out in order to determine the flexural strength of bamboo reinforced concrete covering slab and was compared to the flexural strength of steel reinforced concrete covering slab. The experiments that were involved in this are compression test or cube test, and bending test.

4.1. Compression test

The results of the compressive strength are as stated in Table 3. All the cube shown that the concrete strength are more than the strength design which is 25 N/mm$^2$. The result shown that the compression strength of the concrete were increasing which shows that the longer the slab is cured by putting it in a full fill with water, the stronger the concrete.

Table 3. Result of compression test.

| Cube      | 7 Days | 14 Days | Average value |
|-----------|--------|---------|---------------|
| 1         | 30.9 N/mm$^2$ | 37.75 N/mm$^2$ | 30.40 N/mm$^2$ | 36.84 N/mm$^2$ | 29.87 N/mm$^2$ |
| 2         | 30.40 N/mm$^2$ | 36.84 N/mm$^2$ | 28.31 N/mm$^2$ | 36.54 N/mm$^2$ | 37.04 N/mm$^2$ |
| 3         | 28.31 N/mm$^2$ | 36.54 N/mm$^2$ | 29.87 N/mm$^2$ | 37.04 N/mm$^2$ |               |

4.2. Flexural strength test

Six of the specimens were bamboo reinforced concrete covering slab and the rest were steel reinforced concrete slab.

4.2.1. Flexural Strength for Control Sample with Meshing Opening

Figure 5 shows the result of flexural test for control sample with meshing opening size 100mm x 100mm. The maximum load for these samples are 13.31 kN, 13 kN and 13.53 kN respectively.

![Load versus Deflection for control Sample (100 mm x 100 mm)](image)
Figure 5 shows that load versus deformation for the control samples with 100 mm by 100 mm meshing opening. Figure 6 shows that load versus deformation for the control samples with 100 mm by 50 mm meshing opening. All the three lines show the same pattern as it increase within the displacement and the load. Then the load decrease drastically due to the cracks. Even after the first crack happen, the load still increasing because the slab endure more load due the steel reinforcement still can cater those loads.

![Figure 6. Load versus Deflection for Control Sample (100 mm x 50 mm)](image)

### 4.2.2. Flexural Strength For Bamboo Sample With Meshing Opening 100mm x 100mm

Figure 7 shows the result of flexural test for bamboo sample with meshing opening for the size 100mm x 100mm. Figure 8 shows the result of flexural test for bamboo sample with meshing opening size of 100 mm x 50 mm.

![Figure 7. Load versus Deflection for Bamboo Reinforced Sample (100 mm x 100 mm)](image)
Figure 8. Load versus Deflection Graph for Bamboo Reinforced Sample (100 mm x 50 mm)

Figure 7 shows that load versus deformation for the bamboo reinforced slabs samples with 100 mm by 100 mm meshing opening. Figure 8 shows that load versus deformation for the bamboo reinforced slabs samples with 100 mm by 50 mm meshing opening. All the three lines show the same pattern as it increase within the displacement and the load. Then the load decrease drastically due to the cracks and the failure of the bamboo to help the concrete slab to cater the deflection.

4.2.3. Comparison of the Flexural Strength Between Steel and Bamboo Reinforced Concrete Cover

Figure 9. Comparison of Average Load versus Deflection between 100mm x 100mm Steel and Bamboo Reinforced Concrete Slab
Figure 9 and 10 show that steel reinforced concrete covering slab could cater more load compared to bamboo meshed concrete covering slab. From this result, it shows that bamboo failed drastically due to its brittle behaviour meanwhile the control sample shows ductile behaviour.

4.2.4. Modulus of Rupture Percentage Difference between Bamboo and Steel Reinforced Concrete Slab

Figure 11 shows the percentage differences between steel and bamboo reinforced concrete covering slab in the modulus of rupture. For 100 mm x 100 mm meshing opening, the bamboo percentage is 41% and 62.34% lower than steel reinforcement respectively.

