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Axial Compression Behaviour of Full-Scale Prefabricated Wood-Wool Wall Panel

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Abstract: This study aims to investigate an axial compression behaviour of prefabricated wall constructed using wood-wool cement composite panel (WWCP). A total of three full scale wall specimens were fabricated at the laboratory with dimension of 2400 mm width, 2400 mm height and 147 mm thickness. The new fabrication technique namely as cross laminated technique was considered where the walls is fabricated using two layers of 600 mm x 2400 mm x 50 mm thickness of WWCP strips, where each layer consists of four panel strips that were arranged at cross wise panel orientation. The front and rear panel strips were bonded together using 15 mm thickness of mortar paste and as a finishing 16 mm thickness of mortar base plaster were applied on both surfaces. The prefabricated wall specimens were tested under axial compression load up to failure after 28 days of curing period. The axial load carrying capacity, vertical and lateral displacement and failure mode behaviour of walls were observed during and after test conducted. The results of experimental testing recorded that; the maximum axial compression load of prefabricated wood-wool wall specimens achieved the capacity of 1038.54 kN. This shows that the new prefabricated wall constructed using cross laminated wood-wool panel can be used as a load bearing wall system for low rise building.

Keywords: Prefabricated wall, Wood-wool cement composite panel (WWCP), Axial compression behavior, Axial compression load capacity

1. Introduction

Nowadays, the developed country looking forward to the new construction technique and materials that contributes to minimize the construction cost and improving sustainability in the construction industry. Due to this, Malaysian government had aggressively promoted the new construction technique, namely as Industrialized Building System (IBS)[1]. The use of IBS component in building construction significantly minimizes the cost, speed up the construction period, reducing the dependent on foreign labor and minimize the construction waste [2].

The wall is an important building element functioned as shelter to give comfort ability and security to the building occupant [3]. For load bearing wall system, it should have adequate load carrying capacity to support the load from the roof, ceiling, floor and imposed load as well. The precast concrete wall, interlocking brick and concrete block system are the most common IBS component used for wall construction in Malaysia. However, these IBS wall components are

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produced from non-renewable resources, highly carbon emission, labor intensive and heavy weight [4]. Therefore, due to the problems associated with the conventional IBS wall system, the new materials, namely as wood-wool cement composite panel (WWCP) is introduced.

WWCP is a wood based product that produced from low density Malaysian fast grown timber species known as Kelampayan. The WWCP consist of shredded wood-wool (Fig. 1(a)) which uniformly mixed with cement paste and press under concrete block to form a stable panel having hardened density range between 300 kg/m^3 to 500 kg/m^3 as shown in Fig. 1(b). The strength properties test conducted on WWCP have shown that, its properties meet the minimum requirement for structural application as specified in ISO and DIN 1101 standards [5], [6]. In terms of fire resistance, the test conducted based on BS 476: Part 22: 1987 revealed that, the panel has an ability to withstand against fire up to 2 hours fire resistance [7].

(a) (b)

Fig. 1 - (a) Wood-wool; (b) Hardened WWCP

The used of WWCP as a wall element in building construction have been well accepted in Malaysia due to its advantages such as high thermal insulation, lightweight, less embodied carbon emission and low cost. However, the wall construction and panel installation technique using WWCP is not well established [8]. In the current installation technique using WWCP, the panels were in-situ vertically stacked at running bond pattern similarly as concrete block laying process as shown in Fig. 2. This technique was seen unstable in high slenderness wall and cannot be used as load bearing wall system due to it was very low in load carrying capacity.

Fig. 2 - Current installation technique of wall using WWCP

Therefore, a new cross laminated wall prefabrication technique using WWCP has been further investigated in this study. Previous studies conducted by an author on small scale of 600 mm x 600 mm and 1200 mm x 1200 mm woodwool wall panel had shown that, the new fabrication technique proposed significantly increased an axial load carrying capacity of wall about twice compared to the wall that fabricated using the current installation technique [9]-[14]. These results were given the motivation to the author to expand the wall size up to full scale wall dimension. This study aimed to investigate an axial compression behaviour of full-scale prefabricated wood-wool wall panel. The results of study are important criteria in order to explore the potentiality of this wall as part of load bearing wall in industrialized building system (IBS) in Malaysia.

