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Investigation on Wall Panel Sandwiched With Lightweight Concrete

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Abstract: The rapid population growth and urbanization have made a massive demand for the shelter and construction materials. Masonry walls are the major component in the housing sector and it has brittle characteristics and exhibit poor performance against the uncertain loads. Further, the structure requires heavier sections for carrying the dead weight of masonry walls. The present investigations are carried out to develop a simple, lightweight and cost effective technology for replacing the existing wall systems. The lightweight concrete is developed for the construction of sandwich wall panel. The EPS (Expanded Polystyrene) beads of 3 mm diameter size are mixed with concrete and developed a lightweight concrete with a density 9 kN/m^3. The lightweight sandwich panel is cast with a lightweight concrete inner core and ferrocement outer skins. This lightweight wall panel is tested for in-plane compression loading. A nonlinear finite element analysis with damaged plasticity model is carried out with both material and geometrical nonlinearities. The experimental and analytical results were compared. The finite element study predicted the ultimate load carrying capacity of the sandwich panel with reasonable accuracy. The present study showed that the lightweight concrete is well suitable for the lightweight sandwich wall panels.

Keywords: EPS beads, Lightweight concrete, material nonlinearity, Sandwich panel

1. INTRODUCTION

Evolution of the development in construction activities around the world, the demand for construction materials is increasing exponentially. Continued extraction of natural aggregate is accompanied by serious environmental problems. Furthermore, the wall constructed with conventional masonry system contributes higher dead weight to the structure. The reduction in the weight of wall will significantly reduce the dead weight of structure which results in overall reduction in sizes of structural components. Furthermore, the improved technologies are necessary to manage the shortfall in the availability of natural aggregate materials. With these reasons, there is a need for the alternative system to fulfil the construction demand without comprising strength, affordability and environmental friendly. The concrete sandwich panels are such system, which is more suitable for wall construction. The concrete sandwich panel consists of lightweight expanded polystyrene (EPS) plate with skin concrete on both sides. EPS

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panels are factory made and it consists of EPS plate with interconnected steel weld meshes on both sides by fusion welding. The process of welding escalates the cost of EPS panel and the cost escalation becomes a constraint for its effective usage.

2. REVIEW OF LITERATURE

Concrete Structures are very popular and widely used for the construction of the residential and industrial building. The major portions of wealth are spent for the construction of these structures and it becomes a key factor of social development. Researchers are very much interested in developing improved technologies for enhanced strength, safety and economy. The lightweight sandwich wall panels are one of such invention for walls and roofs in the structural construction. The masonry walls are widely used in building construction and it exhibits inferior structural performance during any uncertain loads [1], [4]. Attempts were made to control the deficiencies by introducing steel reinforcement and found that the performance of unreinforced masonry walls is improved [20]. The reinforced masonry walls have slightly higher dead weight than the unreinforced walls. The concrete walls with reduced wall thickness are more beneficial than the reinforced masonry walls. The ferrocement is also reasonably suitable for infilled wall system. Numerous analytical and experimental studies were conducted for understanding the structural characteristics of ferrocement panels. The ferrocement wall panels have higher strength, better crack resistance, improved ductility and good energy absorption characteristics [2], [5]-[10], [15].

The Construction of ferrocement wall panel requires skilled persons and moreover it has lesser sound and heat proof. The deficiencies can overcome with the sandwich wall panel. The sandwich wall panels have two ferrocement outer skins and a lightweight inner core portion. Numerous studies were carried out on sandwich panels with EPS inner core. These wall panels were investigated for both with and without shear connectors. The shear connectors are playing a vital role and affect the performance of composite wall and roof panels [3], [11], [13], [18], [19]. Several alternative lightweight materials like bamboo, reed, rice straw etc., from the renewable sources and the non-degradable waste materials like plastic wastes, are also investigated for infilling the inner core [9]. The availability, storage and psychological acceptability are the primary issues with these lightweight materials.

The sandwich panels require lightweight inner core materials for infill. Lightweight concrete can be a solution to the infill material. The lightweight concrete is produced using lightweight aggregates. Attempts were made to develop a lightweight concrete by mixing expanded polystyrene beads with concrete or cement mortar. EPS beads are a type of artificial lightweight material with a density less than 30 kg/m^3. The compressive strength and the split tensile strength of concrete are reduced with the increased percentage of expanded polystyrene [17], [21].

The insights clearly comprehend that the inner core material is proposed to just fill the gap between the skins. The skins are the component made up of ferrocement, which is expected to carry the loads. In view of this, the lightweight concrete is well suitable for the inner core material.

