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Experimental Study on Prefabricated Lightweight Composite Wall Panels under Flexural Loading

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Abstract: The prefabricated lightweight wall panels have been widely used instead of brick walls in the modern construction industry of building due to its many advantages. As lightweight concrete is week under flexural loading, more reinforcement bars are required to improve the flexural strength of conventional lightweight wall panel. In this paper, steel studs/angles are proposed instead of reinforcement bars because the moment of inertial of steel stud/angle is higher than reinforcement bars. Experimental study has been conducted to investigate the flexural behaviour of proposed prefabricated lightweight composite (PLC) wall panels. Three samples of PLC wall panels are fabricated using lightweight concrete materials and studs. The parameters that are changed in the test specimens are material types (cold-form steel or carbon steel) and numbers of steel studs/angles. The test results show that the material types and numbers of steel studs/angles has significant impact on the flexural strength and stiffness of PLC wall panels.

Keywords: Lightweight wall panels; Composite wall panels; Lightweight concrete; Prefabricated construction; Flexural behaviour.

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1. Introduction

The prefabricated lightweight wall panels have been widely used in the modern building construction industry instead of the brick walls due to the drawback of brickwork [1]. The prefabricated wall panel play a pivotal role towards the environment and sustainable friendly construction. The prefabricated lightweight wall panels have many advantages such as easy to handle and assemble, faster, better, stronger, cheaply, durable, safe and eco-friendly [2]. Due to these benefits, majority of housing industry in Sweden uses the prefabricated lightweight wall panels [3]. Although the concept of prefabricated construction is widely adopted in Sweden, Japan and New Zealand, but in Australia only 3 to 4% uses this material for the new buildings [3]. This is due to the lack of research on prefabricated lightweight wall panels and widely available commercial products.

There are different types of lightweight wall panels, which are made from lightweight autoclaved aerated concrete [4-5], lightweight foam concrete [6], lightweight aggregate concrete [7]. Lightweight autoclaved aerated concrete was first discovered by a Swedish researcher in 1920 and the main aim of his research was to increase the compressive strength of concrete with low density. Lightweight autoclaved aerated concrete is composed of sand, cement, land, water, aluminium powder, quartz, calcined gypsum and water. The dry density of lightweight autoclaved aerated concrete mainly depends on the amount of aluminium powder [8]. The density of such concrete can be reduced significantly by increasing the amount of aluminium powder. But the main problem of it is the compressive strength which decrease with increase the aluminium powder. Lightweight foam concrete i.e. known as lightweight cellular concrete are made of a cementitious material with a minimum 20 percent of foam. The dry density of lightweight foam concrete is ranged from 300 to 1600 kg/m^3 with a compressive strength of ranges from 0.2 to 10 MPa [9]. The water absorption of this type of wall panel is high. Lightweight aggregate concrete has been made of using lightweight aggregates such as expanded shale, clay, perlite, chemosphere, pumice, diatomite, scoria, volcanic cinders, saw dust, rice husk, expanded lightweight glass, and etc.

Despite having some benefits of lightweight wall panels, the existing prefabricated lightweight wall panels are week under flexural loading compared to the conventional normal weight concrete wall panels [10]. Therefore, additional reinforcement bars are required, which are widely used to improve their flexural strength. The use of reinforcement bars also increases the density and corrosion problems [11]. In recent, the lightweight composite wall panels, instead of conventional lightweight wall panels incorporated reinforced bars, are developed using foam concrete and cold-formed steels [12-14]. The flexural strength of such wall panels is significantly improved due to the composite action between cold-formed steel sections and concrete. Cold-formed steel-concrete composite slabs were also investigated in recent year [15]. Extensive researches have been conducted on cold-formed steels with gypsum plasterboards are widely used due to the higher strength to weight ratio [16-20]. It is reported that the local, lateral and distortional buckling of bare cold-formed steel (i.e. also known as steel studs) can be minimised by considering the composite action between these two materials [20,21].

Although, the benefit of composite steel studs with gypsum plasterboards are investigated experimentally and numerically, limited research has been conducted on the steel studs with lightweight concrete to make the prefabricated lightweight composite (PLC) wall panels. This paper investigates the composite behaviour of PLC wall panels under flexural loading for different numbers of steel studs/angles and material types. In this paper, steel studs/angles are proposed instead of reinforcement bars because the moment of inertial of steel stud/angle is higher than reinforcement bars, which will enhance the flexural strength of prefabricated lightweight wall panel. The failure mode, ultimate load capacity, initial stiffness and load-deformation curves of proposed PLC wall panels are mainly discussed in this paper.

2. Experimental program

2.1 Details of PLC wall panels

Three specimens of prefabricated lightweight composite (PLC) wall panels are fabricated using lightweight concrete materials and steel studs/angles. The parameters that are changed in the test specimens are material types (cold-form steel or carbon steel) and numbers of steel studs/angles. The dimension of each wall panel specimen is considered identical as of 1000 mm in length, 300 mm in width and 75 mm in height. In first specimen, cold-formed steel studs are used, whereas slotted steel angles are used in second and third specimens. The main difference between second and third specimens is the number of slotted steel angles. In the second specimen, two slotted steel angles are used, whereas three slotted steel angles are used in the third specimen. In first specimen, two cold-formed steel studs are used. Two reinforcement bars of 260 mm in length and 3 mm in diameter are placed horizontally in the first and second specimens. For the third specimen, three reinforcement bars are used. The cross-sectional dimension of each cold-formed steel stud is 64 mm × 35 mm × 1.15 mm and for slotted steel angle is 38 mm × 38 mm × 1.8 mm. The details of PLC wall panels are given in Fig.1 and Table 1. The yield strength of cold-formed steel stud and slotted steel angle is 290MPa and 450 MPa, respectively, whereas, the tensile strength is 360 MPa and 510 MPa, respectively.

