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Static in-plane shear behaviour of prefabricated wood-wool panel wallets

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Abstract. The green construction material and technique are the current issue toward improving sustainability in the construction industry in Malaysia. The use of construction material that produced from renewable resources is a part of the effort for greening this industry. WWCP (Wood-wool cement panel) is a wood based product available to the construction industry to be used as a structural building wall element. This renewable material has the potential to replace the less eco-friendly materials such as bricks and other masonry element. However, the behaviour of wall subjected to the different load conditions is not well established and therefore, this study aimed to investigate the structural behaviour of the small scale wall (wallettes) subjected to in-plane lateral load. As a comparison, two types of fabrication technique of wallettes with dimension of 1200 mm x 1200 mm (± 30 mm) were considered. The conventional vertical stacking technique was denoted as W1 and new propose techniques (cross laminated) was denoted as W2. Three replicates of each type were fabricated and tested under in-plane lateral load until failure. The test results revealed that, the wallettes fabricated using the new fabrication technique significantly increased two times in load carrying capacity compared to wallettes with conventional technique.

1. Introduction
Improving sustainability in the construction industry is a crucial agenda that aggressively promoted by several government bodies in Malaysia. The construction industry development authorities were encouraged all the construction stakeholders for looking forward toward implementing an industrialized building system (IBS) as well as using materials that produced from renewable resources and less embodied carbon during its life cycle. It is clear that, the development of construction activities and the use of non-renewable resource materials keep increasing recently. If this trend keeps continued, this will intensify environmental deterioration and the shortage of natural resources [1][2][3].

The wall is the important element constructed in every building construction. It's being constructed to provide shelter and security to building occupants and some of them also function as a load bearing structural system. The masonry clay and sand cement brick are the most dominant...
material used for wall element in building construction in Malaysia. However, these materials are produced from non-renewable natural resources, highly carbon emission, heavy-weight, labour intensive and consumed long construction period [2]. Due to this, an alternative building material used for wall construction has been introduced and aggressive research studies have been conducted [4][5].

WWCP (Wood-wool cement composite panel) is one of the solutions for improving the sustainability in building construction. Its have been produced from wood-wool, which shredded from Malaysian fast grown timber species known as Kelampayan. This panel can be categorized as a lightweight material due to having a density in the range of 300 kg/m³ to 500 kg/m³ and available for the construction industry. The WWCP are suitable to replace less eco-friendly materials such as bricks and other masonry element [4][6].

![Figure 1. Wood-wool cement composite panel (WWCP).](image)

The application of WWCP as a building material has been introduced since 1920’s, however, the application of this panel limited to non-structural application such as wall partition, ceiling, insulation, acoustic and decorative panel [7]. Nowadays, its application was further expanded as a structural application. 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 behaviour of wall subjected to the different imposed load is not well established and required further exploration.

The mechanical properties of WWCP produced using shredded wood-wool from Kelampayan tree was explored by Ahmad et. Al, [4]. The results indicated that the strength properties of WWCP achieved the minimum requirement stated in the related standard and potential to be used in structural applications. The fire resistance performance of WWCP was investigated by Ahmad et. al, [8] through the application of WWCP as permanent formwork for reinforced concrete column. It was found that, the panels have the capability to withstand against fire about two hours and there was no severe damage occurred.

The structural behaviour of 600 mm x 600 mm wallettes under axial and diagonal compression load condition was discovered by Md Noh et al, [9][10]. The wallettes were fabricated with different panel configuration and bonding agents without surface plaster were explored. The results shown that, the fabrication technique of wallettes significantly influenced the load carrying capacity of wallettes. The wallettes fabricated using a new technique, namely as cross laminated technique bonded with 15 mm thickness of the mortar joint recorded the highest load capacity among the tested wallettes. The capacity of wallettes with application of surface plaster under imposed load was then further explored by Md Noh et. Al, [11][12]. The application of 16 mm surface plaster on both sizes of wallettes significantly gave additional restraint to the wallettes to resist the higher loads.

In the previous recent study, the dimension of the wallettes had been expanded to 1200 mm x 1200 mm (± 30 mm). There are two fabrication techniques considered which are vertical stacking technique and cross laminated technique. A total of six wallettes has been tested under axial compression load up to failure. The experimental results show that, the axial compression load capacity of wallettes fabricated using cross laminated technique recorded two times higher compared to wallettes fabricated using the vertical stacking technique [13].
This study is a continuation of the previous study, where the fabrication technique and size of wallettes was remained at 1200 mm x 1200 mm (± 30 mm). However, the wallettes were tested under in-plane lateral load test in order to investigate their lateral load capacity and its behaviour. Through this experimental testing, the structural performance of the prefabricated wall has been identified and it is very important criteria as develop a better understanding of their actual shear behaviour under imposed load [14].