The present investigation is conducted to develop a lightweight inner core concrete with expanded polystyrene beads. From the literature review, it is found that the concrete smeared crack model and damaged plasticity model are found suitable to simulate the behaviour of concrete structures [12], [14]. In the present study, the damaged plasticity model is proposed to simulate the behaviour of lightweight concrete. The non-availability of assured material data onto the lightweight concrete, a primary study is carried out with cubes of 150mm size. The lightweight concrete mix with a higher volume percentage of EPS bead is developed and investigated experimentally. The density, compressive strength and stress–strain characteristics of lightweight concrete are obtained. The cube is modelled with the material data arrived experimentally. The other parameters required for the analysis were reasonably assumed by trial and error basis. The model is analysed and the results were compared with experimental results. The second phase of the investigation is carried out on sandwich wall panels with lightweight concrete infill. The sandwich wall panel is cast and tested for in-plane compression loading. The nonlinear finite element analysis is carried with the established material data and compared with the experimental results.

3. EXPERIMENTAL DETAILS

Inner Core Materials and Mix Proportions

Ordinary Portland cement, river sand, fly ash and coarse aggregates were used for preparing the concrete mix. The trial mix is carried out to obtain the mix ratio and the material requirements for three cubes are tabulated in Table 1. The mix ratio for normal concrete consist of 1 part of the cementitious material, 1.5 parts of river sand, 1.5 parts of quarry dust and 1.5 parts of coarse aggregate (10-12 mm). A portion of the cementitious material is split into 75% of cement and 25% parts of fly ash. The lightweight concrete is produced by replacing the 75% of normal concrete's volume with EPS beads.

Table 1 Details of trial mix for infill cubes

<table>
<tr><th>Materials,
(for 3 cubes)</th><th colspan="2">Weight of materials, kg
(Normal Concrete)</th><th colspan="2">Inner core Concrete, kg
(25% of weight)</th></tr>
<tr><td>Cement (OPC)</td><td>8.1</td><td rowspan="2">10.8</td><td>2.025</td><td rowspan="2">2.7</td></tr>
<tr><td>Fly ash</td><td>2.7</td><td>0.675</td></tr>
<tr><td>Coarse Aggregate</td><td colspan="2">16.2</td><td colspan="2">4.05</td></tr>
<tr><td>Fine Aggregate</td><td colspan="2">16.2</td><td colspan="2">4.05</td></tr>
<tr><td>Quarry Dust</td><td colspan="2">16.2</td><td colspan="2">4.05</td></tr>
<tr><td>SP(Ceraplast 400)</td><td colspan="2">189 ml</td><td colspan="2">47 ml</td></tr>
<tr><td>Water</td><td colspan="2">5.62 lit</td><td colspan="2">1.405 lit</td></tr>
</table>

Development of Inner core mix

Two sets of six cubes with normal concrete and lightweight concrete are cast with the proposed mix. The pan mixer is used to prepare the lightweight concrete. EPS beads of 3mm size were uniformly sprayed into the normal concrete and mixed thoroughly. Cubes are tested in compression testing machine and obtained its 7th day and 28th day compression strength as shown in Figure.1. The compressive strength obtained for the specimens are presented in Table 2. Based on the physical observations, the lightweight bead concrete has slightly higher lateral expansion compared to the normal concrete. The poison's ratio of 0.33 is assumed for the lightweight concrete as a trailing data. Three normal concrete cubes are tested for comparison. The average compressive strength of normal concrete cubes is found as 31.23 N/mm^2. The average stress and strain result of lightweight bead concrete were calculated and plotted.

Figure 1 Typical view of lightweight concrete cubes under compression

Table 2 Results of lightweight bead concrete cubes

S.No	Weight (g)	Density (kg/m^3)	Load (kN)	Compressive Stress (N/mm^2)
7th Day Test Results				
1	3100	918.53	10.25	0.45
2	3050	903.7	5.7	0.25
3	3100	918.53	10.6	0.47
28th Day Test Results				
4	3100	918.53	14.5	0.64
5	3200	948.15	14.2	0.63
6	3085	914.07	5.6	0.24

The lightweight concrete cubes are found very light in weight and stable during handling. The observations shows the suitability of lightweight concrete for infilling the concrete sandwich wall panels. The young's modulus of lightweight EPS beads concrete [16] "E" is obtained by converting the cube strength "f_{cu}" to cylindrical strength "f_{cy}" and substituting the cylindrical strength and the dry density "γ_w" of lightweight concrete into equation 1. The observed results are consolidated and listed its material characteristics in Table.3.