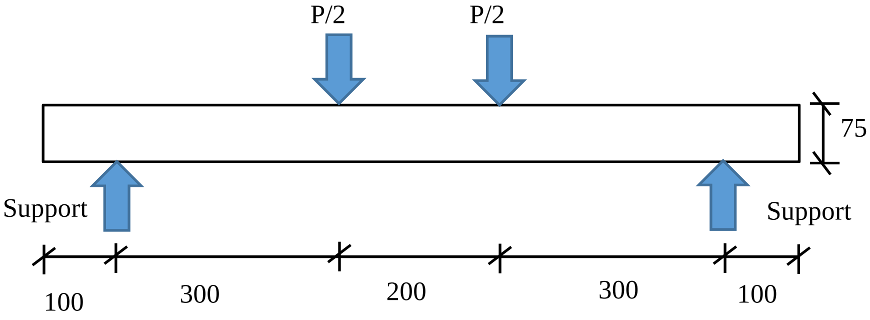
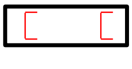
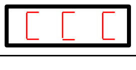


Fig. 1. Dimension details of PLC wall panel including loading points

Table 1. Test specimen details

Specimen No	Dimension (mm)	Details of Stud/angle				Ultimate Load (kN)
		Number	Spacing (mm)	Types	Location	
PLC-WP1	300×1000×75	2	200	Stud		10.31
PLC-WP2	300×1000×75	2	200	Angle		15.24
PLC-WP3	300×1000×75	3	100	Angle		19.26

Note: PLC-WP: Prefabricated lightweight composite wall panel

2.2 Materials and mix design

Lightweight concrete which are used to fabricate the PLC wall panel is prepared using cement, lime, fly ash, fine sand and expanded glass aggregate. The mix proportion used in this study is given in Table 2. Three different types (Type 1, Type 2, Type 3) of expanded glass aggregates are used as shown in Table 2 and Fig. 2. For the Type 1 expanded glass as shown in Fig. 2(a), the size varies from 0.5 to 1 mm, whereas for Type 2 and Type 3 expanded glasses, the sizes are 1-2 mm as shown in Fig. 2(b) and 2-4 mm as shown in Fig. 2(c), respectively. The density of expanded glass varies from 140 kg/m^3 to 190 kg/m^3 depending on the size of glass aggregate. The finer particles have higher density. The water absorption of expanded glass aggregate is around 20 %. The extra water is calculated based on the water absorption capacity of total expanded glass aggregates, which is added in the mix design. Superplasticiser is also used.

Table 2. Mix design of lightweight concrete

Cement	Lime	Fly ash	Fine Sand (g)	Expanded glass (g)			Water	Extra water	Additives
				Type 1	Type 2	Type 3			
536	134	268	153	138	107	77	230	214	17

(a) Type 1: 0.5-1 mm (b) Type 2: 1-2 mm (c) Type 3: 2-4 mm

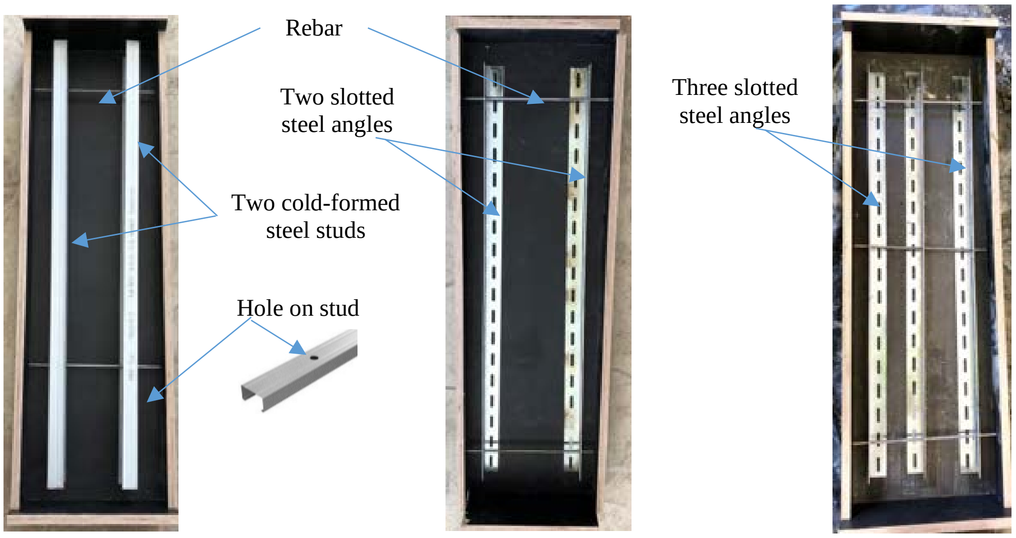
Fig. 2. Expanded lightweight glass aggregate used in this research [22]

