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Axial Compression Behaviour of Cross-Laminated Wood-Wool Cement Composite Panel Wallette Bonded With Lightweight Cement Mortar

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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 eco-friendly 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 400 kg/m^3 to 1850 kg/m^3 and also capable to support an imposed load from the building. This study was conducted as to investigate an axial compression behaviour prefabricated reinforced wallettes constructed with two layers of wood-wool cement panel at a cross wise orientation. The two layers of WWCP were bonded with 15 mm thickness lightweight mortar paste. As to improve the load carrying capacity, the wallettes specimens were reinforced with A6 wire mesh that provided in the middle of mortar paste. Three replicates of wallettes specimen with dimension 900 mm width and 900 mm length were tested under axial compression load after 28 days of fabrication. The results indicated that the wallettes have an ability to sustain maximum axial compression load of 93 kN. This shows that the new panel arrangement technique, namely as cross-laminated was observed as the technique that can withstand a higher axial compression load better than the single orientation technique either in longitudinal or transverse panel arrangement.

Keywords: Lightweight Cement Mortar, Wood-Wool Panel, Axial Compression Test

1. Introduction

An application of wood based composite product as a structural building component drastically increases as it plays important roles in improving sustainability in the construction industry. Besides, wood based material is good in bending and more economic rather than a steel structure [1]. The use of non-renewable materials for building wall element, such as bricks are widely used as, it is economically and easily available. The use of brick materials was adversely affecting the environment due to the

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mining of the non-renewable resources such as sand to produce bricks for construction. Brick and other masonry element also produced a big amount of carbon emission, heavy in weight, the use of numerous labours to construct and consumed long construction period [2]. Thus, science and technology have brought the new ideas and innovation of the wood-based product that compositely combined with other materials such as wood-wool cement composite panel (WWCP). An application of this composite panel, significantly able to reduce CO_2 emission, low energy consumption and available to be used as a structural building wall element. The wood-wool that sheredded from local fast grown timber species known as Kelampayan acts as a base material whenever combined with cement paste as a binding agent. Based on previous physical and mechanical properties test conducted, the WWCP complies the minimum requirement as stated in the ISO and DIN 1101 specifications for use in the structural application [3].

Therefore, this study investigates the structural behaviour of 900mm x 900mm wallettes fabricated using two layers of WWCP in a cross laminated panel arrangement reinforced with wire mesh and bond with lightweight cement mortar. The wallettes specimens were tested under static axial compression load until failure. The provided wire mash size A6 was to increase the stiffness of core mortar as well as increase the load carrying capacity of wallettes. On the other hand, for minimizing the weight of fabricated wallettes, lightweight cement mortar was used to investigate the effect of this type of bonding agent to the load carrying capacity of wallettes.

2. Materials and Methods

2.1 Materials

2.1.1 Wood-wool cement composite panel (WWCP)

Wood-wool cement composite panel is the main material used in the fabrication of wallettes. WWCP used in this study was supplied by the sole local manufacturer of Duralite (M) Sdn. Bhd. The standard panel size of 600 mm width, 2000 mm length and 75 mm thickness was cut into 3 desired small panel size of 300 mm x 450 mm, 300 mm x 500 mm and 300 mm x 300 mm as shown in Figure 1(a) to accommodate the design configuration to form 900 mm x 900 mm wallettes.

2.1.2 Lightweight cement mortar

Portland cement (Figure 1(b)), fine sand (Figure 1(c)), water and foaming agent were used to produce the lightweight cement mortar with desirable mix ratio. The lightweight cement mortar was used as an adhesive to bond the panels together. Sand used was sieved to passing 2 mm size for finer grained of aggregate. The prescribe mix of lightweight cement mortar having a ratio of 1 : 2 cement and sand with the water cement ratio of 0.4. The foaming agent to water ratio used is 1:10 in order to achieve the target density of 1700 kg/m^3. Three samples of lightweight cement mortar at different batching process were considered in the fabrication of wallettes. The density and strength properties of lightweight cement mortar in terms of flexural and compressive strength at 28 days age were investigated.

