Experimental study of variation of models and layers in bamboo’s perpendicular connection to fiber with fiber-reinforced polymer (FRP)

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Abstract. Bamboo is a natural material that is a great demand in the field of simple construction, so connection is one of the things that need to be considered. Research on bamboo connection has been carried out using bolts, steel gussets with wood or mortar fillers, and Fiber Reinforced Polymer (FRP). The use of FRP has advantage since FRP is light, strong, and has adequately high stiffness. This research uses two types of perpendicular connection to fiber (TLS) with two layers methods, different number of layers, and two bolts which function as lateral connection. The used connection testing method is quasi-static monotonic loading. From the results of the study it is found that TLS01-2L increased the maximum load by 80.05 percent compared to TLS01-1L, while in TLS02-2L there is a decrease of 20.65 percent compared to TLS02-1L. In addition, the average ductility value is 2.63 for TLS01 and 2.11 for TLS02 so the stiffness value only reaches 1.75 for TLS01 and 1.97 for TLS02. It can be concluded that the numbers of layer do not affect the strength of the TLS connection but rather the FRP bonding area and the windings method which influences the strength and stiffness of the connection.

1. Introduction
Connection is the most important thing in structure since if it undergoes failure the entire structure will be failed as well. There are several connections in bamboo, such as using bolt, bamboo pegs, palm fiber, and gusset plate with mortar and wood fillers. Nonetheless those connection types have several weaknesses. The connection using bolt and gusset plate as the connector with mortar and wood fillers on its hole makes shear force may be supported by its composite structure, but the use of gusset plate with mortal and wood fillers makes the load of connection heavier with less economic price. Connection with palm fiber is lighter and more economical, but the strength of this connection only relies on the string pull and bamboo’s shrinkage and does affect the strength of the connection. It is different with bolt connection which its strength can be analyzed. Based on [1] as performed a research about connection strength with connecting device in form of Fibre Reinforces Polymer (FRP) and epoxy resin adhesive which its result is compared to bolt and palm fiber connection. It turns out that the strength of FRP connection is higher. FRP is a polymer material resulting from combination between fibers from glassfiber, carbon, and aramid. FRP has adequately high pull strength, even more when it is combined with epoxy resin adhesive. Hence it will generate high-strength fibre wrap. The use of FRP is expected to reduce structure weight without exempting the strength of the connection. Therefore, this latest
research emphasizes more on influence of the use of layer method and the numbers of layer upon lateral resistance strength of a connection system. Specimen is made with variation on the layer method and the numbers of layer. The emerged hypothesis is that lateral resistance strength of a bamboo connection system with FRP is not affected by the numbers of layer, otherwise it is affected by method of layer and FRP bond field area on the connection. The specimen is loaded in quasi-static monotonic manner until a failure happen. The strength of that connection sample is expected to be more significant in order to apply it on bamboo structure connection.

Bamboo connection with Fibre Reinforced Polymer (FRP) is a type of connection that still needed further research. This research is performed by assuming that FRP layer method and the numbers of layer may increase the strength of connection and observe the emerged failure method. From the failure method, it is analyzed connection strength due to FRP bonding and FRP bonding area influences towards bamboo connection.

This research aims to determine FRP bonding value on bamboo connection, determine lateral resistance strength of connection which depends on FRP bonding and FRP bonding area with formulation $P = \tau \times A$, generate comparison of connection strength on two layer methods according to the FRP numbers of layer in simple structure of perpendicular connection to fiber, establish connection failure model by using such FRP and then it is connected with FRP bonding influence on bamboo, hence the lateral resistance strength of bamboo connection with FRP can be predicted.

The used bamboo is bamboo wulung which has been previously preserved with diameter $\pm 80 – 95$ mm, material testing of bamboo and connection tool is not conducted before, the used connection tool of Fibre-Reinforced Polymer (Tyfo SEH-51A comes from fiberglass with ultimate tensile strength to the value of 575 MPa, breaking strain to the value of 2,2%, and tensile modulus to the value of 26,1 GPa) and epoxy bonding (Tyfo S), testing is carried out on perpendicular connection to fiber simple structure with loading quasi-static monotonic manner until the testing object shows failure, on perpendicular connection, two bolts with diameter 16 mm are used, FRP lateral resistance on this connection is calculated based on FRP bonding strength on bamboo according to the result of this experiment.