$$E = 1.146\,\gamma_{\omega}^{\,1.1} f_{cy}^{\,1/2} \qquad (1)$$

Table 3 Properties of EPS Bead concrete

Dimensions mm	f_{cu} (Cube)	f_{cy} (Cylinder)	E (Mpa)	Density (kg/m^3)	Poisson Ratio
150x150x150	0.25	0.1954	898.915	918.0	0.33

Development of Sandwich wall Panel

The lightweight concrete is developed in the preliminary study is proposed for the inner core material in the sandwich wall panel. A sandwich wall panel of size 1.25 x 1.25 x 0.15 m is cast with lightweight concrete inner core infill. Several mix trails are tried and the concrete mix proportion of 0.75 parts of cement: 0.25 parts of fly ash: 1.6 parts of river sand (passing through 4.75mm): 1.3 parts of coarse aggregate (10-12 mm): 0.36 parts of water cement ratio and 0.5%

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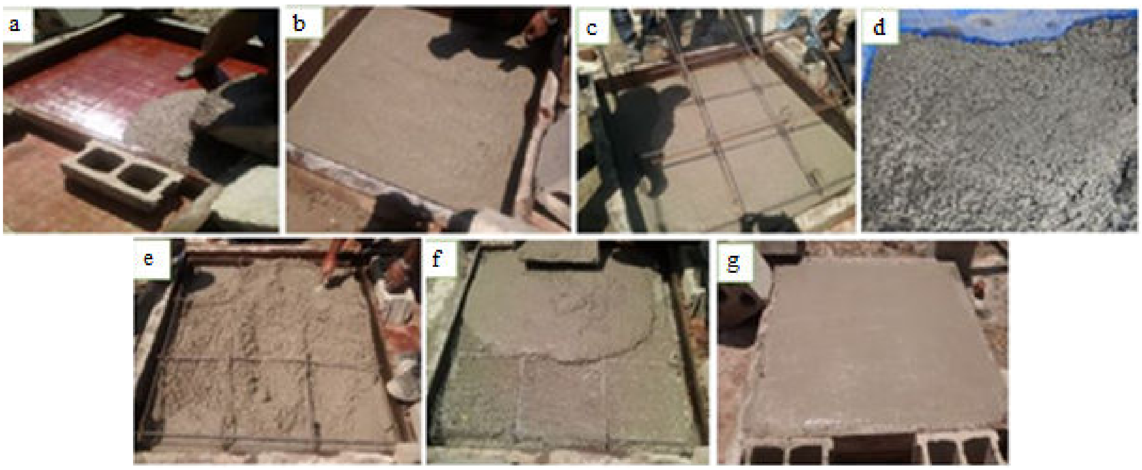
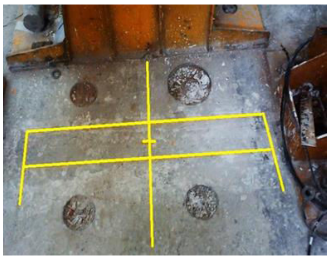
of super plasticizer is chosen by weight ratio to produce self compacting concrete (SCC). This concrete mix is used for casting the both 25mm thick ferrocement skins of wall panels and 100mm thick lightweight concrete inner core. The reinforcement cage is fabricated from 16 numbers of 6mm reinforcements in which the individual skins have four numbers of steel rods in each direction with spacing of 105 mm c/c. A chicken mesh is tied with skin reinforcement to avoid any temperature and shrinkage cracks. Skin reinforcements are tied with Shear connectors as shown in figure 2c. The bottom skin concrete layer is first laid, levelled and maintained uniform skin thickness. The reinforcement cage is placed over the bottom skin concrete. The lightweight concrete for the inner core is prepared in parallel, using another mixer machine. The materials were weighed for a volume equal to 25% of inner core volume and prepared SCC concrete. The 3mm EPS beads of volume equal to 75% by inner core volume are taken and sprayed uniformly into the SCC concrete and obtained a uniform mixer. The prepared lightweight concrete is laid over the bottom skin concrete and levelled. The chicken mesh tied with top skin reinforcement and over that SCC is placed. The overall panel thickness is maintained to 150 mm. The sequential steps involved in the casting of the lightweight sandwich panel are shown in Figure 2.



a. Concrete bottom layer, b. Levelling bottom layer, c. Placing reinforcement, d. EPS bead concrete, e. Lightweight Inner core, f. Top concrete layer, g. Levelling top surface
Figure 2 Typical views of sequences in casting of lightweight concrete infilled wall panel