2. Materials and Methods

In the present study, the wall dimension has been expanded to a full-scale wall size of 2400 mm width, 2400 mm height and 147 mm thickness. The configuration of wall is shown in Fig. 3. The following subsections describe the materials and methodology of the study conducted.

2.1 Materials

Wood-wool cement composite panel (WWCP) is the main material used in fabrication of full-scale prefabricated wall. WWCP is local Malaysian product which manufactured by Duralite (M) Sdn. Bhd. The panel is produced in standard panel size of 600 mm width and 2400 mm length. There varying thickness from 25 mm up to 100 mm, however, in this study the 50 mm panel thickness was considered as shown in Fig. 4a. The strength properties of 50 mm thickness of WWCP is highlighted in Table 1. In the fabrication of wall using cross laminate technique, the two layers of 50 mm thickness of panel strips are bonded together using mortar mix. As to ensure the uniformity of mortar mix, the premix mortar namely as EMACO R1 produced by BASF (M) Sdn. Bhd. have been used. The EMACO R1 mortar is supplied with a dry mix of cement and fine sand in a bag containing 25 kg per bag as shown in Fig. 4b. The dry mix to water ratio used is 5:1 of weight as suggested by the manufacturer and the compressive strength of hardened mortar at the age of 28 days is shown in Table 2.

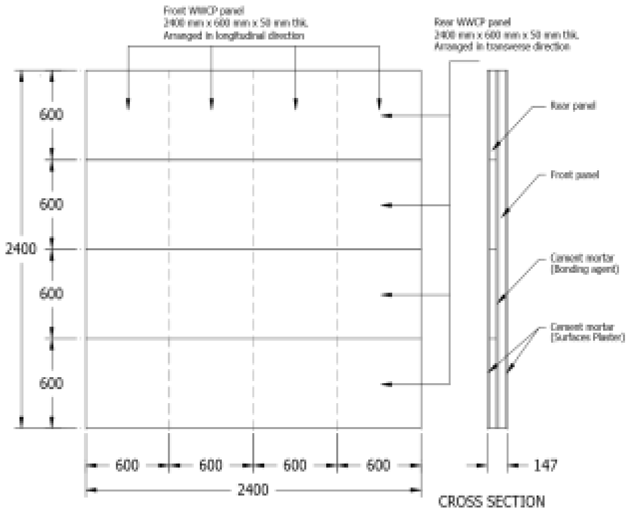

Fig. 3 - Configuration of full-scale prefabricated wood-wool wall panel

(a) **(b)**

Fig. 4 - (a) 50 mm thickness of WWCP (b) EMACO R1 premix mortar

Table 1 - Strength properties of 50 mm thickness of WWCP [8]

Density	Bending properties		Compressive strength		Tensile strength
	MOE	MOR	Perpendicular	Parallel	
(kg/m^3)	(N/mm^2)	(N/mm^2)	(N/mm^2)	(N/mm^2)	(N/mm^2)
328	444	1.15	0.84	1.00	0.060

Table 2 Compressive strength of EMACO R1 mortar mix at 28 days [9]

Application of mortar	Dry mix : water ratio	Compressive strength (N/mm^2)
Bonding agent	5 : 1	26.02
Plaster	5 : 1	27.11

2.2 Fabrication of Wall Panel Specimens

The fabrication process of three wall specimens was carried out at laboratory nearby to the testing frame as shown in Fig.5. As prefabricated wall system, the wall is fabricated by horizontally laid on the laboratory floor. The temporary wooden formwork was first constructed along the wall perimeter as guidance to ensure the uniformity of wall size. Then, the rear panel strips consist of four WWCP panels were laid in transverse direction. The 15 mm thickness of mortar paste was used as a bonding agent and rendered on top of rear panel strips. The uniformity thickness of mortar paste was controlled by placing hardened mortar stopper. The front panel strips that also consist of four WWCP panels, then were laid immediately on top of bonding agent and arranged in the longitudinal direction. After 24 hours drying process, the walls, then were plastered using 16 mm thickness of mortar paste on both surfaces. To ensure the maturity of mortar paste, the wall specimens were open air curing for 28 days before an axial compression load test being carried out.

