The Effect of Minimum Distance Between Bamboo Strengtheners on Flexural Strength of Bamboo Reinforced Cement

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Abstract. Various species of Bamboo is widely available in Indonesia. Usually it is used as pillars, roof frame, and for walls in a woven form and it can be used for steel substitute in reinforced concrete. In making bamboo as a strengtheners or reinforcement a proper volume fraction should be chosen. Besides that, the minimum distance between bamboo bars or inter-strengtheners distance must be determined so that the reinforcement effect on cement matrix takes place. Ten variations of mixtures were used in this research. The number and distance between reinforce bars and its arrangement perpendicular or parallel with loading direction. From the observation it is found that both of the vertically and horizontally arranged bamboo bars at minimum inter-strengtheners distance of 10 mm gave maximum reinforcement and the flexural strength are 16.1 ± 0.3 MPa and 15.8 ± 0.6 MPa. Whereas cement only sample gave 7.2 ± 0.6 MPa hence 2 folds increase. For distance less than 10 mm, the flexural strength is lower, even volume fraction is relatively high and it supposed to give higher strength, in fact this is due to composite reinforcement effect did not occur and this is belief due to a hindered hydration process.

Keywords. Cement, bamboo, composite, minimum inter-strengtheners distance, flexural strength.

1. Introduction

There are about 154 types of bamboo and can be found abundant in Indonesia [1]. One of the usages of bamboo is to be used for masonry or house building and has it been used since long time ago. Usually used as column, roof frame or as a woven for partition. Bamboo has a high tensile strength that almost near to steel [2]. Besides it is cheaper than steel it also grows very fast i.e. between 3-5 years before it can be used for masonry. The disadvantage of bamboo is easily attacked by moths, less resistance to weather and easily get burnt off [3]. Bamboo can also be used to replace steel as reinforcement in a concrete. The amount of bamboo used should be optimized. Besides the volume fraction the minimum distance between strengtheners (inter-strengtheners distance) is very important so that the properties of a composite take effect.
this research besides observing the minimum distance between the strengtheners also direction of its arrangement was also observed to the effect to flexural strength of bamboo composite.

2. Method of Experiment
This research used Gombong bamboo (Gigantochloa Pseudoarundinacea) that is widely available in in West Java. The rectangular bamboo reinforced cement was made with an arrangement as shown in figure 1 and 2. Prior to cement casting the bamboo should be treated first with a polychloroprene solution to make sure the interfacial strength between bamboo and cement is high [4]. This research is an analogy to ACI 318-08 chapter 7 that is specifically for steel bar in a concrete. The three point bending test or flexural test was undertaken on the rectangular specimen. The bamboo is arranged vertical and horizontal in the cement rectangular sample perpendicular or parallel to the load. The rectangular specimen could consist of 2, 3 and 4 bamboos strengtheners as shown in figure 1. Two sizes of bamboo bar or strengtheners were used which are 5x5 mm and 7x7 mm. The sizes of the rectangular were kept the same for the specimens, hence the more the bamboo added distance between them became narrower, this is to observe the effect of strengtheners distances on the composite behaviour. The length of specimen is 290 mm with a rectangular shape 50 x 50 mm. To maintain a fixed distance between bamboos a stiff cable ties was used, hence on cement casting the arrangement will keep in its predesigned configuration.

![Figure 1](image-url)  
**Figure 1.** Cross sectional BRC with horizontally arranged bamboo strengtheners shown as squares. Distance between bamboos is shown on the above schematic.

The three points bending test on rectangular specimens were carried out in the Metallurgical and Materials Engineering Laboratory of Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology. The tests were carried out by using a hydraulic compression machine Tarnogrocki with a loading speed of 7 mm/min and the distance between supports is 17 mm and specimen were necessary measured for further calculation.

3. Results and Discussion
The specimens were tested on a three point bending test or flexural test. The results are as shown in table 1, table 2.

| Table 1. Flexural strength of cement only specimen. |
In table 1 it is shown that the flexural strength of a cement only rectangular sample is 7.2 ± 0.6 MPa. The hydration process took place to form the CSH and the specimens were cured for 28 days. In table 2 is shown the flexural strength of vertically arranged BRC under three point bending or flexural test.

