Axial compression behaviour of cross laminated wood-wool panel wallettes

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Abstract. This study reported on the investigation of the structural behaviour of wallettes fabricated using wood-wool cement panel (WWCP) under axial compression load. WWCP is a wood based product, which produced by mixing a wood-wool, cement and water and compressed to form a stable panel with dimension of 600 mm x 2400 mm x 50 mm. In the fabrication of wallettes, two parameters were considered which are wallettes without surface plaster denoted as WNP and wallettes with 16 mm thickness of surface plaster on both sides denoted as WP. The 50 mm thickness of WWCP was used and cut into size 300 mm and 600 mm length. The cut panels were then horizontally laid in two layers (each layer consists of two panel strips) at different panel orientation to form a 600 mm x 600 mm wallettes. The front and rear layer were bonded together using 15 mm thick of normal mortar mix at a mixing ratio of 1: 3 (Cement : Fine sand). A total of five wallettes specimens were fabricated and tested under axial compression load test until failure. The testing results indicated that, the application of surface plaster on both side significantly increased the load carrying capacity of wallettes about 31 % compared to the wallettes without surface plaster.

1. Introduction
Every single year human tries to improve one by one the building construction. The improvements are made as to ensure better dream house for future generation [1]. From a sustainability point of view, the best improvement of the structure in a green building should balance between building development and the sustainable environment. In addition, the sustainable construction can help developing in creating greener structures. The aim of the environmental construction is to cut down the impact of built on human health and the natural surroundings [2-3].

One of the improvements that can be made is by replacing the less eco-friendly material to the material that more eco-friendly such as replacing the conventional brick to the wood-wool cement panel for wall construction [4]. Previously, the wood wool cement panel has been used for a long time ago, but this material not widely used in the building construction industry as a structural element [5]. There are several types of wood-wool that have been produced from different type of timber species throughout the world, but in Malaysia wood-wool is produced from timber species known as
“Kelampayan”. The timber log is shredded from this species that also known as low density and fast grown timber species in Malaysia [6]. As a fast grown timber species, the tree can be harvested within five to six years and the replanting process will be conducted thereafter to ensure the availability of these resources for the next cycle.

Wood-wool cement panel is a composite material that built up from the combination of water, cement and wood-wool. The manufacturing of this panel undergoes the compression process of the mixture into the wooden mould to make a panel after it hardened. The wood-wool reacts as core material when mixing with cement paste and potential to be a lightweight material that essential for structural application. The previous studies [6-7] reported that, the strength properties of WWCP meet the minimum requirement stated in the standards of ISO 8335 and DIN 1101 and can be employed in the building industry.

The wall is the compulsory building element constructed in all housing construction. It provides shelter for the safety purposes and control the comfort level of the building occupants. The selection of the right material for wall construction is very important, especially for the country with hot and humid climate like Malaysia [8]. Due to this, the demand on the fired clay brick as a wall material is quite high due to its high strength and high thermal insulation properties [9]. However, the resources used in producing this brick are made from non-renewable resources, emit large quantities of carbon emission and heavy weight. The wall construction using this brick significantly labours intensive and consumed a lot of time. Therefore, the use of wood-wool cement panel as new material for wall construction is a great potential to improve the sustainability in the construction industry [3].

The acceptance in using WWCP as a wall element in Malaysia has been increased due to the advantages of this panel such as environmental friendly, low energy consumption, lightweight, low-cost and easy to process and fabricate. However, the construction technique and the behaviour of wall subjected to axial compression load are not well established [7]. Figure 1 shows the application of WWCP as wall element in the building construction in Malaysia.