The panel is cured for 28 days and prepared for testing. The panel is weighed and shifted to test floor for testing. The test specimen is cleaned, whitewashed and grid lines are marked at 4 cm interval. The centerline of loading frame is measured and the positioning panel is marked. Over the marking, wet plaster of Paris paste is applied and the panel is positioned at right location as shown in Figure.3. The vertical and horizontal levels for the test setup were continuously checked. The strain gauges and dial gauges are fixed to observe the response of panel for the in-plane loading. A 2000 kN Enerpac jack is fixed in the loading frame and the load is measured using 2000 kN load cell and cross checked with the pressure gauge fixed in the hydraulic jack. The load is applied in increasing steps and the corresponding response of panel is observed. The strain and the deflection at different locations were observed using the data logger. The cracks developed on the panel surface are marked with a pencil mark and the failure pattern is observed for the comparison.



a. Centre line marking

b. Grid line marking

c. Testing of Panel

Figure.3 Typical view of testing arrangements for testing wall panel

4. FINITE ELEMENT ANALYSIS

The nonlinear finite element is carried out using standard finite element software package. Modelling of concrete composite requires more attention. Concrete is a heterogeneous, nonlinear and orthotropic material characteristics with relatively high compressive strength and significantly lower tensile strength. Replacing the basic constituent material of concrete with expanded polystyrene beads becomes further more complicated. Experimental tests were conducted and the material characteristics arrived. The present study considers the concrete with EPS beads as a single material component, i.e., lightweight concrete. The observed density and Young's modulus of lightweight concrete are shown in table3. The stress-strain behaviour of lightweight bead concrete in compression is obtained from the compression test as shown in Figure.4. Damaged plasticity model is used to simulate the nonlinear behaviour of lightweight concrete. The dilation angle is assumed as 35 degrees and the ratio between equi-biaxial to uniaxial compressive stresses is taken as 1.16. The ratio of the second stress invariant on the tensile meridian to that on the compressive meridian, K is assumed as 0.667. The tension stiffening option is used to define the post failure behaviour of concrete. The tension behaviour of concrete is modelled with in terms of yield stress and cracking strain. The consolidated material data proposed to simulate the lightweight concrete model are present in table 4. The cube size of 150 mm with lightweight concrete materials is modelled and analysed**.** The results obtained from the experimental and analytical investigation of lightweight concrete cubes confirms the material model and hence the material model used for the inner core of sandwich panel. The skin concrete has been modelled with the properties of normal concrete with damaged plasticity model. The density of concrete is taken as 24 kN/m^3 ,Young's modulus is taken as 25000 N/mm^2 with the Poisson ratio of 0.18. The stress-strain curve obtained for the cylinder is used to model the compression behaviour and the tensile behaviour of the concrete model is assumed with bilinear behaviour. The steel reinforcement is modelled with plasticity model. The material density is taken as 77 kN/m^3 and Young's modulus is assigned as 2.1x105 N/mm^2. Poison's ratio is assumed as 0.3. The stress-strain relation given in table 4 is used to define the steel behaviour.

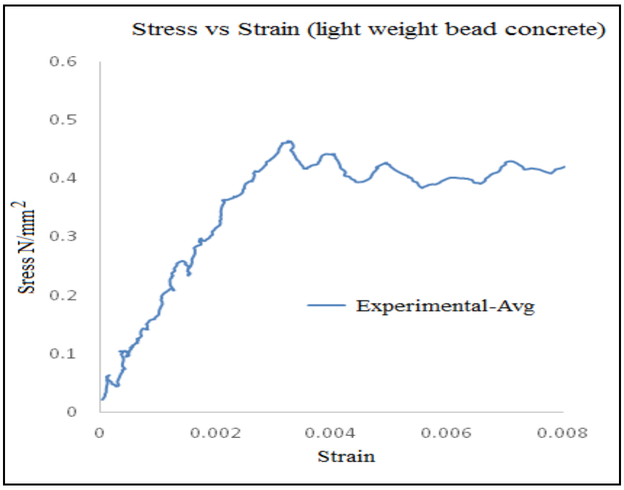


Figure 4. Stress strain behaviour of EPS bead concrete under compression.

