

Axial compression behaviour of reinforced wallettes fabricated using wood-wool cement panel

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Abstract. Wood-wool cement composite panel (WWCP) is one of wood based composite material that produced in a stable panel form and suitable to be used as building wall system to replace non-ecofriendly material such as brick and other masonry element. Heavy construction material such as brick requires more manpower and consume a lot of time to build the wall panel. WWCP is a lightweight material with a density range from 300 kg/m³ to 500 kg/m³ and also capable to support an imposed load from the building. This study reported on the axial compression behaviour of prefabricated reinforced wallettes constructed with wood-wool cement panel. A total of six specimens were fabricated using two layers of cross laminated WWCP bonded with normal mortar paste (Portland cement) at a mix ratio of 1:3 (cement : sand). As part of lifting mechanism, the wallettes were equipped with three steel reinforcement (T12) that embedded inside the core of wallettes. Three replicates of wallettes specimens with dimension 600 mm width and 600 mm length were fabricated without surface plaster and with 16 mm thickness of surface plaster. The wallettes were tested under axial compression load after 28 days of fabrication until failure. The result indicated that, the application of surface plaster significantly increases the loading capacity about 35 % and different orientation of the panels improve the bonding strength of the wall.

1. Introduction

The innovation in the construction industry had brought the new material to be utilized in building construction. The innovative material produced should have the characteristic that toward improving sustainability in the construction industry. As the time change, the sustainability is becoming important where people were seeking a new material for their building that can minimize the environmental destruction, improve the living comfort of human being and also minimize cost expenses [1][2]. Due to this, a new material, namely as wood-wool cement panel have been introduced to fulfil all the sustainability state criteria [3].

Wood-wool cement composite panel (WWCP) is one of wood based composite material that produced in a stable panel form and suitable to be used as building wall system to replace non eco-



friendly material such as brick and other masonry element [3]. WWCP is made up from renewable resources, less embodied carbon emission, lightweight and highly thermal insulation. *Kelampayan* or its scientific name *Neolamarckia Cadamba* is one of the low density and fast grown timber species that were selected to be used in the making of WWCP in Malaysia. The process began with the shredding of the timber log to produce the wood-wool, then mixed with cement and water at a specific mix ratio. As the main component, the wood wool reacts as reinforced agent and cement paste as a binder, then pressed into designated moulds to form a panel. The low density of the panel with a range of $300 \text{ kg/m}^3 - 500 \text{ kg/m}^3$ are highlighted as lightweight material that essential for structural application [5]. The standard requirement of ISO and DIN 1101 shows that the attributes of this WWCP meet their requirement to be employed in the building industry [6]. In terms of fire resistance, the WWCP used in a structural application meet the minimum requirement specified in BS 476-22:1987 and classified as good in fire and heat transfer resistance [7].

In Malaysia, WWCP is a factory product and available to be used as construction materials. The panel is produced in standard dimension of 600 mm width, 2000 - 2400 mm long and available in different thickness from 25 mm to 100 mm. The strength properties of WWCP are influenced by the panel thickness where the less thicker panel exhibits high strength and thus, its application also depended on panel thickness [5]. The 25 mm thickness of WWCP normally been used as ceiling, decorative and acoustic panel. Meanwhile, for 50 mm panel thickness, it has been used as partition wall and 75 mm – 100 mm being used as building wall panel. The application of WWCP as building wall system have been well accepted recently. The construction technique practiced is similarly as a brick laying process where the 75 mm or 100 mm of WWCP were in situ stacked vertically in running bond pattern as shown in Figure 1. Then each layer of panel were bonded together using mortar paste and steel bars were inserted between panels. In some cases, the U-nail were clamped on the side surface of panel joints as to strengthen the panel joints [8]. The surface plaster was applied after finish the panel stacking process in order to enhanced the wall strength properties and prevent against the different weather condition. This implemented construction method was seen very difficult, requires the specific skill labour, consumed long construction period and low in load bearing capacity [9].



Figure 1. Current construction practiced using WWCP as wall element (Duralite (M) Sdn. Bhd.)

