Strength Properties of Expanded Polystyrene Concrete and Cold Formed Steel Wall Frame Composite

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Abstract. This study reports the results of strength properties of Expanded Polystyrene Concrete (EPC) and Cold Formed Steel (CFS) wall frame composite. Problem Statement: However, there is lack of previous study about properties of EPC as infill material in composite wall frame. Aims and Objective: Compressive strength of EPC with different ratio by volume of Ordinary Portland Cement (OPC): sand: expanded polystyrene and lateral strength of CFS wall frame with and without infill material are determined. Methodology: Three sets of EPC samples with ratio OPC: sand: expanded polystyrene of 1: 3.5: 2, 1: 2.5: 3 and 1: 1.5: 4 were prepared. Water-cement ratio was remained constant at 0.45 during mixing of EPC. Compressive strength test was conducted to EPC according to BS EN 12390-3:2002 at age of 3-days, 7-days and 28-days. EPC with ratio of 1: 3.5: 2 with the highest compressive strength was used as infill material in CFS wall frame. Lateral strength test was conducted on CFS wall frame with and without EPC infill material samples by applying lateral load on top left edge of wall frame. Result and Conclusion: The results show that EPC can be classified as lightweight concrete as density of EPC is in the range of 300 to 1850 kg/m3 which set by ACI committee. The optimum ratio which produces the highest 28-days compressive strength of 8.53 MPa is 1: 3.5: 2. As compared to CFS wall frame without infill material, CFS wall frame with infill material shows a higher lateral strength, which is 63.18 kN.

Introduction

Cold formed steel-concrete composite structure is commonly be used for structural component. This composite structure is attaching two cellulose fibre cement board to cold formed steel frames and infill concrete to the structure. Lightweight concrete is usually used as the infill material due to its lightweight and easy to handle. Expanded Polystyrene Concrete (EPC) is one of the lightweight concrete in construction industry. It is lighter than the conventional concrete due to its low density and large voids. However, there are some challenges in producing a good quality and high compressive strength of EPC.

The use of EPC as the infill material of cold formed steel composite wall frame is not popular in construction industry. This is because of lack of previous study about the behaviour of EPC as infill material in composite wall frame. The construction industry is lack of confidence in using EPC due to difficulties of choosing the accurate proportion to produce EPC which is suitable to be used in cold formed steel composite structure.

The purpose of this research is to determine the properties of EPC with different cement: sand: expanded polystyrene ratio by volume. By choosing EPC with the best properties, this EPC is used as infill material in cold formed steel wall frame system. With the infill of EPC to cold formed steel composite, the lateral strength is determined in the laboratory. Lateral strength of cold formed steel wall frame and cold formed steel-EPC composite wall frame is being compared. The effect of using EPC as infill material in cold formed steel wall frame system is investigated in this research.

Previous Studies

In the 21st century, many advanced systems have been introduced to the construction industry in order to shorten the project schedule and save costs. These included Cold Formed Steel Building

System which can help in reduce the construction time. They are lightweight, easy to handle and construct, economical, dimensionally stable, energy efficient, and they do not need skilled worker [1]. Cold Formed Steel buildings are an alternative to conventional reinforced concrete buildings.

Cold formed steel-concrete composite construction is construction of building involving cold formed steel and concrete. It is popular in construction nowadays because of its lightweight and easy to be handled. Besides that, concrete is well known as its high compressive strength while steel structure is good in tension. The combination between these two materials contribute to a highly efficient design.

Lightweight Concrete

Normal weight concrete is high in density and increases dead load of the structural. Hence, lightweight concrete is used to replace the normal concrete. Lightweight concrete replaces aggregates of concrete, included the sand and gravel wih lighter materials. The decrease in density of the concrete is obtained by the presence of voids, either in the aggregate, in the mortar or in the interstices among the coarse aggregate particles [2]. Concrete with a density about 1800kg/m3 or less is generally considered as lightweight concrete [2]. As compared to normal or high weight concrete, lightweight concrete has a lower density and as a result it is easier to be handled on site.