2.1.3 Fabric wire mesh

Fabric wire mesh that used in this study is size A6 provided to enhance the strength of wallettes as shown in Figure 1(d). Fabric wire mesh is a set of high strength 6 mm wires welded together to form a square grid fabric mesh. One piece of BRC wire mesh square shape was placed between panels and embedded in lightweight mortar.

(a) (b) (c) (d)

Figure 1: (a) wwcp (b) Portland cement (c) fine sand (d) Fabric wire mesh A6

2.2 Fabrication of wallettes

Three replicates of wood-wool wallettes were fabricated and denoted as W1, W2 and W3 having a dimension of 900 mm x 900 mm. The panel configuration of each side of wallettes is shown in Figure 2. The cut panels of 300 mm x 500 mm, 300 mm x 450 mm and 300 mm x 200 mm were horizontally laid in two layers at opposite panels direction. The wire mesh of A6 was cut using a cutter machine and placed between the front and rear panel embedded in the 15 mm thickness of lightweight mortar. Lastly, all the wallettes were undergone curing process for 28 days before it's ready for axial compression load testing. Figure 3 shows the actual fabrication process of wallettes constructed in this study.

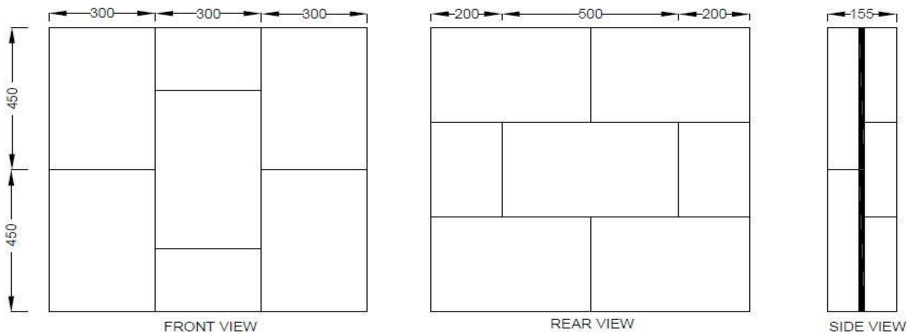


Figure 2: The configuration of WWCP

(a) Wood-wool panel cut into various of sizes
(b) Laying the panel with longitudinal arrangement
(c) Placing wire mesh A6 on the top of the panel

(d) Rendering 15 mm thickness of lightweight mortar
(e) Laying the second panel with transverse arrangement
(f) The wallettes was cured for 28 days after fabricating work

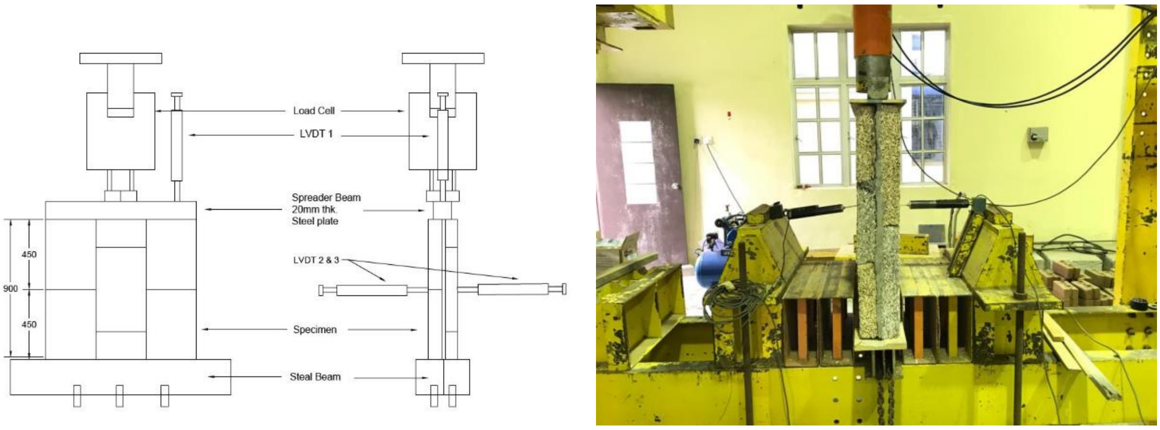
Figure 3: Fabrication process of wallettes