![Figure 1. Application of WWCP in low cost housing construction in Malaysia [4].](image1)

The compatibility between wood and cement is the main issue related to the production of wood-wool cement. There are only a few timber species that suitable to be used in producing this panel, since the organic materials released from the wood inhibit cement setting and reduced the bonding strength of cement [6, 7, 10]. To ensure the suitability of the timber species, the mechanical properties of wood-wool panel should be conducted prior being used in structural applications. The mechanical properties of wood-wool cement panel produced using Kelampayan timber species was conducted by several researchers and they were found that, the properties of WWCP achieved the requirement as specified in DIN 1101 standards and potential to be used as a structural element in building construction [6, 10, 13]. In terms of structural application of WWCP, the performance of reinforced concrete column using WWCP as embedded permanent formwork had been studied by Ahmad et al, [14]. The columns were tested under axial compression load until failure and the results revealed that the column using WWCP as permanent formwork significantly increased the load capacity about 30 % compared to the tested column without permanent formwork. Beside of that, the similar columns
configuration was further evaluated under fire resistance performance test inside the fire furnace for two hours. The experimental observation shows that, the columns using WWCP as permanent formwork covered with surface plaster have capabilities to resist two hour fire rating without critical damage occurred [15].

The structural performance of wall constructed using WWCP under axial compression load was developed by Fathihah [16] via her dissertation project report. The construction technique used is similarly as currently practiced shown in figure 1. The results indicated that, the tested walls have low strength capabilities and the premature splitting failure between panel joint was observed. Due to this, the wall construction technique using WWCP has been improved by Md Noh et al, [10, 13]. In the previous studies, the construction technique, namely as a cross laminated technique has been proposed in the fabrication of 600 mm x 600 mm wallettes where two layers of 50 mm thickness of WWCP were horizontally laid at different panel orientation. The 15 mm thickness of EMACO R1 premix mortar was used as an adhesive to bond in between the two layers of panels. The wallettes with and without 16 mm thickness of surface plaster were tested under axial compression load until failure. The results indicated that, the arrangement of panel at different orientation significantly increased the load capacity of wallettes and the application of 16 mm plaster thickness (EMACO R1 premix mortar) gave additional restraint to the wallettes to resist 8 % higher loading capacity.

As a continuation from the previous study, the fabrication technique and size of wallettes was remained at 600 mm x 600 mm. However, in this study the mortar used for panel bonding agent and the surface plaster is a normal mortar with mixed cement to sand ratio of 1 : 3. The wallettes with and without surface plaster were fabricated accordingly and tested under axial compression load test in order to investigate its compression load capacity and behaviour. Through this experimental testing, the structural performance of the prefabricated wall has been identified and presented in this paper.

2. Materials and Methods

2.1. Materials

WWCP is the main material used in fabrication of wallettes. The panel is a locally manufactured factory product which produced in standard panel size of 600 mm width and 2400 mm length and varies the panel thickness of 25, 50, 75 and 100 mm. However in this study, to fabricate 600 mm x 600 mm size of wallettes, the 50 mm thickness of WWCP has been used and cut into small panel size of 300 mm x 600 mm as shown in figure 2. The strength properties of WWCP used which obtained from the previous study is highlighted in Table 1.

The normal mortar mix was used as an adhesive and surface plaster where the ordinary Portland cement and fine sand were uniformly mixed at 1:3 ratios. The strength properties in term of flexural and compressive strength of hardened normal mortar at 28 days were investigated throughout this study and the results obtained was presented in Table 2.

2.2. Fabrication of wallettes

The fabrication of wallettes in this study was similarly as constructed in the previous study [13] where the two strips of 300 mm x 600 mm WWCP were horizontally laid in two layers at the different orientation. The front and rear panel strips were bonded together using 15 mm thickness of mortar to form the wallettes with the dimension of 600 mm x 600 mm x 115 mm. The two replicates of wallettes without surfaces plaster (W-NP) and three replicates of wallettes with 16 mm thickness of mortar (W-P) were prepared accordingly in Material Laboratory, UTHM. The configuration of wallettes and the fabrication process are shown in figure 3 and figure 4 respectively.
Figure 2. 50 mm thickness of WWCP used in this study (a) 600 mm x 2400 mm standard panel size (b) 300 mm x 600 mm cut panel size.