In order to establish lateral resistance strength of bamboo connection by using FRP and establish connection failure model, FRP is expected to be alternative of other connections.

2. Research Method

Materials which will be used are Bambu wulung as it is seen in figure 1, made with 70 cm length and located in the middle of the rod with diameter uniformity reason. The bamboo have been preserved and without initial material testing. The bamboo is stored in laboratory before it is used. Data of Bamboo material based on [2] in table 1.

| Type of Testing       | Value |
|-----------------------|-------|
| Support Strength (Mpa)| 41,02 |

Figure 1. Bamboo Wulung

Connecting tool of this research used FRP (Fibre Reinforced Polymer) in this research is Type Tyfo SEH-51A by using fiber made from E-Glass. FRP variation in layer numbers in which one and two layers. They used adhesive is epoxy, in which epoxy has resin and hardener contents absorbed by FRP
and has adequately strong binding force. Bolt as a screw with diameter 12 mm and 1.000 mm length and then it is cut in accordance with the needs. By diameter 12 mm, obtained actual diameter of 11.6 mm.

**Figure 2.** Fibre Reinforced Polymer (FRP) Tyfo SEH-51A; Resin; and Epoxy Tyfo S.

### 3. Research Design

Steps of the research in general are the bamboo is cut with size of 70 cm and its nodia is refined. Furthermore, the surface which will be coated by FRP is made rough. Specimen made in accordance with planned method and FRP layer, consists of parallel connection to fiber and perpendicular connection to fiber. Total of all specimens is 24 specimens of connection. Bamboo, FRP, epoxy resin, and bolt are prepared. Testing setting up is prepared and completed with the required tools. Afterward, shear testing on specimen is conducted until it shows failure. Result of the testing is processed to obtain value of maximum load, ductility, and connection strength. By looking at the failure method, FRP bonding strength on bamboo is calculated based on contact field area and load which may be supported by the connection. After bonding strength value is obtained, lateral resistance of connection may be calculated.

Method of perpendicular layer to fiber (TLS01 & TLS02), five bamboos is layered with FRP as in figure 3, start from point A and ended in point B.

**Figure 3.** Method of perpendicular FRP layer to fiber (a) TLS01; (b) TLS02.

In this testing, specimen is placed on loading frame and then load cell is installed in the upper of specimen which connected to hydraulic jack, LVDT is installed in the nearest side from the connection. LVDT is connected to data logger and then will read through laptop. See figure 4.
4. Result And Discussion
Support strength of bamboo Wulung based on experiment [2] obtained value of 41.02 MPa. Data of [2] testing obtains value of bend and yield moment of bolt($M_{yb}$) is to the value of 93.825 Nmm.

4.1. Ductility and Stiffness of bamboo connection

![Figure 4. Scheme of perpendicular connection to fiber testing](image)

\[ \delta_{yield} = 8,46 \text{ mm} \]
\[ \delta_{ultimate} = 27,04 \text{ mm} \]
\[ \text{Ductility} = \frac{\delta_{ultimate}}{\delta_{yield}} = \frac{27,04}{8,46} = 3,19 \] (1)

\[ P_{max} = 22,12 \text{ kN} \]
\[ P_{0,1P_{max}} = 2,21 \text{ kN} \]
\[ P_{0,4P_{max}} = 8,85 \text{ kN} \]
\[ \delta_{0,1P_{max}} = 1,36 \text{ mm} \]
\[ \delta_{0,4P_{max}} = 5,32 \text{ mm} \]
\[ \text{Stiffness (K)} = \frac{P_{0,4P_{max}}-P_{0,1P_{max}}}{\delta_{0,4P_{max}}-\delta_{0,1P_{max}}} = \frac{8,85-2,21}{5,32-1,36} = 1,675 \text{ kN/mm} \] (2)

For further calculation is in tabel.