2.3 Strength properties test of lightweight cement mortar

The density of hardened lightweight cement mortar was determined after 28 days of curing. The density of the lightweight cement mortar prism is formulated from its mass per unit volume. The lightweight mortar that used to fabricate three replicates of wallettes was tested under flexural strength testing to identify the effect of mortar to the strength of wallettes and its stiffness. Flexural strength is measured by the three-point loading of a prism specimen and the compressive strength is measured on each half of the prism as a result of the failure and breakage of that specimen. It was carried out according to BS EN 1015-1 1: 1999 that also being conducted after 28 days of age of the mortar.

2.4 Axial compression load test of wallettes

The three replicates of wood wool wallettes was denoted as W1, W2 and W3 were undergoing the axial compression test. The wallettes was placed between two stiff blocks after 28 days of fabrication. The longitudinal deformation of the specimen was measured using Lineal Voltage Displacement Transduce (LVDT) mounted on the stiff block in the test machine to record the relative displacement of the wallettes through out of the testing. . Figure 4 shows an illustration and the actual test setup.



(a) Illustrate test setup (b) Actual test setup

Figure 4: Illustration and actual testing setup of axial compression load

3. Results and Discussion

The findings from the experimental testing results and data are presented in this section. These include the results of density, flexural test and compression test of nine prisms of hardened lightweight cement mortar and the results of the axial compression load test of three fabricated wallettes denoted as W1, W2 and W3.

3.1 Mechanical properties of lightweight cement mortar prism

The density of the lightweight cement mortar prism determine in this study is shown in Table 1 below.

Table 1: Density of hardened lightweight cement mortar

	Sample 1	Sample 2	Sample 3
Mass (kg)	0.45	0.44	0.43
Volume (m^3)	2.56 x 10^{-4}	2.56 x 10^{-4}	2.56 x 10^{-4}
Density (kg/m^3)	1757.81	1718.75	1679.69

Table 1 shows the density of the hardened lightweight mortar for 3 samples. The dimension of this density test used is 160 mm x 40 mm x 40 mm. For sample 1, the density of the hardened lightweight mortar is 1757.81 kg/m^3. Sample 2 recorded 1718. 75 kg/m^3 and sample 3 recorded 1679.69 kg/m^3. The average density of the hardened lightweight cement mortar for 3 samples is 1718.75 kg/m^3. Thus, the density of lightweight cement mortar in this study is suitable for lightweight mortar in the range of 400-1850 kN/m^3.

Table 2 indicated that the result of the flexural strength of the hardened light mortar used as bonding agent for 3 wallettes specimens after 28 days of curing. The Figure 4.1 shows the actual testing for flexural test. The aim of this test is to ensure that the lightweight mortar mixture is effective for the bonding agent of the WWCP and contributes to the strength of the wallettes themselves. From formula that were calculated, Sample 1 had a flexural strength of 3.17 N/mm2, Sample 2 had a flexural strength of 4.0 N/mm2 and Sample 3 had a flexural strength of 3.19 N/mm2. Based on these three samples of flexural strength, the average flexural strength of three samples is 3.45 N/mm2.