2. Materials and Methods

2.1. Materials

WWCP is the main material used in fabrication of wallettes. The WWCP is a locally manufactured factory product which produced in standard panel size of 600 mm width and 2400 mm length (Figure 2(a)). The panel thickness varies from 25 mm to 100 mm. In this study, the 100 mm and 50 mm thickness of WWCP have been used. The 100 mm used for fabrication of wallettes using the vertical stacking technique, while 50 mm used for fabrication using cross laminated technique. The strength properties of the selected WWCP are shown in Table 1.

In the vertical stacking technique the 8 mm diameter of steel bar (Figure 2(b)) and 6 mm diameter of u-nail (Figure 2(c)) were used to hold the stacked panels. The premix mortar, namely as EMACO R1(Figure 2(d)) was used as an adhesive for bonding the panels and surface plaster for both fabrication techniques. The strength properties of hardened mortar are shown in Table 2 below.

![Figure 2](image-url). Materials used in this study (a) Wood-wool cement composite panel (WWCP) (b) 8 mm diameter mild steel bar (c) 6 mm diameter mild steel U-nail (d) EMACO-R1 premix mortar.

| WWCP Thickness (mm) | Density (kg/m³) | Bending MOE (N/mm²) | MOR (N/mm²) | Compressive Perpendicular Strength (N/mm²) | Parallel Strength (N/mm²) | Tensile Strength (N/mm²) |
|---------------------|-----------------|---------------------|-------------|-------------------------------------------|--------------------------|-------------------------|
| 50                  | 328             | 444                 | 1.15        | 0.84                                      | 1.00                     | 0.060                   |
| 100                 | 272             | 239                 | 0.40        | 0.30                                      | 0.30                     | 0.018                   |
Table 2. Strength properties of the EMACO R1 mortar mix at the age of 28 days [11].

| Application of mortar | Mortar mix ratio | Flexural Strength (N/mm²) | Compressive Strength (N/mm²) |
|-----------------------|------------------|---------------------------|----------------------------|
| Adhesive              | 5 : 1            | 12.44                     | 26.02                      |
| Plaster               | 5 : 1            | 6.55                      | 27.11                      |

2.2. Fabrication of wallettes

The fabrication of wallettes in this study was similarly as constructed in the previous study [13] where two fabrication techniques were considered. The vertical stacking technique was denoted as W1 and the new proposed technique (cross laminated) was denoted as W2. For W1, the 100 mm thickness of WWCP was cut into smaller block size, then vertically stacked in four layers. The stacked block panels were connected using mortar paste, embedded steel bars and u-nail as shown in Figure 3(a). For W2, the four strips of 300 mm x 1200 mm x 50 mm WWCP were horizontally laid in two layers at the crosswise orientation. The front and rear panel strips were bonded together using 15 mm thick of mortar paste as shown in Figure 3(b). The three replicates of each wallettes type were plastered on both surfaces with 16 mm thickness of mortar.

2.3. In-plane lateral load testing setup

In the in-plane lateral load test, three replicates of wallettes specimens of each type were prepared and placed similarly as tested in an axial compression load test [13]. The lateral load was applied through 250 kN hydraulic jack parallel at top edge of wallettes. The pre-compression load was first applied using 600 kN hydraulic jack up to 50 percent of axial load capacity in order to hold down and minimize the uplift of the wall. The testing setup was instrumented with five LVDTs, where LVDT 1 and 2 provided to measure horizontal and diagonal displacement respectively, LVDT 3 is to measure uplift, LVDT 4 is to measure the vertical displacement and LVDT 5 is provided to check the sliding of the wallettes as shown in Figure 4(a) and 4(b). During testing, the wallettes was prevented against sliding by a steel angle stopper. The load was then applied at a uniform rate of 0.005 mm/sec up to failure in order to determine the lateral load capacity, displacement and failure mode. The data logger that connected to the computer was used to record the load and displacement throughout the test conducted.
3. Results and Discussions

3.1. In-plane lateral load capacity

The in-plane lateral load test is important testing method conducted to investigate the shear behaviour and capacity of the composite wall system that subjected to an applied load in the in-plane direction. This test also beneficial in determining the resistance of wall system against lateral wind load [15][16]. A summary of maximum load and displacement at the maximum applied load of wallets W1 and W2 is shown in Table 3.