2.3 Mixing procedure and specimen preparation

The concrete mixture used in lightweight concrete mixing is shown in Fig. 3. All expanded glass aggregates were added into the pan mixer first and then mixed together for 3 min, after that cement, lime and fly ash were added and again mixed for another 3 min. Following that, water was added and mixed for 3-5 mins depending on the homogeneity of mixture. Once, the mixed materials are ready as shown in Fig. 3(a), six concrete cylinders as shown in Fig. 3(b) were prepared before casting the wall panels. In this research, the cylinder size (50 × 100 mm) was considered according to Australian Standard [23]. In generally, the 100 × 200 mm or 150 × 300 mm size of concrete cylinder was used for coarse aggregates to make normal concrete. According to the Australian Standard [23], the 100 × 200 mm size of cylinder was used for normal concrete made of coarse aggregate and fine aggregate, and 50 × 100 mm for mortar made of fine aggregate only. Each cylinder was poured by three layers and vibrated properly in each layer. Before poring the lightweight concrete into the panels as shown in Fig. 4, three moulds were prepared for three panels and then placed cold-form steel studs/slotted steel angles according to the specimen specification. After that the lightweight concrete was placed and compacted using a poker vibrator. After 24 hours, all panels and concrete cylinders were demolded and wrapped with plastic wrap as shown in Fig. 5, and then stored at the lab until testing.

(a) Concrete mixing (b) Before demolding (c) After demolding

Fig. 3. Concrete mixtures used in lightweight concrete mixing



(a) PLC-WL1 (b) PLC-WL2 (c) PLC-WL3

Fig. 4. Three molds before concrete casting for flexural test.

Fig. 5. Demolding of wall panels and curing with plastic wrap.

2.4 Dry density of lightweight concrete

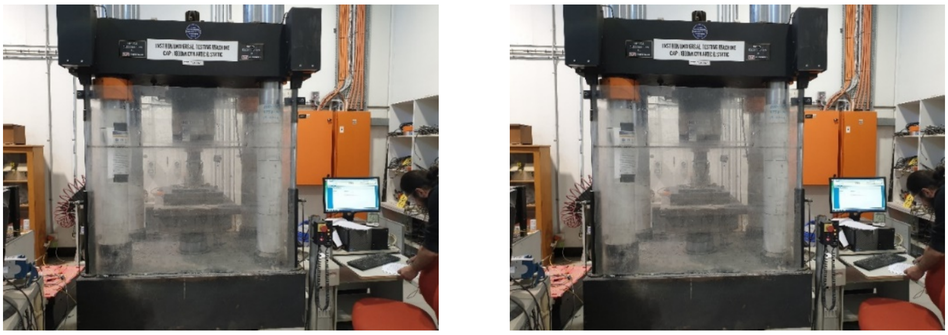
The dry density of lightweight concrete was measured according to Australian Standard AS 1012.12.1 [23]. Five cylindrical specimens (100 × 200 mm) were used to determine the dry density at 28 days. The dimensions (average diameter, height) and weight of all cylinders are measured and determined the density of each specimen as reported in Table 3. The average diameter is calculated based on two diameters of a cylindrical specimen measured using a Vernier calliper at right angle position at the middle height of the cylinder. The average density of lightweight concrete is observed 1367.11 kg/m^3. The maximum error is observed as 1.65%, which is very normal. The measured average density is lower than the limit defined in design code 1850 kg/m^3 in ACI 213R-03 [24], 2000 kg/m^3 in EN 13055 [25], 2200 kg/m^3 in AS 1379 [26]. It means that this type of material can be classified as lightweight material.

Table 3. Measured density of lightweight concrete

Specimen No	Diameter (mm)	Height (mm)	Weight (kg)	Density (kg/m^3)
1	100.09	200.36	2.160	1370.16
2	100.11	201.39	2.180	1375.23
3	100.38	202.54	2.185	1363.33
4	100.75	202.58	2.170	1343.77
5	100.11	200.54	2.175	1378.02
6	100.28	200.68	2.168	1367.98
			Average density =	1366.42

2.5 Compressive and tensile strength of lightweight concrete

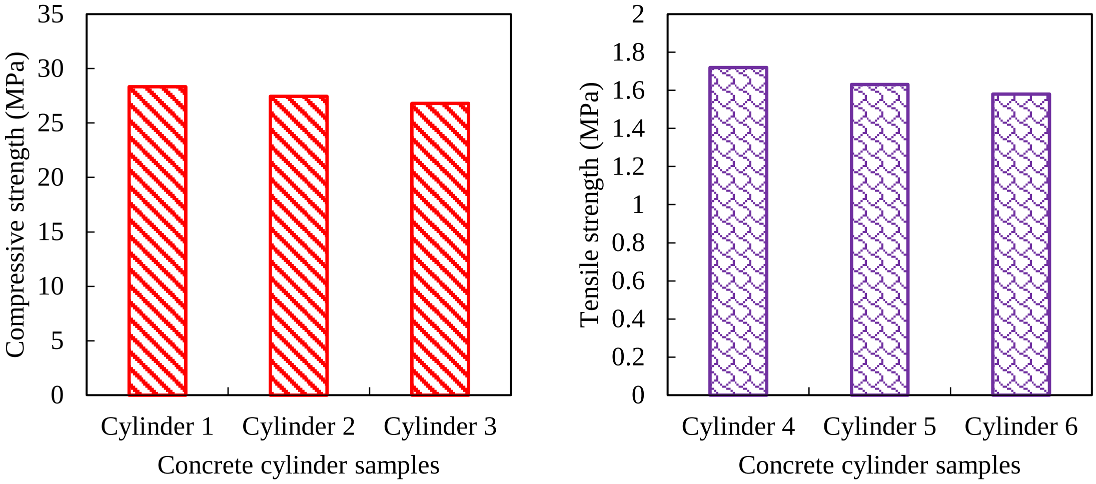
Before the flexural testing of PLC wall panels, the mechanical properties (compressive and tensile strength) of lightweight concrete are investigated according to AS 1012.10 [27] and AS 1012.9 [28] as shown in Fig. 6. The compressive strength of lightweight concrete was determined according to AS 1012.9 [27], and the tensile strength of lightweight concrete was measured using ‘Brazil’ or splitting tests per AS 1012.10 [28]. The loading rates used in compression and tensile tests were 20 ±2 MPa/min and 1.5 ± 0.15 MPa /min, respectively. As it is mentioned before that the compressive and tensile strength are determined based on the concrete cylinder of size 50 mm diameter by 100 mm height used for mortar testing as per Australian Standard [27-28].