Due to the disadvantages of the current construction technique, the new technique, namely as a prefabricated cross laminated technique was proposed. In this new technique, the wall panel has been fabricated outside and deliver to the construction site for the installation purposes. The 50 mm thickness of WWCP was used and horizontally laid in two layers at a crosswise panel strip orientation. The panel strip in the first layer was arranged in a transverse direction and the second panel strip in the longitudinal direction as shown in Figure 2. The first and second layer was bonded together using 15 mm thickness of cement mortar and the wall can be seen as sandwich panel with the WWCP as a sheeting and the mortar as a core. The prefabricated wood-wool wall can be either plastered during fabrication or after the installation process at the construction site [10]. As prefabricated wall system, the wall should be equipped with lifting mechanism as to accommodate the handling and moving of wall panel. By using this technique, the high yield steel bars will be provided embedded inside the core of wall panel to facilitate the lifting process as to avoid an excessive structural damage.

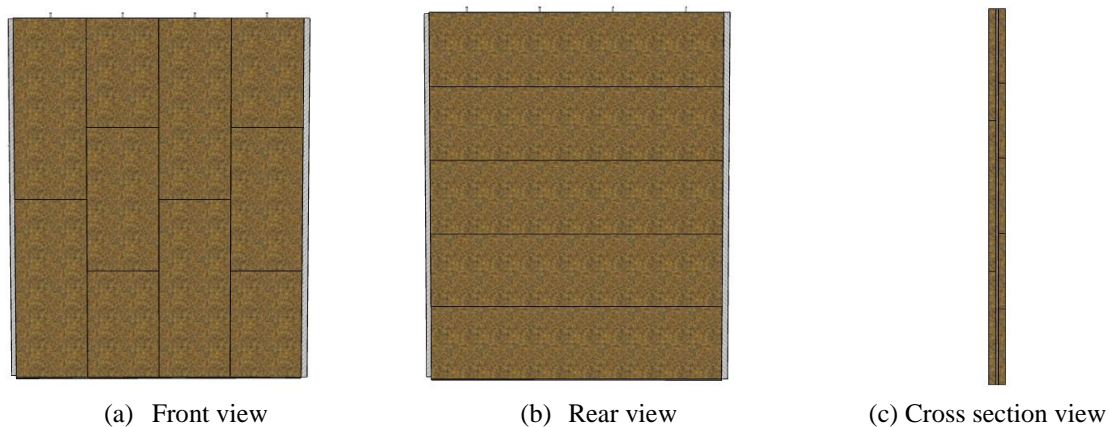


Figure 2. Panel orientation of cross laminated technique

Based on the previous study conducted on the axial compression behaviour of cross laminated wood-wool panel wallettes, the results indicated that, the new panel arrangement technique proposed significantly increased the load carrying capacity of wallettes about two times compared to the wallettes fabricated using current practiced technique [8][9][10]. This show that, the cross laminated technique has great potential to be introduced into the real construction world as to enhance the wall construction technique using WWCP.

As mentioned earlier, the prefabricated wall using a cross laminated technique will be equipped with steel bars as a lifting mechanism and therefore, in this study the effect of steel bars embedded inside the core have been explored. A total of six reinforced small scale walls (wallettes) with dimension of 600 mm x 600 mm were fabricated using cross laminated technique and tested under axial compression load until failure. The behaviour of three replicates of reinforced wallettes without surface plaster and plastered with 16 mm thickness of normal mortar was investigated in term of maximum axial compression load capacity, vertical displacement at failure load and the failure mode characteristic.

2. Materials and Methods

2.1. Materials

Wood-wool cement composite panel (WWCP) is the main material used in fabrication 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 5a. 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 (Figure 5b) and fine sand (Figure 5c) 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.

As part of lifting mechanism, the high yield steel bars with a diameter of 12 mm was used as shown in figure 5d. Three numbers of steel bars were arranged parallel to the wallettes height and placed inside the core of wallettes.

Table 1. Strength properties of wood-wool cement composite panel [7]

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



Figure 5. (a) 50 mm thickness of WWCP (b) Portland cement (c) Fine sand (d) High yield steel bar

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

2.2. Fabrication of wallettes

The fabrication process of wallettes in this study was similarly as constructed in the previous study [8][10] where the two layers of 50 mm WWCP thickness were laid in horizontal condition. Each layer consists of two strips of 300 mm x 600 mm and arranged at the different orientation. The front and rear panel strips were bonded together using 15 mm thickness of normal sand cement mortar to form the wallettes with the dimension of 600 mm x 600 mm x 115 mm. The three numbers of 12 mm diameter of steel bars were placed inside the mortar core parallel to the wallettes height. The wallettes then were plastered on both surfaces with 16 mm thickness mortar. Three replicates of wallettes without surface plaster (NPR) and with surface plaster (PR) were prepared accordingly in the laboratory. The detail configuration of wallettes and the fabrication process are shown in figure 6 and figure 7 respectively.