![Image](a) Illustrated testing set-up  
(b) Actual testing set-up

Figure 4. In-Plane lateral load testing set-up of WWCP wallets.

| Wall types | Wall reference | Maximum load (kN) | Horizontal displacement (mm) | Maximum load (Mean) (kN) | Horizontal displacement (Mean) (mm) |
|------------|----------------|-------------------|-----------------------------|--------------------------|------------------------------------|
| W1         | W1 – 1L        | 59.55             | 10.06                       | 66.72                    | 10.15                              |
|            | W1 – 2L        | 86.10             | 15.30                       |                          |                                    |
|            | W1 – 3L        | 54.52             | 5.09                        |                          |                                    |
| W2         | W2 – 1L        | 156.52            | 25.36                       | 151.82                   | 19.40                              |
|            | W2 – 2L        | 159.70            | 22.43                       |                          |                                    |
|            | W2 – 3L        | 139.23            | 10.42                       |                          |                                    |

From the Table 3, the results showed that the maximum applied in-plane horizontal load of wallets W1 was recorded for W1-2L which achieved its maximum load of 86.10 kN at a horizontal displacement of 15.30 mm. Then the maximum load significantly dropped to 59.55 kN at a displacement of 10.06 mm for specimen W1-1L and W1-3L was recorded the lowest maximum load which failed at 54.52 kN at a displacement of 5.09 mm. Based on three replicates of tested wallets type W1, the average maximum in-plane lateral load recorded was 66.72 kN and average lateral displacement was 10.15 mm. Meanwhile, for wallets type W2, it can be seen that the highest maximum applied load was recorded on W2-2L with failure load of 159.70 kN at a horizontal displacement of 22.43 mm. Then it was followed by the W2-1L which reached its maximum load of 156.52 kN at maximum displacement of 25.36 mm. The maximum applied load was further decreased...
to 139.23 kN at a displacement of 10.42 mm for W2-3L. The average maximum applied load and displacement of three replicates of wallettes W2 was 151.82 kN and 19.40 mm respectively.

The in-plane shear capacity that were presented earlier provides information on the load resistance of the prefabricated wall against lateral load as well as wind load. On the other hand, the shear capacity also provides information on designing the connection system of prefabricated wall as to ensure the continuity of wall to transmit the shear force between wall panels and the ability of wall base connection as to minimise the uplift. From the test results, both types of wallettes W1 and W2 have their own capacity to resist in-plane lateral load, however the shear strength of wallettes type W2 approximately two times higher than wallettes type W1. The shear strength of wallettes W2 can be as high as 126.52 kN/m height compared to wallettes W1 with shear strength of 55.60 kN/m height. These showed that, the new panel arrangement, using a cross laminated technique contributed to increase load carrying capacity of wallettes against in-plane lateral load. The different panel orientation bonded with 15 mm mortar thickness significantly provides bracing resistance to the wallettes type W2 and enhanced the wall stability compared to wallettes type W1.

3.2. In-plane shear behaviour
In terms of load – horizontal displacement behaviour, Figure 5(a) and 5(b) shows that, the horizontal deformation of wallettes W1 and W2 behave similar response where the applied load increase linearly with the horizontal displacement up to the first crack occurred. After this stage, the wall was seen continue to resist the load, however, there were some fluctuate of load observed until the final failure of wallettes. This due to diagonal shear force that resulted in de-bonding failure of wood-wool panel.

![Figure 5](image)

**Figure 5.** In-plane lateral load – horizontal displacement curve of (a) Wallettes W1 (b) Wallettes W2.

In terms of failure modes, Figure 6(a) and 6(b) shows the failure behaviour of wallettes W1 and W2 under in-plane lateral load respectively. The typical failure mechanism observed for the wallettes W1 is the diagonal tensile crack of surface plaster which propagates along the wallettes height followed by bonding failure of the wood-wool panel. For wallettes W2, the failure mode was observed by the formation of shear crack on web wall surface at the compression end and followed by the bonding failure of wood-wool panel. As the applied load was further increased, the major crack propagates along the wall height and finally the crushing failure of was observed under the loading shoe.
4. Conclusions
Based on the two fabrication techniques considered and in-plane lateral load test conducted on the wallets, it can be concluded that, the used of wood-wool cement panel (WWCP) as a wall element in building construction significantly improves the sustainability in the construction industry as well as promoting the better living condition of the building occupants. The new proposed fabrication technique, namely as cross laminated technique (W2) enhanced the wall construction process using wood-wool cement panel since it was easy to fabricate and install, lightweight, stable and reduced wall construction period. The laboratory testing results showed that, the wallets type W2 show a better performance in term of in-plane lateral load carrying capacity, which able resist shear strength about two times higher compared to wallets type W1. This show that, the cross laminated wood-wool panel with 15 mm mortar thickness as a bonding agent significantly increased the stability and load carrying capacity of this prefabrication system.