Below is the testing result calculation on each model of connection presented in graphic and table.
Figure 6. Comparison Graphic of (a) TLS01-1L – TLS01-2L; (b) TLS02-1L – TLS02-2L.

Based on the above graphic, value of connection ductility and stiffness is obtained as in table 2.

Table 2. Result of TLS01 and TLS02 tests.

| Method | Specimen | Maximum Strength, $P_{max}$ (kN) | Ductility Connection | Stiffness, $K$ (kN/mm) |
|--------|----------|----------------------------------|----------------------|------------------------|
| TLS01-1L | A | 22.13 | 3.19 | 1.68 |
|         | B | 0.00  | 0.00 | 0.00  |
|         | C | 27.38 | 3.78 | 2.02  |
|         | Average | 16.50 | 2.33 | 1.23  |
| TLS01-2L | A | 24.88 | 2.28 | 2.75  |
|         | B | 28.38 | 3.35 | 1.99  |
|         | C | 35.88 | 3.20 | 2.06  |
|         | Average | 29.71 | 2.94 | 2.27  |
| TLS02-1L | A | 40.88 | 2.83 | 2.31  |
|         | B | 36.00 | 2.73 | 1.81  |
|         | C | 39.38 | 1.59 | 1.64  |
|         | Average | 38.75 | 2.39 | 1.92  |
| TLS02-2L | A | 38.88 | 2.04 | 2.38  |
|         | B | 29.38 | 2.19 | 1.78  |
|         | C | 24.00 | 1.26 | 1.91  |
|         | Average | 30.75 | 1.83 | 2.03  |

4.2. Bamboo connection with Bolt and Fibre Reinforced Polymer (FRP)

Variation of bolt connection failure is calculated with equation of EYM as in the following table 3:

Table 3. Variation of Bamboo Connection Failure with Bolt as Connecting Tool.

| Yield Model | I$_r$ (kN) | I$_m$ (kN) | III$_r$ (kN) | IV$_r$ (kN) |
|-------------|------------|------------|--------------|-------------|
|             | 9.52       | 4.76       | 4.76         | 4.76        |

Lateral resistance of connection and bolt is 4.76 kN. Since it consists of two shear area and two bolts; hence 4.76 kN x 2 x 2 = 19.04 kN (failure variation of I$_m$, III$_r$, and IV).

FRP lateral resistance of perpendicular connection to fiber is seen in table 4.
Table 4. Lateral Resistance of Perpendicular Connection to Fiber with FRP in Analysis manner.

| Specimen        | $\tau_{\text{Average}}$ (Mpa) | Bonding Area (mm²) | $P_{\text{max Analyse}}$ (kN) | $P_{\text{max Analys Average}}$ (kN) |
|-----------------|-------------------------------|--------------------|-------------------------------|---------------------------------------|
| TLS01-1L-A      | 0,845                         | 89535,39           | 75690,17                      | 72,36                                 |
| TLS01-1L-B      | 0,00                          | 0,00               | 0,00                          |                                       |
| TLS01-1L-C      | 87650,44                      | 89535,39           | 74096,69                      |                                       |
| TLS01-2L-A      | 89535,39                      | 77283,18           | 75690,17                      |                                       |
| TLS01-2L-B      | 77283,18                      | 89535,39           | 65332,57                      |                                       |
| TLS01-2L-C      | 0,845                         | 89535,39           | 75690,17                      | 72,36                                 |
| TLS02-1L-A      | 81053,09                      | 81053,09           | 68519,52                      |                                       |
| TLS02-1L-B      | 89535,39                      | 81995,57           | 75690,17                      |                                       |
| TLS02-1L-C      | 89535,39                      | 77283,18           | 69316,26                      |                                       |
| TLS02-2L-A      | 89535,39                      | 88592,91           | 74893,43                      |                                       |
| TLS02-2L-B      | 77283,18                      | 88592,91           | 74893,43                      |                                       |
| TLS02-2L-C      | 88592,91                      | 88592,91           | 74893,43                      |                                       |