4.2.5. Maximum Bending Strain Percentage Different between Bamboo and Steel Reinforced Concrete Covering Slab

Figure 12 shows the percentage differences between steel and bamboo reinforced concrete covering slab in the maximum bending strain. For 100 mm x 100 mm meshing opening, the percentage different is 91.80% meanwhile for 100 mm x 50 mm meshing opening, the percentage different is 95.51%.
4.2.6. Modulus of Elasticity

Figure 13 shows the percentage differences between steel and bamboo reinforced concrete covering slab in the modulus of rupture. Figure 13 shows the modulus of elasticity of bamboo-reinforced percentage is 86.10% and 88.08% higher than steel respectively. This shows that bamboo reinforced concrete covering slab is stiffer than steel reinforced.

5. Conclusion

The flexural capacity of bamboo reinforced concrete covering slab are 3.02 N/ and 4.39 N/mm$^2$ respectively. The result of comparison of flexural strength between steel reinforcement and bamboo meshing shows that the percentage of bamboo are 40.95% and 62.37% lower than steel respectively.
References

[1] Bujnan J 2011 Environmental Impact of Steel and Concrete as Building Material.

[2] Angel Pozo Morales, Alfredo Giemes, Antinio Fernandez- Lopez, Veronica Carcelen Valero, Sonia De La Rosa Llano 2017 Bamboo-Polylactic Acid (PLA) Composite Material for Structural Applications.

[3] Wang C, Xian Y, Smith L M, Wang G, Cheng H, Zhang S 2017 Interfacial Properties of Bamboo Fiber-Reinforced High-Density Polyethylene Composites by Different Methods for Adding Nano Calcium Carbonate. Polymers 2017, 9, 587.

[4] Teychenne D C, Franklin R E, Entroy H C 1988 Design of Normal Concrete Mixes. Rosebery avenue, London: Construction Research Communications.

[5] Gupta S M 2007 Experimental Investigation on the Strength and Durability Characteristics of Concrete Containing. Retrieved from https://www.nbmcw.com/tech-articles/concrete/571-experimental-investigation-on-the-strength-and-durability-characteristics-of-concrete-containing.html

[6] David G 2005 Connections and Slab for Bamboo Constructions. The 2005 World Sustainable Building Conference.

[7] Janssen J J A (1987). The Mechanical Properties of Bamboo.

[8] Javadian, Alireza, Hebel, Dirk E, Wielopolsi, Mateusz, Heisel, Felix, Schlesier, Karsten, Griebel, Dragan 2014 Bamboo Reinforcement – A Sustainable Alternative to Steel.

[9] Sevalia J K, Nirav B S, Chetan S A, Shah D B, Kapadia J V 2013 Study on Bamboo as Reinforcement in Concrete.

[10] Guo J, Tang J, Wen Y, Zhang J, Li Y 2013 Development Status of Modern Bamboo Structure Building. Applied Mechanics Materials, 351-352, 26-29.

[11] Ghavami K 2005 Bamboo as Reinforcement in Structural Concrete Element. Cement & Concrete Composites, 27, 637-649.

[12] Mansur M A, Aziz M A 1983 Study of Bamboo-mesh Reinforced Cement Composites. The International Journal of Cement Composites and Lightweight Concrete, 5, 3

[13] Maruthupandian G, Saravanan R, Suresh K S, Siva K B G 2016 A Study on Bamboo Reinforced Concrete Slabs. Journal of Chemical and Pharmaceutical Sciences, 9(2).

[14] Terai M, Minami K 2012 Research and Development on Bamboo Reinforced Concrete Structure.

[15] Schneider N, Pang W, Gu M 2014 Application of Bamboo For Flexural And Shear Reinforcement In Concrete Beams. Structure Congress 2014, 1025-1035.

[16] Pawar S 2014 Bamboo in Construction Technology. Advance in Electronic and Electric Engineering, 4(4), 347-352.

[17] Yu X 2007 Bamboo: Structure and Culture.

[18] Jung Y 2006 Investigation of Bamboo as Reinforcement in Concrete.

[19] Khan I K 2014 “Performance of Bamboo Reinforced Concrete Beam” International Journal of Science and Engineering Technology, Vol-3, No-3.

[20] Ho M, Wang H, Lee J-H, Ho C-K, Lau K-T, Leng J, Hui D 2012 Critical factors on manufacturing processes of natural fibre composites. Compos B Eng 43(8):3549–3562

Acknowledgments
Authors wishing to acknowledge financial support from Universiti Teknologi MARA through MITRA PERDANA grant (600-IRMI/PERDANA 5/3/MITRA (001/2018)-2) and special assistant by Faculty of Civil Engineering technical staff.