(a) Compression test machine (b) Split tensile test machine

Fig. 6. Compressive and split tensile tests of lightweight concrete

The measured compression and tensile strength of lightweight concrete are reported in Fig. 7. The measured compressive strength of three cylinders as shown in Fig. 7 (a) was 28.33 MPa, 27.44 MPa and 26.8 MPa. The average compressive strength was 27.52 MPa. The maximum error was ±2.9%, which is low ever than 5%. In generally, if the error in the test is more than 5%, the results are assumed not consistent or discard that results. The tensile strength of three concrete cylinders tested for lightweight material was observed as 1.58 MPa, 1.63 MPa and 1.72 MPa, as shown in Fig. 7 (b). The average tensile strength was 1.64 MPa, where the error was ±4.24% and. In generally, the tensile strength of lightweight concrete is lower than the normal concrete.



(a) Compression test results (b) Split tensile test results

Fig. 7. Compressive and split tensile test results of lightweight concrete

2.6 Test setup and instruments for wall panels

Fig. 8 shows the test setup of PLC wall panels where a hydraulic MTS machine having capacity of 1500kN was used. The loading rates used in the four-points bending tests was 1 mm/min. The vertical displacement was measured at the mid-span of the wall panel using a linear vertical displacement transducer. Two types of supports such as roller and hinge were used. Schematic sketch of the test setup used, and instrumentation is shown in Fig. 1.

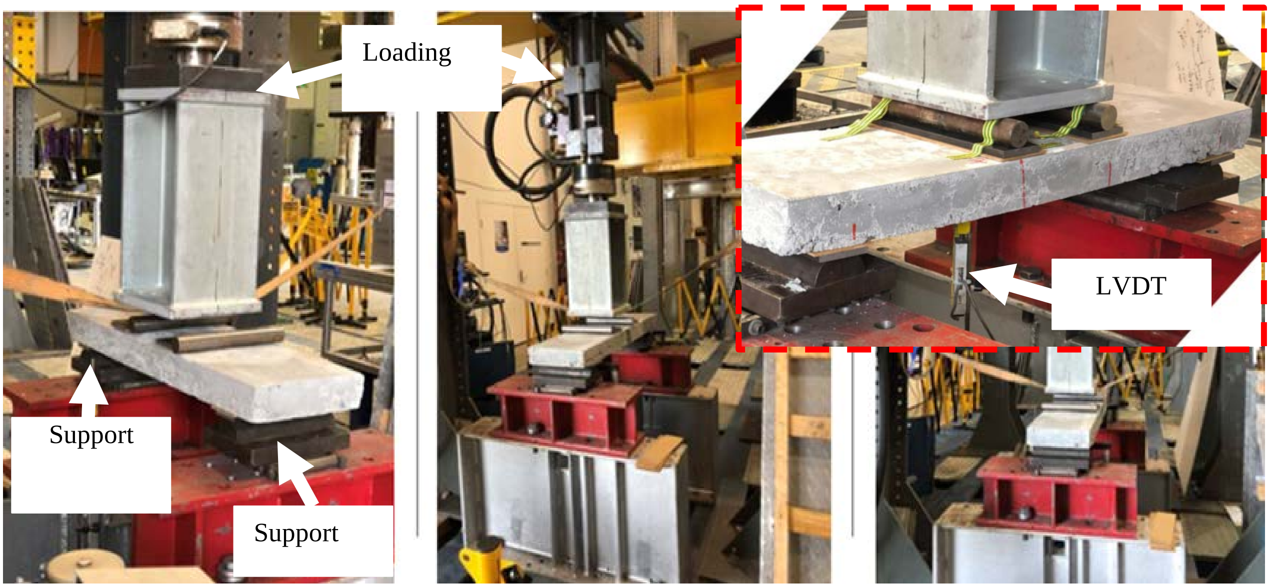


Fig. 8. Test setup of PLC panels

3. Test results and discussion of PLC wall panels

Test results of three prefabricated lightweight composite (PLC) wall panels (PLC-WP1, PLC-WP2, PLC-WP3) are discussed in the below subsections. The failure modes, load-deformation curves, ultimate strength and initial stiffness of each samples are mainly discussed. The summary of test results of prefabricated lightweight composite wall panels are reported in Table 4.