Lightweight concrete can be produced by injecting air into the composition of concrete in order to reduce the weight and density of concrete. Besides that, replacement of normal weight aggregate to hollow, cellular and porous light aggregate is another way to produce lightweight concrete. Generally, lightweight concrete can be categorized into three types:

1. No-fines concrete
2. Aerated concrete
3. Lightweight aggregate concrete

No-fines concrete can be defined as concrete which is only contain cement, rough aggregate and water. These materials can provide voids in the concrete which contributes to reduction in density of concrete. No-fines concrete can be used as pavement of pedestrian pathway (see Figure 1). In India, being a developing country, it has many rural roads to be constructed. Application of no-fines concrete as the pavement material, it will contribute to environmental sustainability [3].

Figure 1: No-fines concrete used as pavement material [3].

Aerated concrete does not contain coarse aggregate. Typically, aerated concrete is produced by introducing air into the cement and fine sand mix. The aerated concrete is produced by adding in a predetermined amount of aluminium powder and other additives into slurry of ground high silica sand, cement or lime and water [4]. Aluminium powder is acting as aerated agent and provides air bubbles in concrete which reduce the weight of concrete. The aerated concrete has its advantages of higher strength to weight ratio, better tensile strain capacity, lower coefficient of thermal expansion and enhanced hear and sound insulation characteristics due to air voids in the concrete [5]. Hence, aerated concrete is commonly used as wall partition and concrete structural elements such as beams and columns. It helps to reduce the dead load and decrease the cross-section of concrete structural elements.

Lightweight aggregate is used to replace the normal weight aggregate in order to decrease the density of concrete. Porous lightweight aggregate with a lower specific gravity can be used in lightweight concrete. Pumice, scoria, expanded blast-furnace slag, clinker aggregate are examples of lightweight aggregate.

Expanded Polystyrene Concrete

Polystyrene is a vinyl polymer which is a long hydrocarbon chain with a phenyl group attached to every other carbon atom [6]. It is produced by free radical vinyl polymerization from the monomer styrene. Polystyrene in raw beds is being steam heated and causing it to expand, and produce Expanded Polystyrene. Expanded polystyrene beads are often used as the basis of packaging material and this leads to a large amount of waste material which is not biodegradable [2]. This material could be granulated and used to replace normal aggregate in concrete to produce Expanded Polystyrene Concrete (EPC). This is a way to manage the used expanded polystyrene beads instead of dispose them and damage to environment.

The polystyrene particle is uniform in size and shape, the concrete can range from that of no-fines concrete with density 300 kg/m^3 or less to that of fully compact concrete with density 1000 kg/m^3 or more [7]. EPC is one of the most common used lightweight concrete in construction industry recently. It uses low strength materials with good energy absorbing characteristics. EPC is good in thermal and acoustic insulation properties and as a result, it is mainly used in non-structural applications such as precast roof, precast wall panels and lightweight infill blocks.

[8] was conducted a study on lightweight concrete made from waste polystyrene and fly ash proved that with the compressive strength of concrete is tend to decrease when amounts of expanded polystyrene and fly ash used to replace natural sand and Portland Cement increased. In the other hand, [9] states that the strength, stiffness and chemical resistance of EPC are affected by water-cement ratio in constant density. According to [6] the study found that EPC is useful to absorb energy and decrease the contact loading loads during hard impact at low density.

In the study report which was conducted by [10], the compressive strength of Expanded Polystyrene Concrete was very low due to the weakness in compression of the polystyrene aggregate. These results show that Expanded Polystyrene Concrete is not suitable for structural concrete. Even though fly ash has been used to reduce water-cement ratio, but this was not enough to increase the strength of EPC. According to [11], by using bigger Styrofoam size and pozzolans will produces denser and stronger concrete. However all the Styrofoam concrete exhibits lower strength at any curing period compared to normal concrete.

Cold Formed Steel (Cfs) Building System

Cold formed steel building system, is also known as light steel framing system. Cold formed steel structural members are light weight which about 60% less than wood members and 85% less than that of reinforced concrete members [1]. Besides that, cold formed steel framing saves maintenance costs in a long term. Cold formed steel is galvanized for rot resistance. Cold formed steel is different from the reinforced steel concrete which is required maintenance regularly to avoid corrosion of reinforcement. Cold formed steel is a green product as it does not emit any volatile organic compounds (VOCs).

CFS-Concrete Composite. Cold formed steel-concrete composite can be defined as cold formed steel frame which is enclosed with two cement boards and infill with material such as concrete. Lightweight concrete is commonly used as the infill material as it is lower in density compared to normal concrete. Cold formed steel-concrete composite is used as structural components such as load bearing wall and beam.