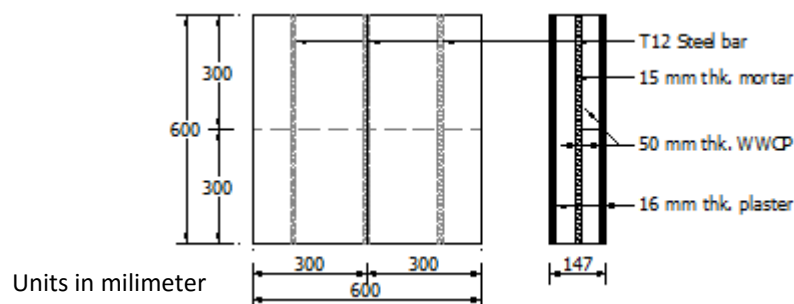


Figure 6. Configuration of wallettes constructed using a cross laminated technique

2.3. Axial compression load testing setup

In the axial compression load test, a total of six wallettes specimens were prepared and curing under air dried condition in the laboratory for 28 days. The wallettes specimens then vertically stand on top of steel beams and the verticality of wallettes were set up 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 LVDT 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 [8][9][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'8.

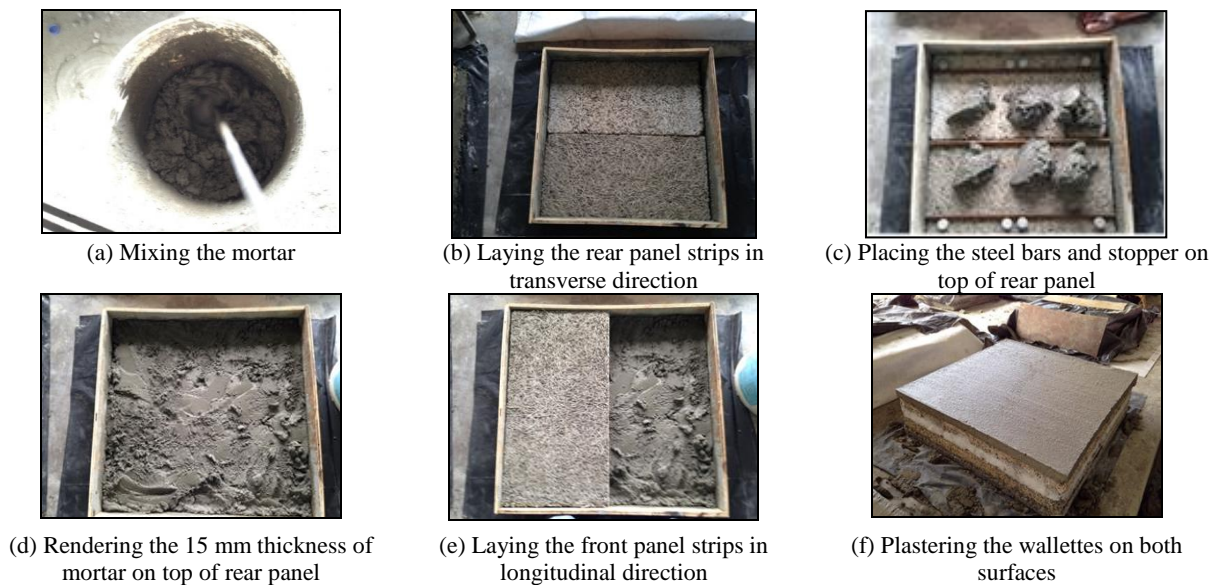


Figure 7. The Fabrication process of cross laminated wood-wool cement wallettes

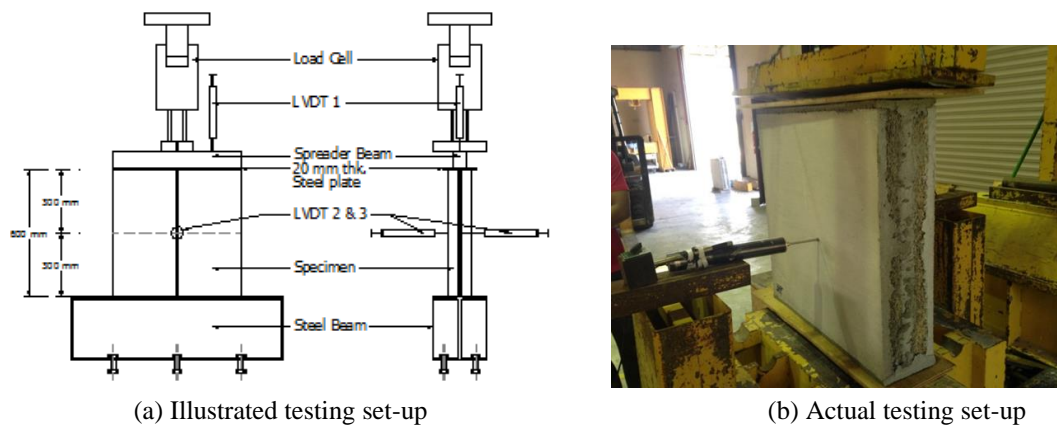


Figure 8. Axial compression load testing set-up of WWCP wallettes

3. Results and Discussions

This section presents the result of an axial compression load test of reinforced wallettes fabricated using wood-wool cement panel bonded with normal sand cement mortar. The axial compression load capacity is a significant parameter in order to investigate the actual behaviour of wall under the action of gravity load on the building [10]. The test results can be used as an indicator to determine the maximum vertical load that can safely carry by the walls and its potentiality as the load bearing wall system can be drawn [11]. The reinforced wallettes without surface plaster (NPR) and plastered with 16 mm thickness of mortar (PR) 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 NPR and PR are shown in table 3.