Table 4. Summary of test results of prefabricated lightweight composite wall panels

Specimen No	Δ_y (mm)	P_y (kN)	Δ_u (mm)	P_u (kN)	Δ_f (mm)	P_f (kN)	Stiffness (kN.m^2)	Flexural strength (MPa)
PLC-WP1	7.30	9.09	11.64	10.31	24.83	7.52	12.14	5.50
PLC-WP2	3.40	10.70	7.53	15.24	21.72	11.06	30.68	8.13
PLC-WP3	3.65	15.32	6.53	19.26	17.73	13.35	40.92	10.27

3.1 Test observation of PLC-WP1

The measured load-vertical mid-span deflection curve of PLC-WP1 wall panel with two cold-formed steel studs is reported in Fig. 9. The first visible crack was observed at 7.30 mm of deflection when load reached to 9.09 kN. After this point, a strain hardening behaviour was observed before reached the ultimate load to 10.31 kN. The ultimate flexural load was observed at 11.64 mm. After the ultimate loading, the softening behaviour was observed, and load was decreased gradually to the failure load (7.52 kN) at 24.83 mm of mid-span deflection.

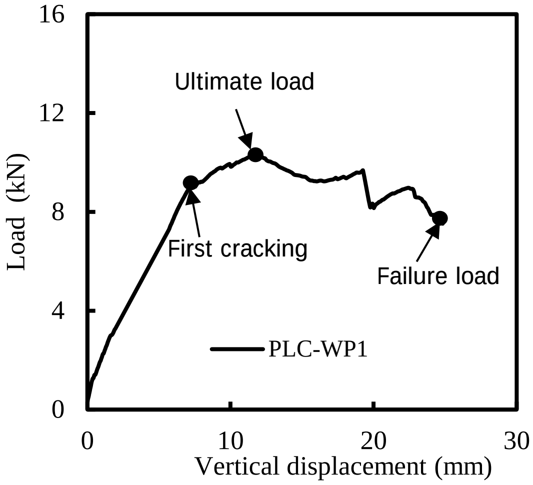


Fig. 9. Load-vertical deformation curves of prefabricated wall panels with cold-form steel studs

The failure mode of this wall panel was dominated by the cracking of concrete first and then deboned the cold-formed steel stud from the concrete. After ultimate load, the concrete cracked severely along the length of wall panel due to the debonding of cold-formed steel stud. The cold-formed steel stud was also twisted, see Fig. 10. The concrete cracking along the length of the panel could also be due to the in-sufficient reinforcement bars in the transverse direction. As there was no connection between bars and studs, this could be another reason for the splitting of concrete. Although, there was severe concrete longitudinal damage, the load did not drop suddenly.

3.2 Test observation of PLC-WP2

The measured load-vertical mid-span deflection curve of PLC-WP2 wall panel with two slotted steel angles is shown in Fig. 11. When load reached to 10.70 kN at a deflection of 3.40 mm, the first crack was observed on the bottom surface of the wall panel. Similar to the PLC-WP1 wall panel, there is a strain hardening behaviour after the first crack. The maximum flexural load of PLC-WP2 wall panel was 15.24 kN at a deflection of 7.53 mm. Although, there was severe concrete damage, the load after peak load did not drop suddenly. This wall panel failed at a load of 11.06 kN when wall panel was subjected to 21.72 mm of mid-span deflection. The failure mode of PLC-WP2 wall panel was dominated by the cracking of concrete at the bottom surface at longitudinal direction and there was no debonding between concrete and steel angle as shown in Fig. 12. As there were so many slotted holes on the steel angles, these holes have significant contribution to develop the bond between steel angle and concrete. Therefore, the load increment after first crack (10.70 kN) to the ultimate load was observed significant.

Fig. 10. Failure modes of prefabricated wall panels with cold-form steel studs

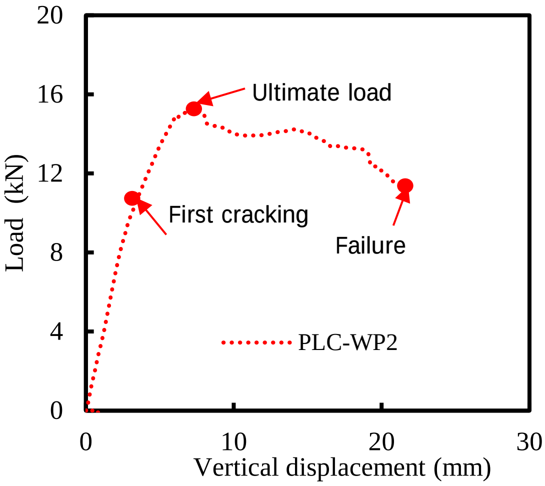


Fig. 11. Load-vertical deformation curves of prefabricated wall panels with two slotted steel angles

Fig. 12. Failure modes of prefabricated wall panels with two slotted steel angles

3.3 Test observation of PLC-WP3

For PLC-WP3 wall panel having three slotted steel angles, the measured load-vertical mid-span deflection curve is shown in Fig. 13. In this wall panel, the first crack was observed at 3.65 mm deflection and the load at first crack was 15.32 kN. A strain hardening behaviour after the first crack to ultimate load was also observed similar to other panels. The maximum flexural load of PLC-WP3 wall panel was 19.26 kN at a deflection of 6.53 mm. The failure load of this panel was 13.35 kN at 17.73 mm deflection at mid-span of the wall panel. The failure mode of PLC-WP3 wall panel was similar to the specimen PLC-WP2 and there was also no debonding between concrete and steel angle as shown in Fig. 14. The slotted holes on three steel angles have significant contribution to develop the bond between steel angle and concrete. Therefore, the load increment after first crack (10.70 kN) to the ultimate load was observed significant.