Therefore, theoretically, lateral resistance of perpendicular connection to fiber with FRP and bolt is $72,36 + 19,04 = 91,40$ kN

4.3. Comparison of $P_{\text{max}}$ Value on Connection

In perpendicular connection to fiber, TLS01-2L has higher strength than TLS01-1L, in which there is escalation around ± 1.8 times. Meanwhile, TLS02-2L connection is lower than TLS02-1L, in which decrease until ± 0.79 times. The decrease happens because technical mistake in hydraulic jack when running test; thus, result of the strength is less optimal. Nevertheless, as a whole, layer numbers influence the increase of strength connection since the use of layer number influence FRP bonding which then also influence connection performance in restraining load and protecting bamboo from splitting. Based on layer method, TLS02 has higher strength value than TLS01. Bonding area in TLS02 is bigger than in TLS01.

Based on the graphic above, the generated values are different. It happens due to the used bamboo diameter in this research is bigger than in Andriani (2014) research, bamboo diameter size result in bigger FRP bonding area towards bamboo so that the generated strength becomes big.
4.4. Comparison of Ductility Value on Connection

Figure 8. (a) Comparison Diagram of Ductility Factor of Perpendicular Connection to Fiber; (b) Comparison with the previous one. (with the same method and numbers of layer)

According to Grace in [1] mentions that a structure can be said ductile if it has ductility value more than four, but ductility factor value in the research is less than four. Therefore, the connection is not ductile since FRP properties when running test has high yield value and ultimate stress. Thus, when determining ductility value, comparison of ultimate and yield value is close and results in less than four.

In figure 8 (right) there is different ductility value, it is remain affected by diameter of the bamboo, in which in this research is bigger than Andriani (2014) research. Thus, it causes more FRP needs plus epoxy adhesive so that the connection more brittle and makes ductility factor value of the connection smaller.

4.5. Comparison of Stiffness Value on Connection

Figure 9. (a) Comparison Diagram of Stiffness of Perpendicular connection to fiber; (b) Comparison with the previous one. (with the same method and numbers of layer).

Stiffness value in TLS01 and TLS02 connection is approximately between 1.5-2.5 kN/mm, so that perpendicular connection to fiber is not stiff. It is caused by bamboo geometry shape influence on the connection which makes bonding area of perpendicular connection to fiber smaller and also may be caused by the existence of bolt in such connection.

The decrease of stiffness can be influenced by FRP installation which its stretch less optimal so that it is less stiff.
4.6. Lateral Resistance of EYM bolt and Analysis FRP with Experiment of Perpendicular Connection to Fiber

![Graph showing lateral resistance comparison](image)

**Figure 10.** Comparison of Lateral Resistance of EYM Bolt and Analysis FRP with Experiment in Perpendicular Connection to Fiber

Figure 10 shows that all result of perpendicular specimen lateral resistance to fiber is lower than theoretical calculation. It is caused by the occurred failure in experiment is not a damage towards FRP, but towards bottom horizontal side of the bamboo and central horizontal side of the bamboo which are broken because of bolt deflection. Therefore, theoretical calculation is overestimate.

4.7. Connection Failure Model

In perpendicular connection to fiber, collapse pattern which happen is the most bottom horizontal side of bamboo broken. It is caused by bolt shape change which installed in straight position but when a load given the bolt undergoes deflection and causes bamboo broken. Below is the photo of testing result (Figure 11).

![Photos showing connection failure](image)

**Figure 11.** Failure of perpendicular connection to fiber.

5. Conclusion

Based on the result and calculation of the research, the obtained conclusions are TLS01.2L increased the maximum load by 80.05 percent compared to TLS01.1L, while in TLS02.2L there is a decrease of 20.65 percent compared to TLS02.1L. Ductility value of bamboo connection with FRP is less than four in various methods. Hence, it can be said that the connection is not ductile and in perpendicular connection to fiber is not stiff. Perpendicular connection to fiber TLS02 has higher value than TLS01.
It is affected by FRP bonding area in bamboo. Failure model from perpendicular connection to fiber happens in deflected bolt and bottom horizontal side of bamboo which broken.

6. References
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