**Figure 2.** Cross sectional BRC with vertically arranged bamboo strengtheners shown as squares. Also written in small letters Theistance between bamboos.

| Specimen Number | Flexural Strength (MPa) | Flexural Strength Average (MPa) | Stdev |
|-----------------|-------------------------|---------------------------------|-------|
| 1               | 8.0                     |                                 |       |
| 2               | 7.1                     |                                 |       |
| 3               | 6.7                     | 7.2                             | 0.6   |
| 4               | 7.6                     |                                 |       |
| 5               | 6.5                     |                                 |       |

**Table 2.** Flexural strength of a vertically arranged BRC

| Type                          | Specimen | Flexural Strength (MPa) | Average | stdev |
|-------------------------------|----------|-------------------------|---------|-------|
| 2 Bamboo, distance 24 mm (BRCv24) | 1        | 11.4                    |         |       |
|                               | 2        | 11.5                    |         |       |
|                               | 3        | 12.7                    |         |       |
| 3 Bamboo, distance 10 mm (BRCv10) | 1        | 15.8                    |         |       |
|                               | 2        | 16.2                    |         |       |
|                               | 3        | 16.3                    |         |       |
| 4 Bamboo, distance 5 mm (BRCv5) | 1        | 11.4                    |         |       |
|                               | 2        | 12.6                    |         |       |
|                               | 3        | 12.9                    |         |       |
| 2 Bamboo, distance 20 mm (BRCv20) | 1        | 11.8                    |         |       |
|                               | 2        | 12.2                    |         |       |
|                               | 3        | 13.5                    |         |       |
In figure 3 it is shown the comparison between semen rectangular and vertically arranged BRC.

![Figure 3. Flexural Strength curve on vertically arranged BRC.](image)

In figure 3 the addition of bamboo as a strengtheners to a cement only rectangular sample will increase its flexural strength from $7.2 \pm 0.3$ MPa to maximum $16.1 \pm 0.3$ MPa. This shows a composite strengthening effect in two folds. Cement or concrete has a resistance to compressive stress rather than a tensile stress. On bending the surface of the specimen undergoes compression, shear in the middle and tension at the bottom. The stress experienced at the top will be at maximum and 0 at the neutral axis. If the load is high at the top hence the bottom of the specimen will experience a high tensile stress, once crack occur the specimen will continue to break. In a BRC the existence of bamboo as a strengtheners will compensate the tensile stress on the bottom part of specimen and at once it can also prevent the crack to propagate further. Hence the flexural strength increased as shown in figure 3. In figure 3 the vertically arranged BRC with 10 mm distance between strengtheners (BRC\textsubscript{V10}) has the highest strength of $16.1 \pm 0.3$ MPa. In BRC with 24 mm and BRC with 20 mm inter-strengtheners distances namely BRC\textsubscript{V20} and BRC\textsubscript{V24} both have 2 bamboos strengtheners. The strengtheners size are respectively 5x5x290 and 7x7x290 mm. According the rule of mixture the volume fraction of bamboo the BRC\textsubscript{V20} has a higher flexural strength than BRC\textsubscript{V24} 12.5 and 11.9 MPa respectively. BRC\textsubscript{V10} and BRC\textsubscript{V7} have the same amount of bamboo strengtheners which is 3 but differ in size which is 5x5 mm and 7x7 mm and distance between bamboos which is 10 and 7 mm. Supposed that the flexural strength of BRC\textsubscript{V7} is higher than BRC\textsubscript{V10} according to volume fraction. In fact it is observed as the other way around the flexural strength of BRC\textsubscript{V10} is higher than BRC\textsubscript{V7} which are 16.1 and 13.5 MPa, hence the inter-strengtheners distance has a dominant effect on the composite properties. This also occurred to BRC\textsubscript{V5} that has higher volume fraction than the BRC\textsubscript{V10} and supposed to have a higher flexural strength too. In fact the observation shows that the flexural strength of BRC\textsubscript{V5} is 12.3 MPa which is lower than the BRC\textsubscript{V10} which is $16.1 \pm 0.3$ MPa.
MPa. From the observation above we can conclude that it is not only strengtheners volume fraction has a dominant effect on flexural strength of a composite but also the inter-strengtheners distance will determined the mechanical properties of the cement composite. At an inter-strengtheners distance of 5 and 7 mm the composite strengthening do not occur. In the case of concrete with steel reinforcement the individual distance between strengtheners should not be less than the diameter of the strengtheners if is uniform and the biggest diameter it is non uniform or 5 mm bigger than the coarse aggregate [5]. In concrete making according to ACI 318-08 chapter 7, the clean distance between parallel strengtheners on the same layer should not be smaller than the dimension of the strengtheners or 25 mm [6]. In case of the distance between strengtheners less than the minimum distance this might hinder the cement paste to enter the gap between strengtheners completely. This will cause the formation of pores or gap with no cement in between hence will decrease the flexural strength of the specimen. Besides tested with a vertical arrangement the BRC is also tested with a horizontal bamboo arrangement as shown in figure 1 and the results is tabulated in table 3.