2.3 Axial Compression Load Testing Setup

The axial compression load testing setup of full-scale prefabricated wood-wool wall panel is shown in Fig. 6. The wall panel specimens were placed in the testing frame with vertically free standing below the middle of a steel spreader beam which directly connected to the load cell with the capacity of 2000 kN.

The wall specimen was instrumented with seven LVDT's where six LVDT's (T2 – T7) were placed at mid and quarter height of wall panel at both front and rear faces for horizontal deflection measurement. The LVDT (T1) also provided on top of wall specimen for vertical displacement measurement and all instruments were checked and adjusted properly before applying the compression load. The axial compression load was then applied on top of specimens via spreader beam at a constant rate and gradually increases up to the failure of the wall specimens. The increment of load and the displacement of wall specimens were measured and recorded by the data logger and computer. The crack patterns on the surfaces were marked and the behaviour of wall specimens at each loading stage was observed until failure.

(a) Arranging the rear panel in transverse direction

(b) Rendering the mortar mix on top of rear panel

(c) Arranging the front panel in longitudinal direction

(d) Applying the front and rear surfaces plaster

(e) Completing the plastering work

(f) Curing the prefabricated wall

Fig. 5 - Fabrication process of full-scale prefabricated wall constructed using wood-wool cement composite panel

Fig. 6 - Axial compression load testing setup of full scale 2.4 m x 2.4 m prefabricated wall constructed using wood-wool cement composite panel

3. Results and Discussion

The axial compression load test is an important test conducted to investigate the actual load bearing capacity and behaviour of wall under imposed load. In this study, the test was conducted on three full scale wall specimens until final failure. The experimental test results in terms of load carrying capacity and vertical displacements of the walls are shown in Table 3.

Table 3 - Maximum load and vertical displacement of full-scale wall under axial compression load test

Wall No.	Maximum load, (kN)	Vertical displacement, (mm)	Maximum load (Mean), (kN)	Vertical displacement (Mean), (mm)
WFS1A	826.36	15.43		
WFS2A	1070.65	14.33	1038.54	14.22
WFS3A	1218.60	12.90		

From the Table 3, the results showed that the highest maximum axial load of full scale prefabricated wood-wool wall was recorded from WFS3A which achieved its maximum applied load at 1218.60 kN at a vertical displacement of 12.90 mm. Then it was followed by the WFS2A which failed at an applied load of 1070.65 kN at a vertical displacement of 14.33 mm and the lowest axial compression load was recorded for wall WFS1A where failed at the applied load of 826.36 kN at a displacement of 15.43 mm. Based on the results of three replicates of walls, the average maximum applied load was 1038.54 kN and the average vertical displacement was 14.22 mm. In this study, the wall was designed as prefabricated load bearing wall system, where the loads from the upper floor and roof of the building will directly transfer to the wall system without any structural framing. Therefore, the wall panel should have an adequate structural integrity to resist an initial imposed load during transportation, erection and installation process [15]. In addition, during services, the wall should have an adequate strength and capability to support the building loads. Based on the results obtained, the prefabricated wall has its own capacity to resist the imposed loads even tested without structural frame. The compressive strength of the wall supporting concentrated load was calculated as high as 344 kN/m up to 508 kN/m width. Based on theoretical calculation of load transfer mechanism for double storey housing, it was estimated that the 50 kN/m ultimate load will be transferred to the wall system during the service [11]. These show that, the tested wall specimens have the potential to be used as prefabricated load bearing wall system in housing and low rise building. The high load carrying capacity of walls was seen governed by the new fabrication technique used, where the cross wise panel orientation bonded with 15 mm thickness of mortar and plastered with 16 mm thickness of mortar on both surfaces significantly increased stability of panel joints and prevent the wall against premature panel joint buckling and thus, consequently increased the load carrying capacity of the walls.