Both normal and lightweight concrete were modelled with eight nodded brick element (C3D8R). The contact surfaces between the skin concrete part and the inner core portion are modelled with penalty stiffness approach, with a stiffness value 0.1 N/mm^2. Steel reinforcements have modelled with 2-Noded, 3D truss element (T3D2). For cube testing, a 1mm thick plate is placed on top and bottom and tied to the concrete surface. For the panel, a 20 mm thick plate is placed on top and tied with panel top surface. A uniform pressure is applied on top of the panel and the bottom is kept fixed. The support and load constraints are shown in Figure.5. The static-riks method of structural analysis is carried out to overcome the issues related to instability point which normally occur in the static general analysis. The history output request is assigned to the appropriate nodes. The deflection, stress and strains are observed from the analysis. The ultimate load carrying capacity of wall panel is obtained by multiplying the applied load with the maximum load proportionality factor (LPF) from the history output.

Table.4. Material model for skin concrete, inner core concrete and steel

Compression Model		Tension behaviour		Concrete Tension Damage (For both normal & lightweight concrete)		Steel Plasticity	
Stress	Plastic Strain	Yield Stress	Plastic Strain	Damage Parameter	Plastic Strain	Stress	Plastic Strain
12	0	For skin concrete		0	0	340	0
20	0.0007	2.5	0	0.9	0.01	365	0.00015
25	0.0016	0	0.0031	Note: For damage parameter, 0 represents no damage and 0.9 represents about to fully damaged		370	0.0003
29	0.002					390	0.001
32	0.0027					430	0.0022
26	0.0029					435	0.003
						440	0.006
For inner core concrete: Stress – strain curve		For inner core				435	0.015
		0.6	0			400	0.05
		0	0.031			370	0.08

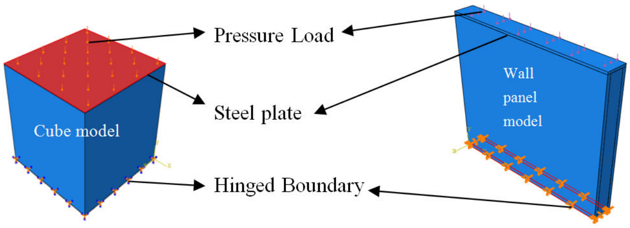


Figure 5 Typical view of model with hinged boundary condition with a pressure load

5. RESULTS AND DISCUSSION

The preliminary study carried out with cubes of 150 mm size to develop the material model for lightweight concrete. The cubes were loaded with uniform compression load and the corresponding displacement is recorded continuously. From the load and deflection observations, the stress-strain behaviour of the lightweight concrete cube is calculated and plotted. The observed material data for the compression test is used to develop the material model. The minimum principal strain in the element with an upper limit is observed corresponding to each step and plotted. The stress-strain graphs obtained from the experiment and the analytical are compared in Figure.6. The cubes have behaved in a similar pattern and it confirms the reliability of material model proposed to model the lightweight concrete. Similar failure pattern of failure is observed from the both experimental and analytical studies as shown in Figure.7. The preliminary study on lightweight concrete is not showing any shrinkage cracks and it seems to be dimensionally stable. Further sight moldability is the most important advantage of lightweight concrete for the wall panel construction to form any shape and size. The average weight density of concrete is found about 9 kN/m3 with better deformability.

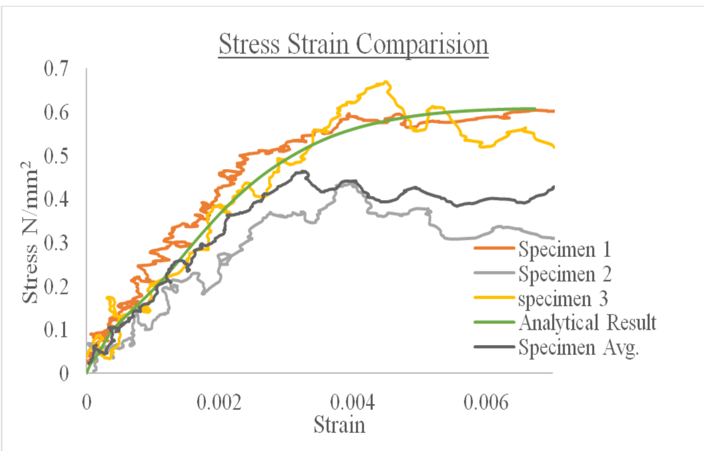


Figure 6 Comparisons between experimental result and analytical result

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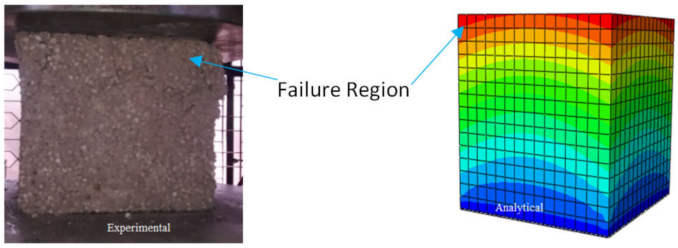