Recent study has been done on the cold formed steel-concrete composite structure to investigate its behaviour and properties. [12] investigated the cracking behaviour of in-filled lightweight concrete in cold formed steel frames. They used finite element analysis method in their study and proved that making use of concrete as infill material leads to an increase in force-displacement under curve surface, strain increase, increase in energy absorption capacity, ductility increase, increase structure’s resistance and reduction of lateral displacement.

[13] stated that when the concrete composite load bearing wall panels are tested under axial compression, the result shows good ductility and a reduction in load carrying capacity at increasing deformation. It is being proved that infill concrete is able to provide support to prevent steel sheeting from inward buckling. [1] found that sheathing type helps in improving the lateral load carrying capacities of wall. Cold formed steel wall which sheathed with reinforced cement boards gave higher lateral load carrying capacities which up to 1.5 times compared to the other sheathing types.

According to [14], it was found that filling hollow steel sections with concrete or mortar would improve their squash load, and it would delay the onset of local buckling and improve the member's post-buckling response. Based on the study of [15], it was found that filling the hollow sections with concrete increased the first cycle peak load, post peak residual strength, ductility and energy absorption capabilities.

Methodology

Materials

The materials will be used in this study are cement, sand, expanded polystyrene beads and water. Ordinary Portland Cement (OPC) was used according to BS EN 197-1:2000. Type 1 Portland Cement was used as binding agent for EPC. Type 1 Portland Cement is suitable for most construction applications, especially for the structural components. Natural sand, as the fine aggregate used in EPC was in saturated surface dry condition. This is to minimize the effect of sand condition to water-cement ratio of EPC. The next step was sieving process of sand. The sand used in the mixing of EPC is natural sand with sieve size of 4.75 μm.

Polystyrene is vinyl polymer. It is a long hydrocarbon chain, with a phenyl group attached to every other carbon atom. Polystyrene in raw beads which being steam-heated, causing it to expand is namely as expanded polystyrene. It is used to produce lightweight concretes. There have many sizes of polystyrene beads to be used for certain applications. In this study, size of polystyrene beads used is in a range of 2.0-3.0 mm as show in Figure 2.

Figure 2: Expanded Polystyrene beads with a size in range of 2.0-3.0 mm.

Tap water is used for mixing of all the concrete ingredients. The water must be ensured that is free from impurities or chemical substance which affect the properties of concrete. Water is important for hydration process for concrete.

Mix Proportion

In this study, 3. 7 and 28 days compressive strength of EPC were determined to obtain the highest strength of specimen concrete. Ratio by volume of cement: sand: expanded polystyrene beads with 1: 3.5: 2 was set as control mix. Polystyrene was added in portions as part of sand replacement as shown in Table 1. Water-cement ratio is fixed to 0.45. Nine specimens will be prepared for each mix proportion. A1 to A9 are specimens which using 1: 3.5: 2 ratio by volume. B1 to B9 are specimens which using 1: 2.5: 3 ratio by volume while C1 to C9 are specimens which using 1: 1.5: 4 ratio by volume.

Table 1: Specimens and ratio by volume of EPC

Ratio by volume Cement: Sand: Expanded Polystyrene beads	Percentage of sand replacement (%)	Specimens
1: 3.5: 2	0	A1 to A9
1: 2.5: 3	15	B1 to B9
1: 1.5: 4	60	C1 to C9

Mixing Procedure

Hand mixing method was used to produce the specimens for EPC. Each material in mixture was prepared according to their ratio by volume. Firstly, cement and sand were placed in the mixing pan. Cement and sand were mixed by using trowels and water was added gradually to the mix of materials until a fluid paste, mortar was obtained. The Expanded Polystyrene beads were then added and mixed with the mortar. Mixing was stopped when all Expanded Polystyrene beads were coated by mortar as shown in Figure 3. The same procedure was repeated for EPC samples with different cement: sand: Expanded Polystyrene ratio by volume.

Figure 3: Mixing of Expanded Polystyrene with mortar.

Slump Test

When fresh EPC was ready, slump test was conducted according to BS EN 12350-2 to determine the consistency and workability of fresh concrete. The decrease in the height of the centre of the slumped concrete was called slump. The slump height was measured by using ruler as shown in Figure 4.