Table 2: Flexural strength of lightweight cement mortar

No of Sample	Specimen	Maximum load (newton)	Flexural Strength (N/mm$^{2)}$	Flexural strength (mean) (N/mm^2)
	1	1220		
Sample 1	2	1420	3.17	
	3	1420		
	1	1920		
Sample 2	2	1580	4.0	3.45
	3	1620		
	1	1220		
Sample 3	2	1680	3.19	
	3	1180		

After undergoing flexural strength test, the half split of prism size 40 mm x 40 mm x 160 mm was undergoing compressive test as shown in Figure 4.2 after 28 days of curing. Each sample provided 6 specimens of a half split prism which is 18 prims in total of 3 samples that were undergoing compressive strength. Table 3 shows the compressive strength of lightweight cement mortar. Based on Table 4.3, it shows that maximum compressive strength of 3 samples. Sample 1 recorded maximum compressive strength of 12.0 N/mm^2, Sample 2 recorded 12.9 N/mm^2 and Sample 3 recorded 12.3 N/mm^2. Thus, the compressive strength of lightweight mortar was increased as a density increase. Sample 2 shows the highest compressive strength and Sample 1 is the lowest compressive strength were recorded.

Table 3: Compressive strength of lightweight cement mortar

Sample	Maximum Load (kN)	Compressive strength (N/mm^2)	Compressive strength (mean) (N/mm^2)
Sample 1	19.28	12.0	
Sample 2	20.60	12.9	12.4
Sample 3	19.67	12.3	

3.2 Axial compression load testing results

3.2.1 Axial compression load for wallettes

The results of three specimens of wallettes were evaluated under compressive test machine, and denoted as W1, W2 and W3 as shown in Table 4. The size of three wallettes that were undergoing axial compressive load test was 900 mm x 90 mm x 155 mm. All the three wallettes we fabricated in the same design mixture of Portland cement, sand and foaming agent. The W2 recorded 93 kN with a vertical displacement of 6.3 mm has been observed as a maximum load capacity retained by this wallettes. W3, with a vertical displacement of 5.49 mm, has been recorded 71 kN as the second-highest maximum load capacity. In addition, with a vertical displacement of 3.55 mm, the W1 has the lower capacities which fail to carry an applied load of 71 kN. Based on three replicates testing that were performed on three replicates wallettes of W1, W2 and W3, the average loading capacity was 78 kN and the average displacement was 5.1 mm.

Table 4: Maximum load and vertical displacement of wallettes

Wall Reference	Maximum Load *(kN)*	Vertical Displacement *(mm)*	Lateral Displacement		Average Maximum Load *(kN)*
			Left (mm)	*Right (mm)*	
W1	69	5.49	0.235	0.435	
W2	93	6.295	3.1	3.345	78
W3	71	3.55	3.88	2.96	

3.2.2 Load vs vertical displacement

The load-displacement curves of three replicates of wallettes subjected to an axial compression load are shown Figure 5. The use of the wire mesh (A6) as a strength mechanism bonded in between these wallettes tends to maintain the stability of the wall structure slightly after the full applied load. The wall attempts to maintain its strength on maximum load before the final failure occurs until the wallettes can no longer resist the load. In fact, the middle layer of the wallettes holding the wire mesh still stands at the end of the failure. In addition, most wallettes raise load almost linearly with vertical displacement before the full load is reached.

For W2, the wallette cracked for the first time at 42 kN, where the little cracked appears on the web. Load W2 wallette keeps rising to 93 kN5 and achieved its final failure of the consecutive load. The panels were split and crushed at full load and LVDT 1 (vertical) reported at 6.3 mm vertical displacement. For W1, the wallette achieved its final failure at the axial loading of 69 kN and the LVDT 1 recorded at 5.49 mm. For W3, the axial compression load achieves is 71kN and the LVDT 1 recorded at 3.55 mm. Based on these three specimens of wallettes, the maximum load achieved is W2 where the maximum load is 93 kN. W1 recorded as the lowest load achieve which is 69 kN and W3 is the second highest load achieved which recorded 71 kN. Figure 5 indicates the load vs the vertical displacement of W1, W2 and W3.