Figure 7 Comparison of failure behaviour of lightweight concrete cubes

The verified material model for the lightweight concrete is proposed for the further study to simulate the inner core of sandwich wall panel. The sandwich concrete wall panel is experimentally tested under in-plane compression loading. The load is gradually applied and the corresponding deflection and strain readings are recorded. The load drops at 600 kN when the first crack is observed. The load is increased further and the panel carries the load steadily and the second load drop is seen when the load reaches to 950 kN. The cracks were formed at the edge beams and several micro cracks were formed on the surface. The load is increased and found that the cracks were enlarged further. The cracks on the vertical side surface are extended and the separation between the outer skins and infill layer occurred. The ultimate failure occurs when the load reaches about 1460 kN. The compressive strength of is found about 12.87 N/mm^2. The load is dropped to about 600 kN with crushing and spalling of concrete. The sequential cracking pattern of lightweight concrete infilled wall panel is shown in figure 8. The results of numerical investigations are documented for comparing experimental results. The load and the vertical deflections of concrete wall panel are compared and presented in figure.9. The load and corresponding strain at the different location of wall panel are presented in figure.10. The maximum load carrying capacity of the lightweight concrete infilled wall panel observed from the analytical model is 1390 kN, which is reasonably comparable with the experimental results. The ultimate load value obtained from the analytical study confirms the effectiveness of material model used for the analysis.

a. Crack pattern on edge beam.
b. Crack pattern on other side of the panel edge beam.
c. Failure pattern on the surface of the panel.
d. First crack at 60T on edge beam.
e. Micro cracks on surface.
f. Failure of edge beam.

Figure 8 Typical view of cracking pattern of panel from crack initiation to ultimate failure

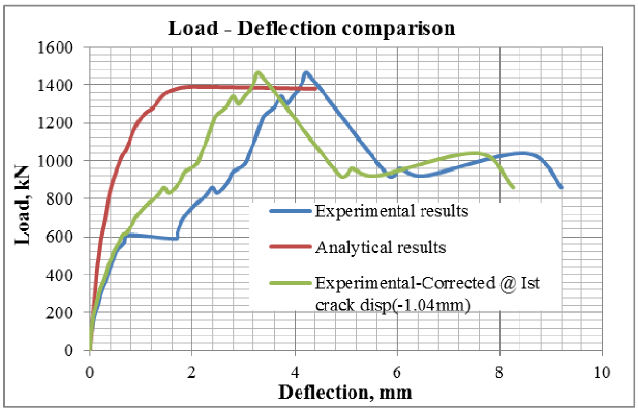


Figure 9 Comparison of experimental and analytical results

The load-deflection curve obtained from the experimental and analytical results are seems to varying slightly. The load deflection curve obtained from the analytical study is steeper compare to the experimental results. The maximum vertical deflection observed from the experiment is 4.25 mm at the peak load and the deflection obtained from the analytical peak load is 1.96 mm. The difference in the deflection observed is mainly due to the uncertainty in the load setup. The concrete panel is very stiff before the formation of the first crack but the deflection reading is increased 1.04 mm excessively at the first load drop at 600 kN. The load deflection plot is corrected at the first load drop and compared in figure 9 for the better understanding. The analytical and the corrected experimental results are seems to be reasonably comparable. The load and the corresponding strains observed from the experimental and analytical results are found comparable. The failure of the panel is observed due to the separation of skins. Both analytical and experimental results showed the same pattern of failure. The panel width side is initially in compression and it becomes tension before reaching the ultimate load. The tension strain in the panel side infers the skin separation. Further, the compression strain in the bottom skin diagonal is increase with the increase of load and it started to decrease before the failure. The vertical deflection recorded in the experiment has slightly differed from the analytical results. The analytical and experimental results are slightly varying. The difference observed is mainly due to the cracking and separation of the skins and the inner core lightweight concrete in the experimental study. The analytical model needs to be improved further to include the cracking and the separation behaviour of skins. The cracking pattern observed from the experimental and analytical studies are compared in table.5.