Figure 4: Measure of slump height by using ruler.

Compressive Strength Test

In this study, cube test was conducted based on BS EN 12390-3:2002. Constant rate of loading, 1.0 MPa/s was applied to concrete cubes during compressive strength test. After removal of concrete cube from mould, the nine cubes are allowed to be cured in water under room temperature. Cubes A1, A2 and A3 will be tested after 3 days. Cubes A4, A5 and A6 will be tested after 7 days and cubes A7, A8 and A9 will be tested after 28 days. The same tests will be conducted to the cubes B1 to B9 and C1 to C9.

Installation of Cold Formed Steel Wall Frame

The cold formed steel wall frames are fabricated from galvanized by High Tensile Steel with G550. After unpacking wall frame in individual strapped, two sets of wall frames with dimension of 2940 mm x 3940 mm are being installed. Wall frames are fastening by using self-drilling screw to connect each end of wall studs to the top and bottom track of the wall frame. After installation of the wall frames, they are being cut into six smaller wall frame with dimension 980 mm x 1114 mm as shown in Figure 5. These six smaller samples are being used to test for lateral strength of cold formed steel wall frame.

Figure 5: Cold Formed Wall Frame with dimension 980mm x 1114mm.

Cellulose Fiber Cement Boards (CFCB) with thickness of 9mm are then fixed to both side of wall frame. Self-drilling screw is used to screw CFCB with a spacing of 200mm to wall frame. After fixing the CFCB, three samples which are named as D1, D2 and D3 can be prepared for lateral strength testing. Figure 6 shows sample of CFS wall frame screwed with CFCB without EPC infill material.

E1, E2 and E3, EPC was used as infill material to these three samples. After pouring of EPC, samples were air cured for 28 days. 28 days later, the samples were tested for lateral strength. Table 2 shows six CFS wall frame samples.

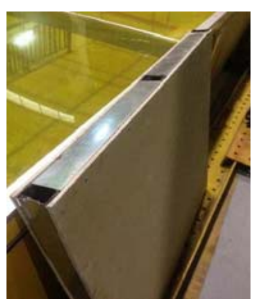


Figure 6: Sample of CFS wall frame screwed with CFCB without infill material.

Table 2: Six samples of wall frames

Samples	No.of sample	Sample No.
Cold formed steel wall frame + CFCB	3	D1 D2 D3
Cold formed steel wall frame + CFCB + EPC as infill material	3	E1 E2 E3

Lateral Strength Test

Each sample was connected to the testing setup using the same connection details. Lateral cyclic loads were applied to the testing setup from one point at the top-left edge using hydraulic actuator.

The top and bottom of the wall were restrained. The top lateral displacement and bottom lateral displacement of each sample are measured and recorded by data logger system. Figure 7 shows the setup of lateral load test on CFS wall frame samples.

Figure 7: Lateral Load test Setup for CFS wall frame samples.

Results and Discussions

Workability

Workability of fresh EPC was determined by conducting slump test before placing. Slump height was measured and recorded after slump cone was lifted vertically. Table 3 shows the slump height for three fresh EPC with different ratio by volume.

Table 3: Slump height for three sets of fresh EPC samples with different ratio by volume

Sample	Ratio by Volume OPC: Sand: Polystyrene	Percentage of sand replacement (%)	Slump Height (cm)
A1-A9	1: 3.5: 2	0	60
B1-B9	1: 2.5: 3	15	50
C1-C9	1: 1.5: 4	60	35
		Average	**50**

Water-cement ratio, 0.45 is a control variable in designing three sets of EPC samples as it affects workability of fresh concrete. From the results shown in Table 4.1, the slump height decreased when percentage of sand replacement by Expanded Polystyrene increased. This indicates that workability of fresh EPC decreases when volume of Expanded Polystyrene beads increases.

When 15% of sand was replaced by polystyrene, the workability reduced 17%. Workability decreased 42% when the replacement level of polystyrene was up to 60%. Results differs from previous studies which stated that the workability of the concrete increased with increasing the replacement level of polystyrene in concrete up to 60%. This is mainly due to different type of sand was used in both mixing and water absorption of sand is different. It affects water-cement ratio and as a result, the workability of fresh concrete is different.