Table 1. Strength properties of wood-wool cement composite panel [10].

| WWCP Thickness (mm) | Density (kg/m$^3$) | Bending Properties | Compressive Strength | Tensile Strength |
|---------------------|---------------------|--------------------|----------------------|-----------------|
|                     |                     | MOE (N/mm$^2$)     | MOR (N/mm$^2$)       | Perpendicular   |
|                     |                     |                    |                      | Parallel        |
|                     |                     |                    |                      |                 |
| 50                  | 328                 | 444                | 1.15                 | 0.84            |
|                     |                     |                    |                      | 1.00            |
|                     |                     |                    |                      | 0.060           |

Table 2. Strength properties of the hardened mortar at the age of 28 days.

| Application of mortar | Mix ratio (Sand : Cement : Water) | Flexural Strength (N/mm$^2$) | Compressive Strength (N/mm$^2$) |
|-----------------------|-----------------------------------|-----------------------------|---------------------------------|
| Adhesive              | 1 : 3 : 1                         | 41.68                       | 37.88                           |
| Plaster               | 1 : 3 : 1                         | 42.50                       | 41.75                           |

Figure 3. Configuration of wallettes constructed using a cross laminated technique (Units in millimeter).
2.3. Axial compression load testing setup

In the axial compression load test, a total of five wallettes specimens were prepared and undergoes curing process under air dried condition in the laboratory for 28 days. The wallettes specimens then vertically stand on top of steel beams with verticality adjustment using spirit level. To ensure the uniformity of the axial load application on top of wallettes specimens, the 20 mm thickness of steel plate was attached to steel spreader beam and directly connected to the 1000 kN load cell. The testing setup was instrumented with three LVDTs, where LVDT 1 was provided to measure the vertical displacement and LVDTs 2 and 3 were used to monitor the lateral displacement of the wallettes. The load was then applied at a uniform rate of 0.005 mm/sec up to failure and the axial compression load capacity, displacement and failure mode were recorded and observed [10]. The data logger that connected to the computer was used to record the load and displacement throughout the test conducted. The illustrated and actual test setup is shown in figure 5 below.

![Figure 4](image)

(a) Mixing the mortar (b) Laying the rear panel strips in transverse direction (c) Placing the stopper on top of rear panel
(d) Rendering the 15 mm thickness of mortar on top of rear panel (e) Laying the front panel strips in longitudinal direction (f) Plastering the wallettes on both surfaces

**Figure 4.** The Fabrication process of cross laminated wood-wool cement wallettes.

![Figure 5](image)

(a) Illustrated testing set-up (b) Actual testing set-up

**Figure 5.** Axial compression load testing set-up of WWCP wallettes.
3. Results and Discussions
This section highlights the result of an axial compression load test of wallettes fabricated using wood-wool cement panel. The axial compression load capacity is a significant parameter in order to simulate the actual behaviour of wall under the action of permanent and variable gravity load of the building. The test conducted also can be used as an indicator to determine the maximum vertical load that can be carried by the walls. The wallettes without surface plaster (W-NP) and plastered with 16 mm thickness of mortar (W-P) have been observed in term of maximum load carrying capacity, load-vertical displacement behaviour and failure mode of each type of wallettes. A summary of maximum load and displacement at the maximum applied load of W-NP and W-P are shown in Table 3.

| Wall types | Wall reference | Maximum load | Vertical displacement | Maximum load (Mean) | Vertical displacement (Mean) |
|------------|----------------|--------------|-----------------------|---------------------|----------------------------|
| W-NP       | W-NP1          | 236.50       | 6.27                  | 275.00              | 12.17                      |
|            | W-NP2          | 313.50       | 18.07                 |                     |                            |
| W-P        | W-P1           | 285.50       | 12.57                 | 360.30              | 14.83                      |
|            | W-P2           | 394.50       | 16.64                 |                     |                            |
|            | W-P3           | 401.00       | 15.27                 |                     |                            |

From the Table 3, the results showed that the highest applied axial compression load of wallettes W-NP was recorded for W-NP2 which achieved its maximum load of 313.50 kN at a vertical displacement of 18.07 mm. Then the load significantly dropped to 236.50 kN at a small displacement of 6.27 mm for specimen W-NP1. Based on two replicates of tested wallettes type W-NP, the average maximum axial compression load recorded was 275.00 kN and average vertical displacement was 12.17 mm. Meanwhile, for wallettes type W-P, it can be seen that the highest maximum applied load was recorded on W-P3 with failure load of 401.00 kN at a vertical displacement of 15.27 mm. Then it was identically dropped by the W-P2 which reached its maximum load of 394.50 kN at maximum displacement of 16.64 mm. The maximum applied load was further decreased to 285.50 kN at a displacement of 12.57 mm for W-P1. The average maximum applied load and displacement of three replicates of wallettes W-P was 360.30 kN and 14.83 mm respectively.