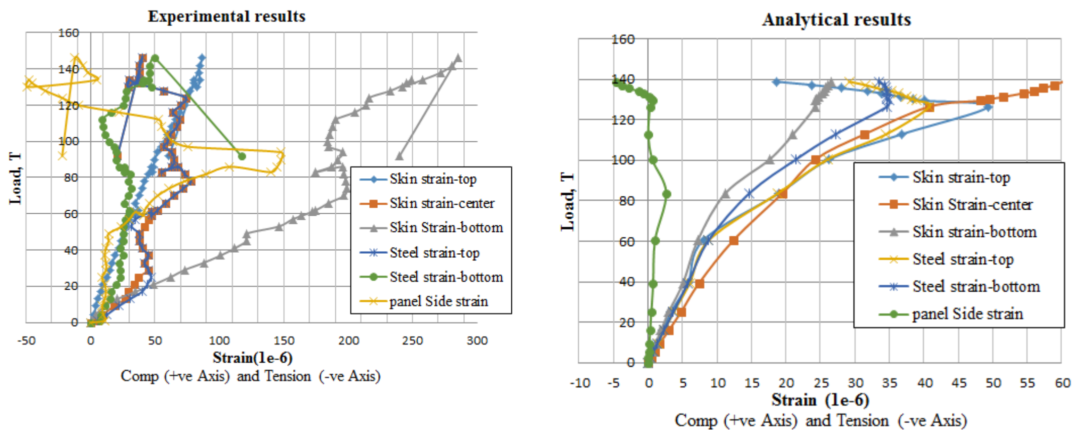
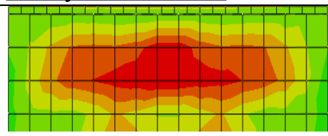
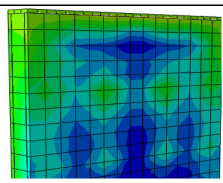
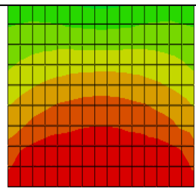
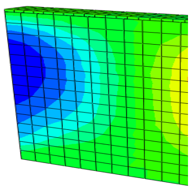


Figure 10 Comparison of experimental and analytical results

Table. 5 Comparison of failure pattern of lightweight concrete infilled wall panel

Experimental Results		Analytical Results	
	Spalling of concrete (nearer to top beam)		Maximum principal Stress contours (nearer to top beam)
	Formation of surface cracks at failure load		Plastic strain contours arrived in similar pattern
	Crushing of bottom		Similar principal stress distribution observed
	Failure of side due to heavy stress		maximum stress contour on sides

The failure of the sandwich wall panel with lightweight concrete infill is gradual and several micro and macro cracks are formed before the ultimate failure. The failure pattern observed from the analytical study resembled the experimental results. The analytical model is not predicting the crack opening at different locations and it results in stiffer behaviour with reduced deflection than the experimental results. The cracking pattern clearly indicates the deficiency in the shear interaction between the skin concrete layers. This interprets that the shear connector system should be enhanced to avoid the skin layer separation. No bursting or easing out of lightweight concrete is seen from the experiment. The present investigation revealed that the lightweight concrete developed using EPS bead is well suitable for inner core infill. Further, the study proposed a material model for the light weight concrete and validated.

6. CONCLUSION

From the experimental and analytical investigation of the lightweight concrete for developing lightweight infilled sandwich wall panels, the following conclusions have arrived.

1. The present study developed a lightweight concrete with weight density of about 900 kg/m^3. No segregation between the concrete slurry and beads were observed. The lightweight bead concrete exhibited more compressible behaviour and failed in a gradual manner. The ultimate compression strain observed is about 0.007 which very high compared to normal concrete.
2. The experimental and analytical results of lightweight concrete cubes are found comparable. The result confirms the reliability of material model proposed for the light weight concrete.
3. The lightweight concrete with a higher percentage of EPS bead is suitable for sound and heat insulation. Further sight moldability is the most important advantage of lightweight concrete for the wall panel construction to form any shape and size. The cost on lightweight concrete infill is very low compared to the factory made EPS wall panel.
4. The wall panel with lightweight bead concrete infill is performed well. The first crack is observed at a load about 45 % of the ultimate load. Numerous micro and macro cracks were developed for the increase of load. From the failure pattern, it is inferred that the wall has shown ductile behaviour.
5. The finite element analysis predicted the ultimate strength of lightweight concrete infilled wall panel. But, the load deflection behaviour of the wall panel obtained from the finite element analysis and the experimental results are not matching precisely due to the deficiency in modelling the skin concrete separation, which needs to be improved.
6. The ultimate compressive strength of panel is found about 12.87 N/mm^2 and the compressive strength at first cracking is 4.71 N/mm^2. The result confirms the suitability of lightweight concrete infilled panels for the load bearing and non-load bearing walls.
7. The chicken mesh sufficiently confined the panel skins and effectively reduced the concrete spalling out of outer skin layer. It is seems to be a good alternate for welded mesh to reduce cost.