Density

Density of concrete is the first indicator to determine whether the concrete can be considered as lightweight concrete. EPC samples with different ratio of volume are weighed at 3-days, 7-days and 28-days age. Moulds with dimension 100 mm x 100 mm x 100 mm were used for casting of EPC, hence the volume of EPC samples is 1.0 x 10^{-3} m^3.

According to American Concrete Institute, ACI 213R-03, the density of concrete which is in the range of 1120 to 1920 kg/m^3, can be categorised as lightweight concrete. Hence, as shown in Figure 8, three types of EPC with different ratio by volume are categorised as lightweight concrete because their densities are within the range 1120 to 1920 kg/m^3. Samples EPC with ratio 1: 3.5: 2 gives the highest average density, which is 1485.7 kg/m^3 while samples EPC with ratio 1:1.5:4 shows the lowest average density, which is only 979.8 kg/m^3. Figure 8 shows the average densities of EPC with different ratio by volume.

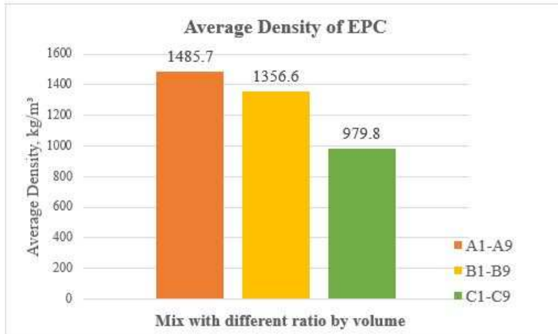


Figure 8: Average Density of EPC with different ratio by volume.

In this study, samples A1-A9 with 1: 3.5: 2 ratio were designed as the control mix. Average density of samples A1-A9 was 1485.7 kg/m^3. As compare to the control mix, density of samples B1-B9 with ratio 1: 2.5: 3 decreased 8.7%, which was 1356.6 kg/m^3. For samples C1-C9 with ratio 1: 1.5: 4, the density decreased 34.1%, which is only 979.8 kg/m^3. As conclusion, when the proportion of Expanded Polystyrene beads increases, the density of EPC decreases. This was mainly due to the density of Expanded Polystyrene is much lower than that of natural sand. When more sand is being replaced by Expanded Polystyrene, the density of EPC is lower.

The results obtained in this study shows the similar results which done by Herki *et al*, 2013. In his study, the density of concretes decreased with increasing the replacement level of Expanded Polystyrene aggregate. This is due to the density of Expanded Polystyrene aggregate was much less than that of natural aggregate.

Compressive Strength

For compressive strength test, compressive load was added gradually to EPC cubes until failure occurs. EPC samples were tested after curing for 3 days, 7 days and 28 days. 3-day strength, 7-day strength and 28-day strength are obtained and recorded.Compressive strength of EPC samples at age of 3-days, 7-days and 28-days were tested to get strength development of EPC. Figure 9 below shows the strength development of EPC samples at age of 3-days, 7-days and 28-days.

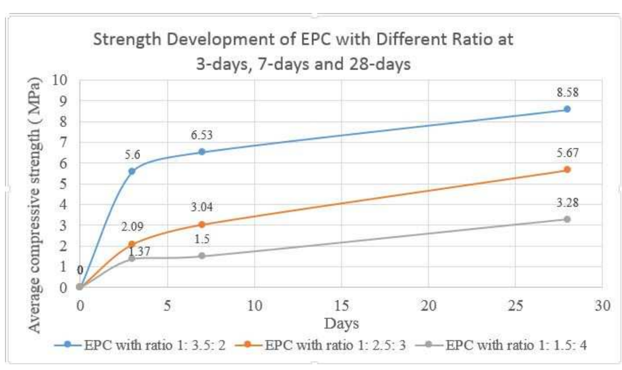


Figure 9: Strength Development of EPC samples with different ratio at age of 3-days, 7-days and 28-days.

From Figure 9, the highest compressive strength was obtained by series 1, EPC with ratio 1: 3.5: 2 while samples from series 3, EPC with ratio 1: 1.5: 4 gave the lowest strength throughout the curing time. As the hydration process of cement progressed, the strength of concrete gets stronger with its age. EPC samples with ratio 1: 3.5: 2 get average compressive strength 5.6 MPa at 3-days, 6.53 MPa at 7-days and 8.53 MPa at 28-days. Hence, the characteristic compressive strength of this EPC samples is 8.53 MPa. For this sample, it was able to gain 66% strength at 3-days, 77% strength at 7-days. Its compressive strength development was started to remain constant at the age of 28-days. This indicates the strength gained of EPC reached maximum at 28-days age.