From the table 3, the results showed that the highest applied axial compression load of reinforced wallettes without surface plaster (NPR) was recorded for NPR3 which achieved its maximum load of 242.50 kN at a vertical displacement of 6.00 mm. Then the load significantly dropped to 221.50 kN at a small increment of the displacement of 6.54 mm for specimen NPR2 and NPR1 recorded the lowest axial compression load capacity of 187.00 kN at a vertical displacement of 7.32 mm. Based on three replicates of testing wallettes type NPR, the average maximum axial compression load recorded was 217.00 kN and average vertical displacement was 6.62 mm. Meanwhile, for reinforced wallettes with surface plaster (PR), it can be seen that the highest maximum applied load was recorded on PR3 with failure load of 395.50 kN at a vertical displacement of 12.25

mm. Then it was identically dropped by the PR2 which reached its maximum load of 358.50 kN at maximum displacement of 14.81 mm. The maximum applied load was further decreased to 289.50 kN at a displacement of 14.06 mm for PR1. The average maximum applied load and displacement of three replicates of wallettes PR was 335.80 kN and 13.71 mm respectively.

Table 3. Maximum load and vertical displacement of wallettes under axial compression load

Wall types	Wall reference	Maximum load (kN)	Vertical displacement (mm)	Maximum load (Mean) (kN)	Vertical displacement (Mean) (mm)
NPR	NPR1	187.00	7.32	217.0	6.62
	NPR2	221.50	6.54		
	NPR3	242.50	6.00		
PR	PR1	289.50	14.06	335.8	13.71
	PR2	358.50	14.81		
	PR3	359.50	12.25		