The axial load-vertical displacement behaviour of the wall is shown in Fig. 7. The curves show that, the axial deformation of three wall specimens behaved a similar response where the vertical displacement increase almost linearly with the load up to the maximum applied load. The load was seen gradually increased and this behaviour probably due to the porosity of wood-wool panel, where the panels tend to absorb energy by compressing the void between wood-wool. The load was observed to slightly drop when the first crack of panel occurred after the panels totally compressed. However, the load was then further increased until the panel reached the maximum load capacity. After this load, a sudden drop in of applied load was observed due to crushing and splitting of wood-wool panel and the walls cannot resist any load beyond this point.

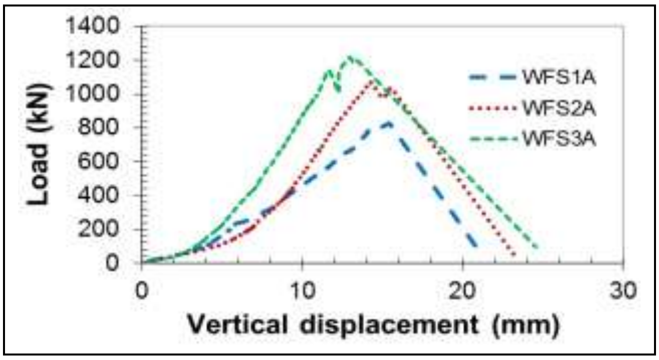

Fig. 7 - Axial load-vertical displacement curve of full-scale prefabricated wood-wool wall panel

The axial load-lateral displacement behaviour of prefabricated wall WFS1A, WFS2A and WFS3A at mid height were shown in Fig. 8, Fig. 9 and Fig. 10 respectively. The lateral displacement of walls is important criteria as to investigate the composite behaviour of walls and the effectiveness of mortar as an adhesive between panels [16]. The curve shows that, the load-lateral displacement profile of each wall is almost similar on both surfaces throughout the testing and these indicated that, the compression load was concentrically applied and there was no bending moment induced during load application [17]. It also can be seen that the lateral displacement of each wall was deflected at similar side and these clearly indicated the used of mortar as an adhesive between two layers of panels significantly developed the full composite action and there was no de-bonding failure occurred on the interface of the panel and mortar joint. The wall specimen WFS1A was found to have the largest lateral displacement about 16.68 mm at right side surface and -11.32 mm at left side surface at maximum compression load application. The displacement was seen significantly decreased to 9.26 mm at right surface and -7.04 mm on the left surface for specimen WFS3A. The smallest lateral displacement was recorded for specimen WFS2A which deflected at -2.91 mm at right surface and 2.20 mm on the left surface of the maximum load applied. For prefabricated composite wall panel that consists of two layers of wood-wool panel, the results obtained can be considered within tolerable lateral deflection limits.

In terms of failure mode, Fig. 11 shows the failure behaviour of full scale prefabricated wall under axial compression load. The failure mechanisms of wall specimens were observed almost identical for all specimens. At an early stage of load application, the gradual increase of compression load significantly compresses the voids within wood-wool panel. The first crack internally occurred after the panels were totally compressed then the formation of shear cracks on the 50 mm thickness panel cross section start to appear. When the applied load was further increased, the large crack propagates along the height of the wall and the panel started to horizontally split out. The final failure of the wall was occurred after a part of panels was totally splitting and debonding. There was no failure occurred on the panel joint interface, however the bonding failure of within wood-wool panel was observed as a main failure mechanism and if the load being further applied consequently the wall will collapse.