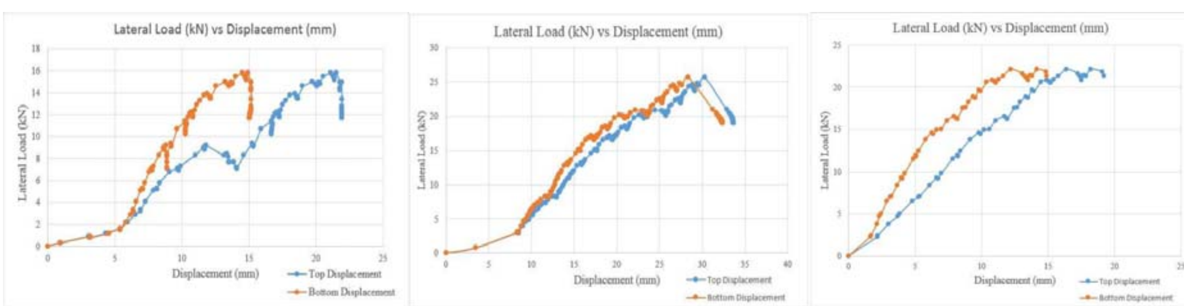
At the age of 3-days, EPC samples with ratio of 1: 1.5: 4 achieved 1.37 MPa which is 42% strength of EPC while it gain 1.5 MPa which is 46% strength at the age of 7-days. The characteristic compressive strength of this EPC samples is 3.28 MPa. From the compressive strength test results, it shows that EPC with ratio 1: 3.5: 2 gives the highest compressive strength, which is 8.53 MPa at 28-days age. However, in BS 8110, it states that the range of concrete strength for structural purposes is within 17-35 MPa. Besides that, compressive strength of EPC with these three ratio are not able to reach 15 MPa, which is the expected compressive strength in the beginning of study. As a result, EPC samples with these three ratio are not able to be applied for structural purposes.

Selection of EPC samples as Infill Material for CFS Wall Frame Composite

For the second part of this study, lateral strength test of Cold Formed Steel (CFS) wall frame composite is conducted. From the compressive strength test, EPC with ratio by volume of OPC: Sand: Polystyrene of 1: 3.5: 2 shows the highest compressive strength with 8.53 MPa as compared to the other EPC samples. Its density is 1485 Kg/m^3 and it can be categorized as lightweight concrete as stated in ACI-201. It shows a high workability with 60mm slump height. Hence, EPC with ratio 1: 3.5: 2 is chosen as the infill material for CFS wall frame composite to test for its lateral strength

Lateral Strength of CFS Wall Frame Attached with CFCB and without EPC as infill material

Three samples, D1, D2 and D3 with dimension 980mm x 1114mm were screwed with CFCB and without filling EPC as infill material. After preparation of lateral strength test setup, lateral load was applied to the sample by hydraulic actuator. Top displacement and bottom displacement were recorded with the use of data logger. Figure 10(a), Figure 10(b) and Figure 10(c) show the graphs of lateral load applied to sample D1, D2 and D3 respectively versus displacements.



(a) (b) (c)

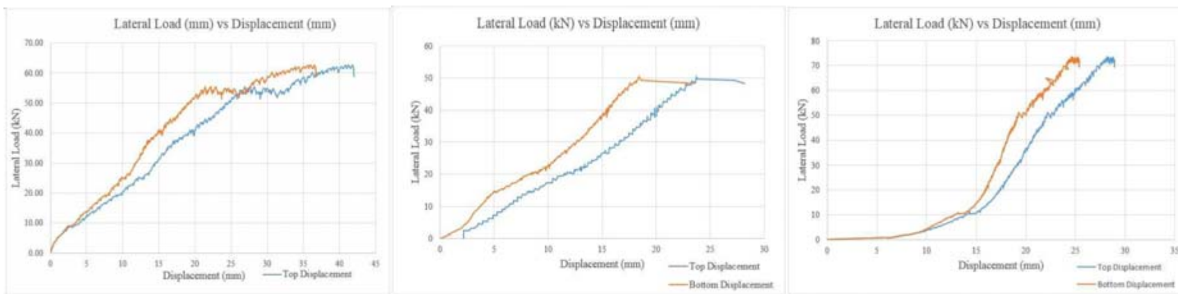
Figure 10: Lateral strength of (a) D1, (b) D2, and (c) D3