| Type                  | Specimen | Flexural Strength (MPa) | Average | stdev |
|-----------------------|----------|------------------------|---------|-------|
| 2 Bamboo, distance 24 mm (BRCh_{24}) | 1        | 13.0                   |         |       |
|                       | 2        | 14.7                   | 14.2    | 1.0   |
|                       | 3        | 14.9                   |         |       |
| 3 Bamboo, distance 10 mm (BRCh_{10}) | 1        | 15.1                   |         |       |
|                       | 2        | 16.2                   | 15.8    | 0.6   |
|                       | 3        | 16.2                   |         |       |
| 4 Bamboo, distance 5 mm (BRCh_{3}) | 1        | 12.7                   |         |       |
|                       | 2        | 13.4                   | 13.3    | 0.6   |
|                       | 3        | 13.9                   |         |       |
| 2 Bamboo, distance 20 mm (BRCh_{20}) | 1        | 12.8                   |         |       |
|                       | 2        | 13.5                   | 13.3    | 0.4   |
|                       | 3        | 13.7                   |         |       |
| 3 Bamboo, distance 7 mm (BRCh_{7}) | 1        | 12.6                   |         |       |
|                       | 2        | 14.1                   | 13.7    | 0.1   |
|                       | 3        | 14.5                   |         |       |

In table 3 it is shown that the horizontal arrangement BRC with inter-strengtheners distance 10 mm or BRCh_{10} has the highest flexural strength of 15.8 ± 0.6 MPa. This result is similar with the the vertically arranged BRC with 10 mm inter-strengtheners distance or BRCh_{10}. 


In figure 4 it is shown that the flexural strength of all BRCh is higher than the BRCv except for 10 mm distance between strengtheners. The flexural strength of BRCh has a higher value relatively to BRCv, this might be due to the bigger load bearing area. The area under the load for bamboo with vertical arrangement strengtheners is smaller in compare with the area under load on horizontal arrangement, which were 5 x 290 mm and 5 x 290 x by number of bamboo bars or strengtheners. Hence the stress experienced by the bamboo will become smaller too. In figure 1 it is shown the thickness of cement above the bamboo on horizontal arrangement will be thicker in comparison with the vertical one. The thickness of the cement above bamboo arrangement will determine the flexural strength and also the crack propagation behaviour once a crack initiate on the BRC’s surface.

4. Conclusions
The flexural strength of bamboo reinforced cement (BRC) with horizontal and vertical arrangement of bamboo bars or strengtheners is not only determined by the volume fraction of the components but also depending on the minimum inter-strengtheners distance. As shown above as the inter-strengtheners distance of 10 mm the effect of components on composite strengthening still occurred and giving a value of 16.1 ± 0.3 MPa for BRCv10 and 15.8 ± 0.6 MPa for BRCh10 less than 10 mm the flexural strength will decrease. The minimum value of 10 mm could be proposed to ACI for standard in making bamboo reinforced cement as stated in ACI 318-08 chapter 7 for steel bar reinforcement. The hydration state of the cement matrix between strengtheners strongly affects the flexural strength hence minimum inter-strengtheners distance became the main issue.

5. References
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