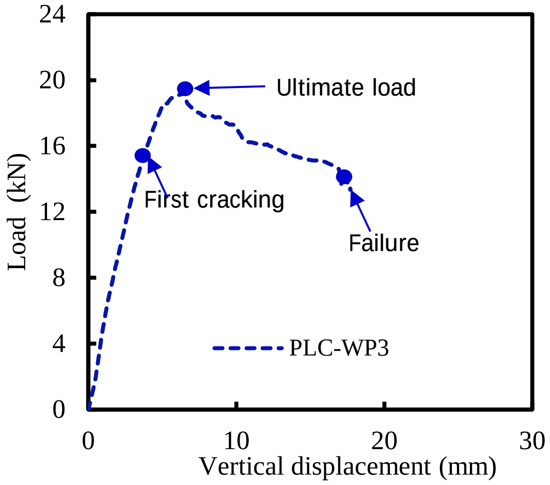


Fig. 13. Load-vertical deformation curves of prefabricated wall panel with three slotted steel angles

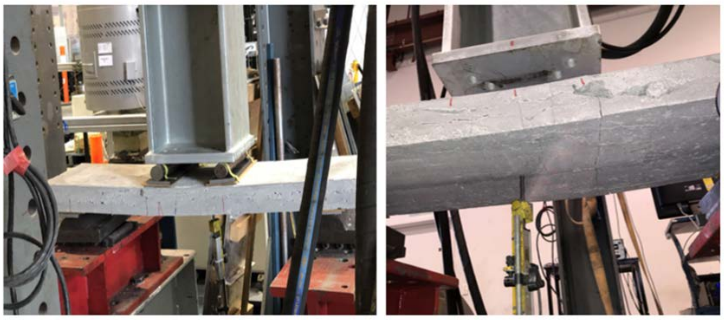


Fig. 14. Failure modes of prefabricated wall panels with three slotted steel angles

3.4 Effect of cold-form steel studs and slotted steel angles on PLC wall panels

The effect of cold-formed steel studs and slotted steel angles on PLC wall panels are compared in Fig. 15 for flexural strength-relative deformation curves, Fig. 16(a) for initial flexural stiffness, Fig. 16(b) for flexural strength. The relative deformation was calculated using the mid-span deflection (Δ) divided by effective length (L) of wall panel. The initial stiffness (EI) of each wall panel was calculated based on the cracking deflection (Δ_y) and its corresponding load (P_y) used in Equation 1. The flexural strength (σ) of each panel was determined using Equation 2 based on their ultimate load (P_u).

$$EI = \frac{Pa(3L^2-4a^2)}{48\,\Delta} \tag{1}$$

$$\sigma = \frac{3Pa}{bd^2} \tag{2}$$

Where, L is the effective span length of wall panel i.e. support to support distance, a is the distance of loading point to the support i.e. shear span, P is the first cracking load, Δ is the mid-span deflection at first visible crack, b is the width of wall panel and d is the depth of the wall panel.

It can be seen from Fig. 15 that when two cold-formed steel studs were used in the PLC wall panel, the flexural strength-relative deformation curve of PLC-WP1 wall panel is different than that of the PLC-WP2 wall panel. The initial stiffness of PLC-WP1 (12.14 kN.m^2) before the formation of the first visible crack is 60.43% lower than that of PLC-PW2 (30.68 kN.m^2) as shown in Fig. 16 (a). Even the flexural strength of PLC-WP1 (5.50 MPa) is 32.35 % lower than that of PLC-WP2 (8.13 MPa) as shown in Fig. 16 (b). However, the mid-span deflection of PLC-WP1 (11.64 mm) at maximum load is higher than that of PLC-WP2 (7.53 mm) as shown in Fig. 15. It was also noticed that the relative deformation of both wall panels (PLC-WP1 & PLC-WP2) was higher than 1% of panel support-to-support length at the ultimate stage. It can be concluded that both wall panels have enough deformation ability and showed good ductility, but, in term of initial flexural stiffness and flexural strength, the PLC-WP2 wall panel is better than the PLC-WP1 wall panel.