The maximum lateral loads which sample D1 can sustain was 15.8 kN with a top displacement of 21.51 mm and bottom displacement of 14.93mm. Sample D2 can sustain maximum lateral loads of 25.7 kN with top displacement of 30.29 mm and bottom displacement of 28.34 mm. At last, for sample D3, the maximum lateral loads which it can sustain was 22.1kN with top displacement of 16.36 mm and bottom displacement of 12.2 mm.

The average maximum lateral load which CFS wall panel attached with CFCB and without infill material can sustain was 22.2 kN. This proves that CFCB contributes to increase the lateral load carrying capacity of CFS wall frame. It shows the similar result as study conducted by [1]. His study showed that 9mm cement board increased lateral load carrying capacity of CFS wall frame by two times, which was then became 10kN. When increased the thickness of cement board to 12mm, the lateral load carting capacity increased 50%, which was 15kN. It shows that without infill material to the CFS wall frame, cement board is the main lateral strength contributor for the system.

Lateral Strength of CFS Wall Frame Attached with CFCB and with EPC as Infill Material

Three samples, E1, E2 and E3 with dimension 980 mm x 1114 mm were screwed with CFCB. After that, EPC with ratio by volume of OPC: sand: Expanded Polystyrene of 1: 3.5: 2 was added to these samples as infill material. Lateral load was applied to the top left edge of the sample. Lateral load, top and bottom displacement were recorded for further analysis. Figure 11(a), Figure 11(b) and Figure 11(c) show the lateral load in kN applied to samples E1, E2 and E3 respectively versus displacement in mm.



(a) (b) (c)

Figure 11: Lateral strength of (a) E1, (b) E2, and (c) E3

The average of maximum lateral load which samples E1, E2 and E3 can sustain was 63.18 kN. As compared to the samples D1, D2 and D3, it can be shown that with infill material, the lateral strength of CFS wall panel increased from 22.2kN to 63.18kN, which was about 2.8 times. This proves that EPC as infill material increases the lateral strength of CFS wall frame. EPC is able to resist the lateral load applied onto CFS wall frame and in a composite action.

The similar result shown in the study conducted by [15]. It was found that filling the hollow CFS sections increased their lateral strength, ductility and energy absorption capabilities. The mode of failure of these two types of samples are the same, which is local failure at the edge stud and no damage at all at the CFCB. This shows that the lateral strength of CFCB is high enough to sustain the load before failure of CFS wall frame. Figure 12 shows the failure mode of CFS wall frame samples without infill material after tests were conducted.

Figure 12: Failure mode of CFS wall frame samples without infill material after tests

For samples with EPC as infill material, failure of edge stud occurred due to the cracking of infill material, EPC. It showed a similar result with the study which was conducted by [16]. In their study, it found that the failure of shear wall initiated due to cracking of concrete followed by yielding of sheet associated with buckling of profiled steel sheet.

However, the result is different from the study which was conducted by [13]. In his study, the failure of the wall panel was started by local buckling of the steel sheeting, which then followed by crushing of the lightweight foamed concrete. Even though the steel sheeting provided ductility to the panel, the screwed steel edges were not sufficient to provide lateral strength to the panel. There was no separation of the steel sheeting from the lightweight foamed concrete until failure. This indicate that the infill lightweight concrete enabled CFS wall panel to resist the applied load in a composite action.

Conclusion

From the study, it can be concluded that all the objectives were achieved. Hence, the results and discussion can be summarized as follow.

Water-cement ratio of 0.45 is sufficient to provide high workability, with average slump height of 50mm for Expanded Polystyrene Concrete (EPC) with ratio of OPC: Sand: Polystyrene of 1: 3.5: 2, 1: 2.5: 3 and 1: 1.5: 4. According to American Concrete Institute, ACI-213, EPC can be classified as lightweight concrete. This is because the density of EPC is in the range of 300 to 1850 kg/m^3 which set by ACI committee. When the proportion of Expanded Polystyrene beads increases, the density of EPC decreases. 28-days compressive strength of EPC is 8.58 MPa, 5.67 MPa and 3.28 MPa with ratio of 1: 3.5: 2, 1: 2.5: 3 and 1: 1.5: 4 respectively. When the proportion of Expanded Polystyrene beads increases, the 28-days compressive strength of EPC decreases. However, compressive strength of EPC with these three ratio are not able to reach 15 MPa, which is the expected compressive strength in the beginning of study.