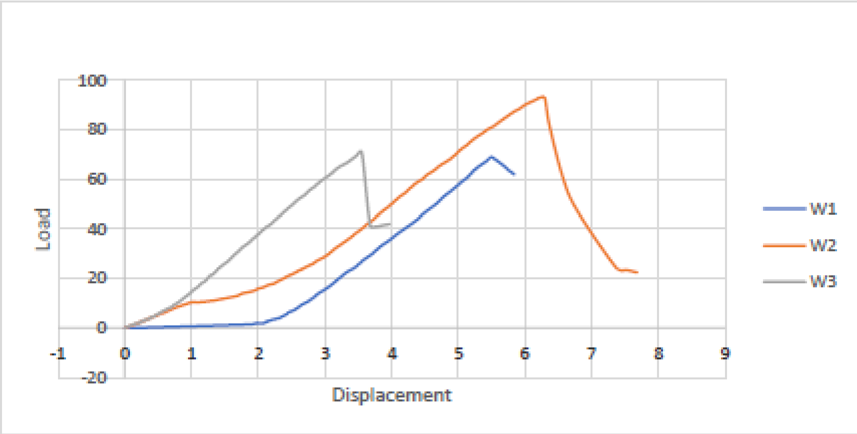


Figure 5: Load vs vertical displacement

3.2.3 Failure mode behavior of wallettes

Based on the results and observation of modes of failure, it was determined where the wallettes were mostly a failure of the wood-wool panel itself. Refer to Figure 7. The failure of W1 begins at the longitudinal top panel where it is near the load applied. Failure begin by splitting the longitudinal arrangement panel from 15 mm of lightweight mortar on the right side where LVDT 2 located and leaves the middle mortar layer still standing after failure same as W2 as shown in Figure 4.11. This was due to the continuous loading to the wallettes and the debonding of the panels with lightweight mortar and some of the panels crushed due to the compression momentum. For the W3, crushing failure occur in the middle of the web panel at the longitudinal arrangement of the panel. The limitation of this wallette is the bonded between panels and the lightweight mortar as the longitudinal panel arrangement starts to debonding. As the load rises from time to time, the crack spreads along the web and crushes the wallette.

a) W1 b) W2 c) W3

Figure 7: Failure mode of wallettes

3.3 Discussions

Referring to the previous study conducted by Degirmenci and Yilmaz (2011) [5], it was found that, the combination of Portland cement and pumice fine aggregate to make lightweight cement mortar recorded a low density of 1146 kg/m^3, however, the compression strength recorded was 12.55 N/mm^2 and flexural strength was 3.08 N/mm^2. Alsharie et al. (2015) [6], indicated that, the lightweight cement mortar can be mixed with three types of materials which is Portland cement, limestone fine aggregate and alkaline solution. The results, stated that, the treated prism with alkaline solution show the density achieved was 1467 kg/m^3, compression strength was 27.7 N/mm^2 and flexural strength was 4.3 N/mm^2. From the previous research [7], the Portland cement, sand and recycled polyurethane foam is used to make lightweight cement mortar. As results, the recorded data for density achieve was 1528 kg/m^3, compression test was 13 N/mm2 and flexural test was 3.2 N/mm^2. From observation of the average compression strength of lightweight mortar obtained from this study that was recorded 12.4 N/mm^2. If compared against the previous study [5] [7], it can be seen that, the compressive strength obtained was identical to the lightweight mortar that mixed with lime stone fine aggregate and alkaline solution which achieved compressive strength of 12.55 N/mm^2. The lightweight mortar using pumice fine aggregate and recycle polyurethane achieved the strength of 13.0 N/mm^2. These three sets of compression strength show that the differences of the lightweight mortar can be classified as S-type and N-type according to ASTM C 270.

Through this experimental study, the cross laminated wood-wool cement composite panel bonded with lightweight cement mortar show a great potential in load bearing wall development. The average maximum load that the wallette can withstand is 78 kN where it is passing the theoretical load transfer as indicated from previous study Md Noh et al. (2014) [4], where the minimum requirement of an axial compressive strength of the WWCP wall for two storey building is about 50 kN/m. By referring the tabulated data recorded, the results indicate that the wall strength recorded is 1.8 times higher than the minimum requirement for load bearing wall of two storey building. It shows that the new cross laminated arrangement techniques of wallette is effective in increasing the axial compression load of the wall. Besides, the used of lightweight cement mortar as bonding agent for wood-wool cement composite panel recorded in decreasing the maximum load of wallettes. Based on the previous study [4], the use of normal mix mortar as bonding agent was achieved the maximum axial load of 275 kN. From the observation of these two types or mortar used, the lightweight cement mortar has decreased about 72% in the axial compression load test.