The axial compression load capacity that was presented above provides information on the vertical load resistance of the prefabricated wall constructed using a cross laminated technique bonded with normal sand-cement mortar. From the test results, both of wallettes W-NP and W-P have their own capabilities to resist axial compression load. For wallettes without surface plaster W-NP the compressive strength calculated as high as 458 kN/m. The strength properties recorded shows the cross laminated technique used significantly increased the stiffness of the wallettes as well as increased the load carrying capacity of wallettes even tested without surface plaster. This is very beneficial since at the most condition in real construction practice the wall starts to support the vertical load after being constructed even without surface plaster. This performance will ensure that the wall able to safely resist an initial service before the full service is applied. For wallettes with surface plaster W-P, the calculated compressive strength increased about 31 % up to approximately 600 kN/m. This show that, an application of surface plaster on both surfaces of wallettes not just enhanced the appearance of wall surfaces but significantly increase the wall strength. Based on theoretical load transfer estimation, the minimum requirement of an axial compressive strength of the WWCP wall for two storey building is about 50 kN/m and the experimental results indicated that the wall strength recorded is 12 times higher. It is no doubt to classify that, the cross laminated WWCP wall system as a low weight load bearing wall system.

If compared against the previous study [10], the used of different mortar types as an adhesive and surface plaster had the greatest impact on the compressive strength of the wallettes. The used of
normal mortar as panel bonding agent significantly increased the load carrying capacity of wallettes about 75% compared to the wallettes that fabricated using EMACO R1 premix mortar. Further than that, the application of surface plaster using normal mortar also increase the load carrying capacity about approximately two times of wallettes using premix mortar. These shows that, the appropriate selection of mortar in the fabrication of WWCP wall, contributed to enhance the strength properties of wall as well as reduced the overall wall construction cost since the price of premix mortar is expensive compared to the normal mortar.

In terms of axial load - vertical displacement behaviour, figure 6(a) and 6(b) shows that, the vertical deformation of wallettes W-NP and W-P behave similar response where the applied load increase linearly with the vertical displacement up to the maximum failure load. After reaching the maximum load, the loads were observed drastically drop until final failure and the wallettes lost an ability to resist more load beyond this point. It can be seen that, the overall strength of the wallettes were governed by the strength of the normal mortar and once the mortar start to crush, the immediate failure will occur. Therefore, the precaution should be care taken as the actual imposed load should not exceed the maximum capacity of wallettes in order to avoid immediate fracture failure.

In terms of failure modes, figure 7(a) and 7(b) shows the failure behaviour of wallettes W-NP and W-P under axial compression load respectively. The failure mode of both wallettes shows the similar pattern where the vertical crack start to propagate along the cross section of the panels near to the panel and mortar bonding surface. As the applied load increase, the panel at each layer start to split out and at this stage load was totally carried by the mortar joint and the surface plaster up to the maximum load. The final failure was observed when the mortar reaches its ultimate strength and the load drastically drop due to crushing failure of the mortar joint.

![Figure 6. Axial compression load - vertical displacement curve of (a) W-NP (b) W-P.](image)
Figure 7. Failure mode behaviour of WWCP wallettes under axial compression load test.

4. Conclusions
Based on the experimental axial compression load test conducted on the wallettes, the conclusions can be drawn as follows;

• The new proposed fabrication technique, namely as cross laminated technique enhanced the wall construction process using wood-wool cement panel since it was easy to fabricate and install, lightweight and stable.
• The application of 16 mm thickness of surface plaster on both surfaces significantly increases the load carrying capacity of wallettes about 31 % up to 600 kN/m compressive strength.
• The compressive strength of wallettes is governed by the mortar used as a bonding agent and surface plaster.
• The used of normal mortar at mixed cement to sand ratio of 1:3 as a bonding agent in the fabrication of wallettes significantly 75 % increased the carrying capacity compared to wallettes fabricated using premix mortar.

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