EPC with ratio of 1: 3.5: 2 can be selected as infill material of Cold Formed Steel (CFS) wall frame which attached with Cellulose Fibre Cement Board (CFCB). The EPC with this ratio shows the highest compressive strength among all the three types of EPC. The effect of CFCB is significant in improving the lateral strength of CFS wall frame because failure of CFS edge occurs but there is no damage on CFCB after testing. The thickness and strength of CFCB are sufficient to resist the lateral load acting to CFS wall frame. As compared to CFS wall frame which attached with CFCB and without infill material, CFS wall frame with infill material shows a higher lateral strength, which is 63.18 kN. This proves that EPC improves lateral strength of CFS wall frame.

Reference

[1] Mowrtage, W., YEL, H., & Karakale, E. (2015). International Burdur Earthquake & Environment Symposium (IBEES2015). *CFS Building System for Safer and Sustainable Buildings in Seismic Areas: Experimental Work and Applications in Turkey*, 175-180.

[2] Kuhail, Z. (2003). Journal of the Islamic University of Gaza. *Mechanical Properties of Polystyrene-Lightweight Concrete*, 93-114.

[3] Eathakoti, S., Gundu, N., & Raju, P. M. (2015). Journal of Mechanical and Civil Engineering . *An Innovative No Fines Concrete Pavement Model*, 34-44.

[4] J.Hamad, A. (2014). International Journal of Materials Science and Engineering Vol.2. *Materials, Production, Properties and Application of Aerated Lightweight Concrete: Review*, 152-158.

[5] Shafigh, F. S. (2012). Arabian Journal of Science and Engineering, vol 37. *High Strength lightweight concrete using leca, silica fume and limestone*, 1885-1893.

[6] Bischoff. (1990). *Polystyrene Aggregate Concrete Subjected to Hard Impact.* Proceedings-Institution of Civil Engineers, Part 2: Research and Theory, Vol.89.

[7] Neville, A. (1981). *Properties of Concrete.* London: Pitman Press Publisher.

[8] Herki, B., Khatib, J., & Negim, E. (2013). World Applied Sciences Journal 21. *Lightweight Concrete Made from Waste Polystyrene and Fly Ash*, 1356-1361.

[9] Ravinrajah, R., & Tuck, A. (1993). *Properties of Hardened Concrete Containing treated Expanded Polystyrene Beads.* Sydney: Faculty of Engineering, University of Technology, Sydney.

[10] Park, S., & Chisholm, D. (1999). *Study Report on Polystyrene Aggregate Concrete.* New Zealand: Building Research Levy.

[11] Ahmad, M. H., Yee Loon, L., & Adnan, S. H. (2008). *Strength Development of Lightweight Styrofoam Concrete*.

[12] Nastaran, H., & Hossein, P. (2012). International Research Journal of Applied and Basic Science. *The investigation of in-filled lighweight concrete cracking in frames made of cold-formed steel*, 2671-2678.

[13] Mydin, M. A. (2011). Concrete Research Letters Vol.2 (2). *Potential of Using Lightweight Foamed Concrete in Composite Load Bearing Wall Panels in Low-rise Construction*, 213-228.

[14] Broderick, B., Elghazouli, A., & Goggins, J. (2004). 13th World Conference on Earthquake Engineering. *Cyclic Behaviour of Hollow and Filled Axially-Loaded Members*, 2589.

[15] Zhao, X. L., Grzebieata, R., & Lee, C. (2002). Journal of Structureal Engineering. ASCE. *Void-filled Cold-Formed Rectangular Hollow Section Braces Subjected to Large Deformation Cyclic Axial Loading*, 746-753.

[16] Lakshmi, k. S., Ajitha, B., Prabha, P., & Palani, G. (2015). International Journal of Engineering Research & Technology. *Inplane Shear Behaviour of Steel-Foam Concrete Composite Wall Panels*, 248-254.