References
[1] Okino E Y, Souza M R d, Santana M a, Alves M V d S, Sousa M E De and Teixeira D E 2004 Cement-bonded wood particleboard with a mixture of eucalypt and rubberwood J. Cement and Concrete Composites, 26(6) 729–734
[2] Goverse T, Hekkert M P, Groenewegen P, Worrell E, and Smits R E H 2001 Wood innovation in the residential construction sector; opportunities and constraints J. Resources, Conservation and Recycling, 34(1) 53–74
[3] Mohd Jaini Z, Mokhatar S N, Mohd Yusof A S, Zulkifly S, Rahman M H A 2016 Effect of pellitized coconut fiber on the compressive strength of foam concrete MATEC Web Conference 47
[4] Ahmad Z, Wee L S and Fauzi M A 2011 Mechanical properties of wood-wool cement composite board manufactured using selected Malaysian fast grown timber species. ASM Science Journal 5(1) 27–35
[5] Mustafa M M, Mokhatar S N and Jaini Z M 2016 Properties of different artificial lightweight aggregate and their effect on concrete strength. ARPN Journal of Engineering and Applied Science 11(6) 3726–30

[6] Ashori A, Tabarsa T, Azizi K and Mirzabeygi R 2011 Wood–wool cement board using mixture of eucalypt and poplar J. Industrial Crops and Products 34(1) 1146–49

[7] Elten V 2006 Production of wood-wool cement board and wood strand cement board (Eltoboard) on one plant and application of product Conference Proceeding of 10th International Inorganic-Bonded Fiber Composite Conference IIBCC 2006, Sao Paulo, Brazil, 15 – 18 November 2006

[8] Ahmad Z, Ahmad N, Ali Rahman A, Abdul Hamid H and Md Noh M S 2014 Fire resistance performance of reinforced concrete column with embedded permanent formwork using wood-wool panel Applied Mechanics and Materials 661 111-117

[9] Md Noh M S, Ahmad Z and Ibrahim A 2014 Axial compression behaviour of wallettes constructed using wood-wool cement composite panel Advanced Materials Research 1051 671-677

[10] Md Noh M S, Ahmad Z, Ibrahim A, Walker P, 2015 Diagonal compression behaviour of wallettes constructed using wood-wool cement composite panel, Conference Proceeding of International Conference Civil, Architectural, Structural and Constructional Engineering 2015 (ICCASCE 2015) Busan South Korea 21 – 23 August 2015

[11] Md Noh M S, Ahmad Z, Ibrahim A, Walker P, 2015 Axial Compression Behaviour of Plastered Wood-Wool Cement Composite Panel Wallettes. Conference Proceeding of 3rd International Civil and Infrastructure Engineering Conference (INCIIEC 2015) Shah Alam Selangor Malaysia 21 – 22 September 2015

[12] Md Noh M S, Ahmad Z, Ibrahim A, Walker P, 2015 The diagonal compression behaviour of plastered wallettes fabricated using wood-wool cement panel. International Journal of Applied Engineering Research Vol. 10 (81) 88 – 92.

[13] Md Noh M S, Ahmad Z, Ibrahim A, Walker P, 2016 Development of new prefabricated wall constructed using wood-wool cement composite panel. Procedia Environmental Sciences Vol. 34 298 – 308

[14] Idris N S, Boon K H, Kamarudin A F, Sooria S Z, 2016 Ambient vibration test on reinforced concrete bridges MATEC Web Conference 47

[15] Manalo A 2013 Structural behaviour of a prefabricated composite wall system made from rigid polyurethane foam and Magnesium Oxide board Construction and Building Materials 41 642–653

[16] Yusoff S M A M, Sooria S Z, Kamarudin A F, Boon K H, 2016 Identification of dynamic characteristic of bridge crossing sungai simpang kiri using free vibration analysis MATEC Web Conference 47

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