The axial compression strength of the WWCP result revealed that the WWCP is able to withstand a high-capacity load, which can stand up to 87 kN/m of concentrated load per length. From previous research, the using of normal cement mortar can withstand minimum of 360 kN/m concentrated load per length [8]. Based on theoretical load transfer as indicated from [4], the minimum requirement of an axial compressive strength of the WWCP wall for two storey building is about 50 kN/m and the experimental tabulated results indicated that the wall strength recorded is 1.8 times higher. The findings indicated that these walls may be a new prefabricated load bearing wall structure for construction of house and building. The results show that a strong bonding of lightweight cement mortar to braced axial compression was provided with the proposed cross laminated arrangement of the 2-layer panels with 15 mm thickness of lightweight cement mortar.

4. Conclusion

From an experimental investigation that have been conducted, it can be concluded that,

- The density affects the strength of lightweight cement mortar.
- Higher density of lightweight cement mortar gives the higher flexural and compressive strength.
- New arrangement technique of wallette which is cross-laminated give a significant effect to the load carrying capacity.
- The average value of the axial compression load capacity of wallettes bonded with lightweight cement mortar was 78kN.
- The density of lightweight cement mortar were also give significant effect to the strength of wallettes under axial compression.

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References

[1] A. Ashori, T. Tabarsa, and S. Sepahvand, “Cement-bonded composite boards made from poplar strands,” *Constr. Build. Mater.*, vol. 26, no. 1, pp. 131–134, 2012, doi: 10.1016/j.conbuildmat.2011.06.001.

[2] T. Goverse, M. P. Hekkert, P. Groenewegen, E. Worrell, and R. E. H. M. Smits, “Wood innovation in the residential construction sector; opportunities and constraints,” *Resour. Conserv. Recycl.*, vol. 34, no. 1, pp. 53–74, 2001, doi: 10.1016/S0921-3449(01)00093-3.

[3] M. S. Md Noh, Z. Ahmad, and A. Ibrahim, “Axial compression behaviour of wallettes constructed using wood-wool cement composite panel,” *Adv. Mater. Res.*, vol. 1051, pp. 670–677, 2014, doi: 10.4028/www.scientific.net/AMR.1051.670.

[4] M. S. Md Noh *et al.*, “Axial compression behaviour of cross laminated wood-wool panel wallettes,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 271, no. 1, 2017, doi: 10.1088/1757-899X/271/1/012072.

[5] N. Degirmenci and A. Yilmaz, “Use of pumice fine aggregate as an alternative to standard sand in production of lightweight cement mortar,” 2011.

[6] H. Alsharie, T. Masoud, A. I. Abdulla, and A. Ghanem, “Properties of lightweight cement mortar containing treated pumice and limestone,” *J. Eng. Appl. Sci.*, vol. 10, no. 5, pp. 96–101, 2015, doi: 10.3923/jeasci.2015.96.101.

[7] J. Gadea, A. Rodríguez, P. L. Campos, J. Garabito, and V. Calderón, “Lightweight mortar made with recycled polyurethane foam,” *Cem. Concr. Compos.*, vol. 32, no. 9, pp. 672–677, 2010, doi: 10.1016/j.cemconcomp.2010.07.017.

[8] M. S. Md Noh *et al.*, “IOP Conference Series: Earth and Environmental Science Axial compression behaviour of reinforced wallettes fabricated using wood-wool cement panel,” *IOP Conf. Ser. Earth Environ. Sci*, vol. 140, p. 12154, 2018, doi: 10.1088/1755-1315/140/1/012154.