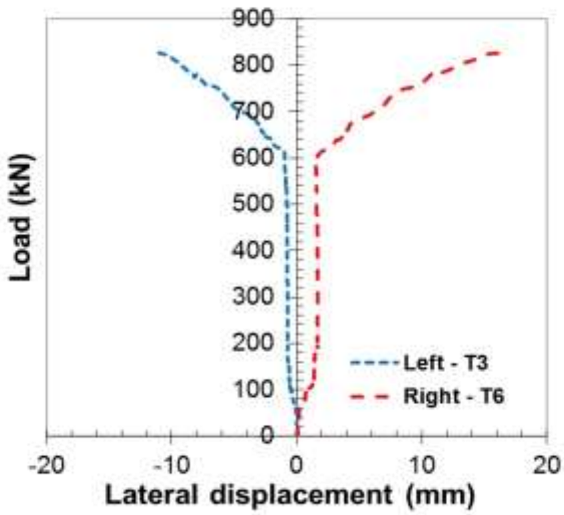

Fig. 8 - Axial load-lateral displacement curves at mid height of wall WFS1A

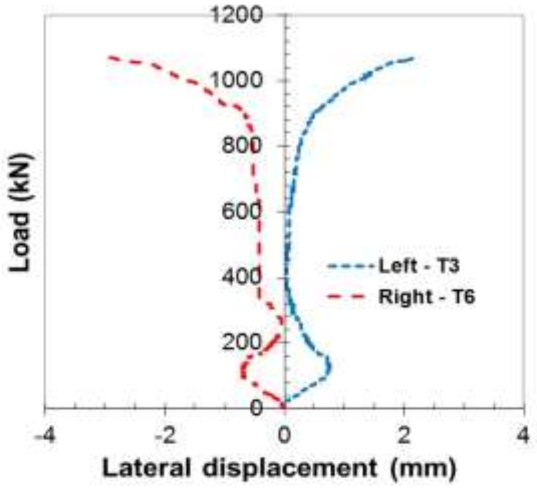

Fig. 9 - Axial load-lateral displacement curves at mid height of wall WFS2A

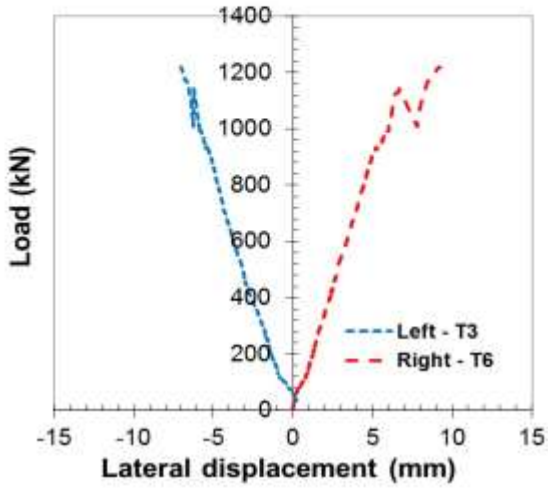

Fig. 10 - Axial load-lateral displacement curves at mid height of wall WFS3A

Fig. 11 - Failure mode behaviour of full-scale prefabricated wood-wool wall panel under axial compression load test

4. Conclusions

Based on experimental test on axial compression behavior of full-scale fabricated wood-wool wall panel and the results, the several conclusions can be drawn as follows:

- The used of wood-wool cement composite panel as prefabricated wall system significantly potential for improved sustainability in building construction as this material manufactured from renewable resources, lightweight, low carbon emission and faster the building construction process.
- The new fabrication technique proposed in this study significantly enhanced the wall construction process using wood-wool cement composite which is easy to fabricate, structurally stable and speeds up wall construction time.
- The experimental results showed that, the full-scale prefabricated wall shows a good performance in term of axial load carrying capacity, which can resist compressive strength up to 508 kN/m width. This show that, the cross laminated wood-wool panel with 15 mm mortar thickness as a bonding agent 16 mm thickness of surface plaster significantly increased the stability and load carrying capacity of this prefabrication system.
- The lateral displacement of the wall indicated that, the wall deflected at similar side and bondings between panels develop full composite action without debonding occurred on the interface of the panel.
- The splitting and debonding of wood-wool panel cross section is observed as the main failure mechanism of fullscale prefabricated wood-wool wall panel.

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