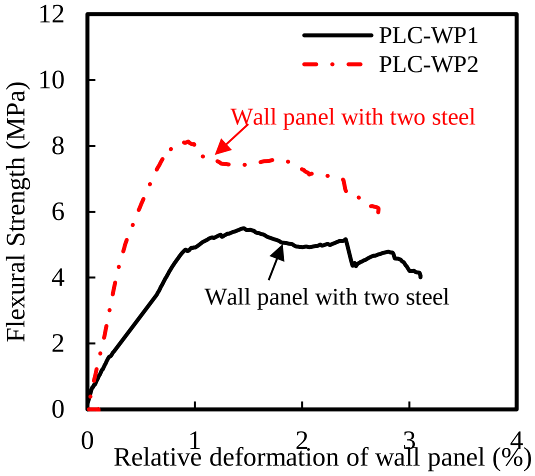
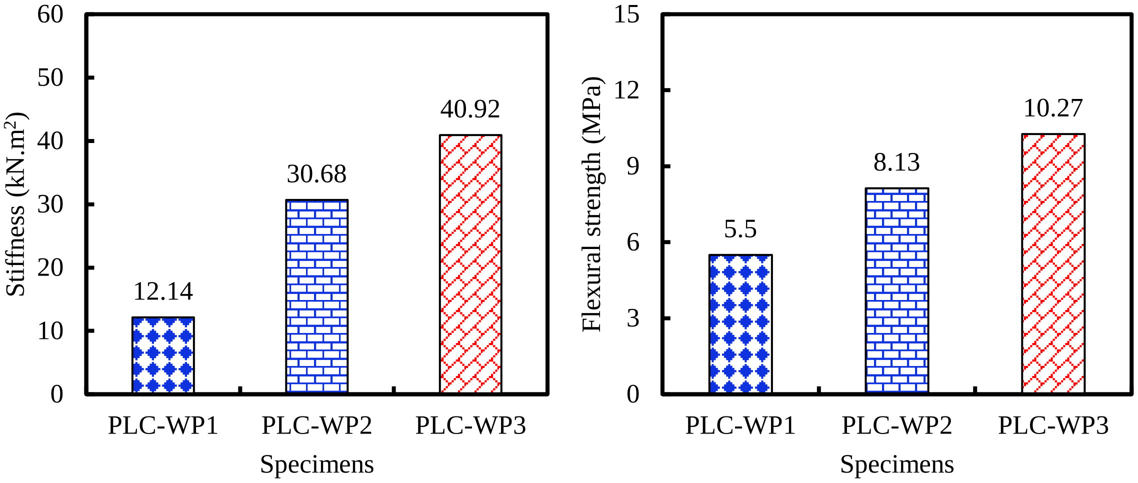


Fig. 15. Comparison between PLC-WP1 and PLC-WP2 wall panels for strength-relative deformation curves



(a) Initial stiffness (b) Flexural strength

Fig. 16. Initial stiffness and flexural strength of PLC wall panels

3.5 Effect of number of slotted steel angles on PLC wall panels

The effect of total numbers of slotted steel angles on the flexural strength-relative deformation curves of PLC wall panels are compared in Fig. 17. When three slotted steel angles were used in PLC-WP3 wall panel, the strength-deformation curve was different than that of PLC-WP2 wall panel having used two slotted steel angles. The initial stiffness of PLC-WP3 wall panel (40.92 kN.m^2) was 33.38% higher than that of PLC-PW2 wall panel (30.68 kN.m^2) as shown in Fig. 16 (a) and as shown in Fig. 17. In addition, the flexural strength of PLC-WP3 (10.27 MPa) was 26.38 % higher than that of PLC-WP2 (8.13 MPa) as shown in Fig. 16 (b) and as shown in Fig. 17. Although, the mid-span deflection of PLC-WP3 wall panel (3.65 mm) at first crack load was higher than that of PLC-WP2 (3.40 mm), it was opposite at ultimate loading stage. The mid-span deflection at ultimate loading was observed as 6.53 mm for PLC-WP3 and 7.53 mm for PLC-WP2. It means that the PLC-WP2 wall panel showed better ductility compared to the PLC-WP3 wall panel although the flexural strength was lower. In addition, the post-peak softening curve of PLC-WP3 wall panel was stiffer compared to the PLC-WP2 wall panel. It can be concluded that both wall panels have enough deformation ability and showed good ductility, but, in term of initial flexural stiffness and flexural strength, the PLC-WP2 wall panel is better than the PLC-WP1 wall panel.

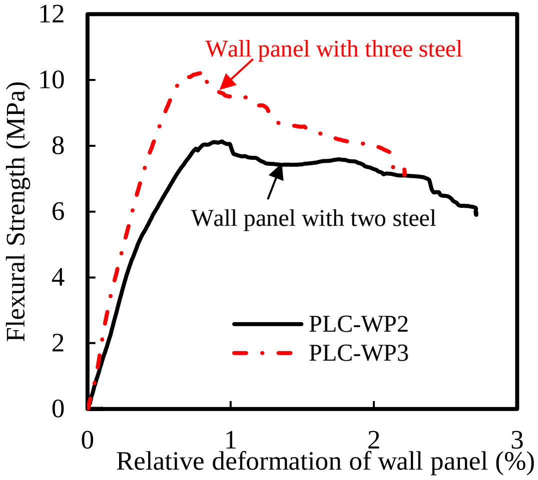


Fig. 17. Comparison between PLC-WP2 and PLC-WP3 wall panels for strength-relative deformation curves

4. Conclusions

The prefabricated lightweight composite wall panels were developed using the expanded glass aggregate and cold-formed steel studs/ slotted steel angles. Based on the experimental work of this study, the following concrete can be drawn:

1) The density of lightweight concrete made of expanded glass aggregates was 1367.11 kg/m^3, while the compressive strength was 27.52 MPa. However, the split tensile strength was lower than conventional lightweight concrete.

2) Prefabricated lightweight composite (PLC) wall panels were proposed to improve the flexural strength of wall panel.