The results of axial compression load capacity that were presented above provides information on the vertical load resistance of the reinforced prefabricated wall constructed using a cross laminated technique bonded with normal sand-cement mortar. From the test results, both of wallettes NPR and PR have their own capabilities to resist axial compression load. For reinforced wallettes without surface plaster NPR the compressive strength calculated as high as 362 kN/m. This shows that, the new technique proposed come with steel bars as the lifting mechanism significantly able to carry a high distributed load along the wallettes length. The testing of wallettes without surface plaster was purposely conducted as to simulate the actual compression behaviour of prefabricated wallettes during its transportation and initial installation stage [12]. This performance will ensure that the wall able to safely resist an initial service before the full service is applied [13]. For the reinforced wallettes with surface plaster PR, the calculated compressive strength increased approximately about 35 % up to 560 kN/m. The wallettes strength indicated that, an application of surface plaster on both surfaces of wallettes significantly increase the wall strength as well as enhanced the aesthetic value of this prefabricated wall. If compared against the theoretical estimation of load distribution for two storey building [14], the experimental results recorded 11 times higher and these shows that, the reinforced wood-wool panel wallettes constructed using a cross laminated technique have a great potential to be used as prefabricated load bearing wall system for low rise building. If looking at the effect of steel bars provided as lifting component, the comparison has been made on the previous study conducted [15] the results significantly show that, the provision of steel bars embedded inside the mortar core adversely reduced the load carrying capacity of wallettes about 21 % from 275.00 kN for wallettes without surface plaster and 7 % from 360.30 kN for wallettes with surface plaster. This indicated that, the provision of steel bars did not contribute to the strength increment of wallettes due to reduction of bonding area between two layers of wood-wool cement panel. The previous study had clarified that, the strength of cross laminated wood-wool wallettes was governed by the thickness of mortar as a bonding agent [8][9][10].

In terms of axial load - vertical displacement behaviour, figure 9(a) and 9(b) shows that, the deformation behaviour of wallettes NPR and PR behave identical response where the applied load increase slightly linear with the vertical displacement up to the maximum failure load. After reaching the maximum load, the loads were observed drastically dropped for NPR and this type of wallettes cannot resist more load beyond this point. However, for PR wallettes the curves show the slowly dropped off load until the final failure. It can be seen that, the ability of the wallettes to resist a higher load were mainly governed by the normal mortar either used for bonding the panels or surface plaster. The bonding failure within wood-wool panel matrix is the first failure mechanism and followed by the crushing of mortar significantly contributed to the immediate final failure. Figure : (a) and : (b) shows the failure mode behaviour of wallettes NPR and PR 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.

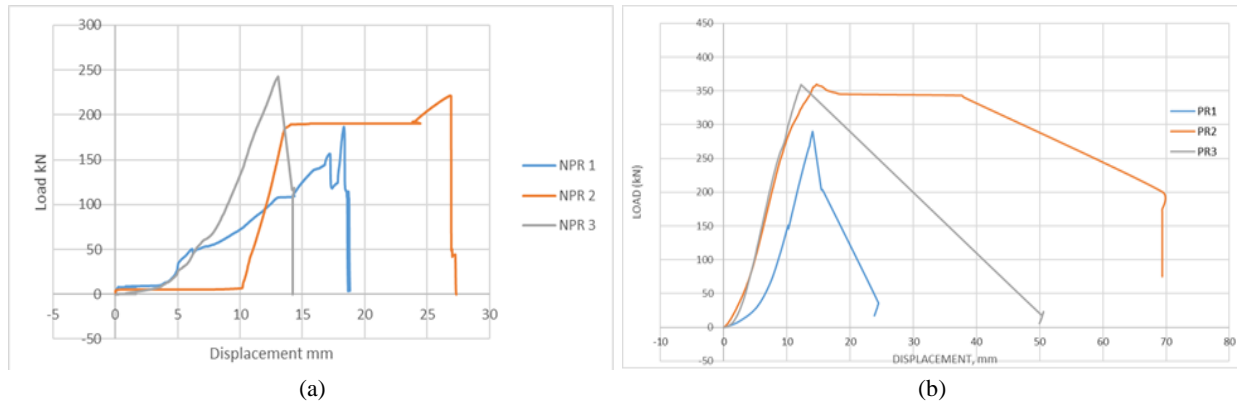


Figure 9. Axial compression load - vertical displacement curve of (a) NPR (b) PR



(a) Wallettes NPR



(b) Wallettes PR

Figure 8. Failure mode behaviour of WWCP wallettes under axial compression load test

4. Conclusions

Based on the axial compression load test conducted on the reinforced wood-wool wallettes, the conclusions can be drawn as follows;

- The cross laminated technique improved the wall fabrication 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 35 % up to 560 kN/m compressive strength.
- The compressive strength of wallettes is mainly governed by the mortar used as a bonding agent and surface plaster.
- The provision of steel bars as the lifting mechanism for prefabricated wood-wool wallettes significantly reduced the load carrying capacity about 7 % to 21 % compared to un-reinforced wallettes [15].

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