3) The flexural strength and stiffness of PLC wall panel having used two cold-formed steel studs (PLC-WP1) were lower compared to the PLC wall panel having two slotted steel angles (PLC-WP2).

4) When three slotted steel angles were used in the PLC wall panel (PLC-WP3), the flexural strength and stiffness of PLC-WP3 wall panel were enhanced significantly compared to the PLC-WP2 wall panel.

5) The relative deformation of PLC-WP1 and PLC-WP2 wall panels was observed higher compared to the PLC-WP3 wall panel.

5. Acknowledgements

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6. References

[1] Benefits of hebel. https://hebel.com.au/benefits.
[2] Chun JH. Prefabricated wall panel. United States Patent US 4253288. 1981.
[3] Heaton A. Australia must break through prefabrication barriers. 2017. https://www.kithomebasics.com/australia-must-break-through-prefabrication-barriers.html.
[4] What is autoclaved aerated concrete (AAC)? Benefits of Hebel. https://hebel.com.au/aac/.
[5] Speed panel. https://speedpanel.com.au/.
[6] Dissanayakea DMKW, Jayasinghe C, Jayasinghe MTR. A comparative embodied energy analysis of a house with recycled expanded polystyrene (EPS) based foam concrete wall panels. Energy and Buildings. 2017; 135: 85-94.
[7] Chai YH, Anderson JD. Seismic response of perforated lightweight aggregate concrete wall panels for low-rise modular classrooms. Engineering Structures. 2005; 27(4): 593-604

[8] Narayanan N, Ramamurthy K. Structure and properties of aerated concrete: a review. Cement and Concrete Composites. 2000; 22(5): 321-329.
[9] Hamad AJ. Materials, production, properties and application of aerated lightweight concrete: Review. International Journal of Materials Science and Engineering. 2014; 2(2): 152-157.
[10] Alhassan M, Al-Rousan R, Ababneh A. Flexural behavior of lightweight concrete beams encompassing various dosages of macro synthetic fibers and steel ratios. Case Studies in Construction Materials. 2017; 7: 280-293
[11] Abosrra L, Ashour AF, Youseffi M. Corrosion of steel reinforcement in concrete of different compressive strengths. Construction and Building Materials. 2011; 25(10):3915-3925.
[12] Ghareb A-HYS, Alhashimi OI, Shevchenko AV, Shoja NM. Experimental investigation on flexural behavior of cold formed beams with lightweight concrete. Materials Science Forum. 2020; 992:149–55.
[13] Xu ZF, Chen ZF. Experimental investigation on cold-formed steel foamed concrete composite wall under compression. International Scholarly and Scientific Research & Innovation. 2017; 11(9): 1257- 1263.
[14] Xu ZF, Chen ZF, Yang S. Effect of a new type of high-strength lightweight foamed concrete on seismic performance of cold-formed steel shear walls. Construction and Building Materials. 2018; 181: 287-300.
[15] Qiao W, Yan X, Zhu R, Wang F, Wang D. Flexural properties of new cold-formed thin-walled steel and concrete composite slabs. Journal of Building Engineering. 2020; 31: 101441.
[16] Baran E, Alica C. Behaviour of cold form steel wall panels under monotonic horizontal loading. Journal of Constructional Steel Research. 2012; 79:1-8.
[17] Gunalan S, Kolarkar P, Mahendran M. Experimental study of load bearing cold form steel wall systems under fire conditions. Thin-Walled Structures. 2013; 65:72-92.
[18] Lee YK, Miller T. Axial strength of gypsum-sheathed cold form steel wall studs. KSCE Journal of Civil Engineering. 2000; 4(4): 175-81.
[19] Maduliat S, Mendis P, Ngo T. Failure modes and buckling coefficient of partially stiffened cold form steel sections in bending. Journal of Constructional Steel Research. 2015; 111: 21-30.
[20] Al-Faily F, Dutt R, Mirza O, Hassan MK. Experimental study of cold-formed steel section for wall panel. Proceedings of the 1st International Conference on Engineering Research and Practice. 4-5 February 2017, Dhaka, Bangladesh. 2017. p.76-81.
[21] Dutt R, Al-Faily F, Mirza O, Hassan MK. Parametric investigation of cold-formed steel section for wall panel. Proceedings of the 1st International Conference on Engineering Research and Practice. 4-5 February 2017, Dhaka, Bangladesh. 2017.p. 96-101.
[22] Poraver® – The lightweight a made of post-consumer recycled glass. Available: https://www.poraver.com/en/poraver/
[23] Standard Australia. Methods of testing concrete method 12.1: determination of mass per unit volume of hardened concrete–rapid measuring method. AS 1012.12.1:1998 (R2014), Sydney, Australia.
[24] American Concrete Institute. Guide for structural lightweight-Aggregate concrete. ACI 213R-03, 318-14. USA. 2003.
[25] European Committee for Standardization (CEN). Lightweight aggregate. EN 13055:2016, Brussels; 2016.
[26] Standards Australia. Specification and supply of concrete. AS 1379. Sydney, Australia.
[27] Standard Australia. Methods of testing concrete–determination of the compressive strength of concrete specimens. AS 1012.9: 2014. Sydney, Australia.
[28] Standard Australia. Methods of testing concrete method 10: determination of indirect tensile strength of concrete cylinders ('Brazil' or splitting test). AS 1012.10: 2000 (Reconfirmed 2014). Sydney, Australia.