REFERENCES

1. D. P. Abrams, and T. J. Paulson, "Modelling Earthquake Response of Concrete Masonry Building Structures", ACI Structural Journal, Vol. 88, No. 4, pp. 475-485, Aug. 1991.
2. P. Annie, N. Lakshmanan, P. Sivakumar, and N. P. Rajamane, "A Novel precast roofing scheme for affordable housing" Indian Concrete Journal, , pp 34-39 Jan. 2010.
3. A. Benayoune, A. A. A. Samad, A. A. Abang Ali, D. N. Trikha, "Response of precast reinforced composite sandwich panels to axial loading", Construction and Building Materials, Vol. 21, Issue 3, pp 677–685, 2007.
4. M. Bruneau, "State-of-the-art report on seismic performance of unreinforced masonry buildings", Journal of Structural Engineering, ASCE, vol. 120(1), pp. 230-251, 1994.

5. C. B. Cheah, and M. Ramli, "Load capacity and crack development characteristics of HCWA–DSF high strength mortar ferrocement panel in flexure", Construction and Building Materials, Vol.36(2), pp 348–357, 2012.
6. E. H. Fahmy, M. N. AbouZeid, Y. B. Shaheen, and H. Gaafar, "Behavior of ferrocement panel under axial and flexural loadings", Journal of the American Concrete Institute, Vol. 79(4), pp 313-321, 2005.
7. S. Grija, P. Sivakumar, K. N. Lakshmikandhan, R. Ravichandran, B. Karthikeyan, 'Novel Ferrocement Lightweight Wall Panels', International Journal of Applied Engineering Research, Vol. 9, No. 18, pp. 4645-4657, (2014).
8. A. W. Hago, K. S. Al-Jabri, A. S. Alnuaimi, H Al-Moqbali, and M. A. Al- Kubaisy, "Ultimate and service behavior of ferrocement roof slab panel", Construction and Building Materials, 19 (2), pp 31–37, 2005.
9. S. Karthika, K. N. Lakshimikandhan, P. Sivakumar, and G. Dhinakaran, "Load Deflection Characteristics of Sustainable Infilled Concrete Wall Panels", Arabian Journal for Science and Engineering, Vol.41, No.2, pp, 451-460, 2016.
10. K. N. Lakshmikandhan, "Experimental and evaluation study on ferrocement infilled RC framed structures", Proc. of Int. Conference on recent advances in concrete and construction technology, pp 833-843, December 2005.
11. K. N. Lakshmikandhan, R. Senthil, S. Arul Jayachandran, S. Sivakumar, and R. Ravichandran, "Parametric studies on the behaviour of steel and composite space structures', International Journal of Space Structures", Vol. 10(1), pp 169-183,2010.
12. K. N. Lakshmikandhan, P. Sivakumar, R. Ravichandran, and R. Manisekar (2011), 'Mathematical modelling and evaluation of strengthened concrete beam under flexure', SERC research report no. CAD/OLP 14441/RR-(12). May 2011.
13. Lakshmikandhan K. N., Sivakumar P., Ravichandran R., and Arul Jayachandran S. (2013), 'Investigations on Efficiently Interfaced Steel Concrete Composite Deck Slabs', Journal of Structures, vol. 2013, pp 1-10 pages, doi:10.1155/2013/628759.
14. K. N. Lakshmikandhan, P. Sivakumar,J. Linu Theresa , K. Sivasubramanian,S. R. Balasubramanian, and S. Saibabu, "Parametric Study on Development, Testing and Evaluation of Concrete Funicular Shells", International Journal of Engineering and Innovative Technology, Vol.3, No.12, pp. 183-191, June 2014.
15. N. Mohamad, A. Mahmood, and K. Majeed, "Flexural Behavior of Flat and Folded Ferrocement Panel", Construction and Building Materials, Vol.24 (9), pp 222–229, 2009.
16. R. S. Ravindrarajah, and A. J. Tuck, "Properties of Hardened Concrete Containing Treated expanded Polystyrene Beads", Int. J. of Cement Composites, vol.16, pp. 273-277, December 1994.
17. D. Saradhi Babu, K. Ganesh Babu, T.H. Wee, "Properties of lightweight expanded polystyrene aggregate concretes containing fly ash", Cement and Concrete Research, vol. 35, pp.1218-1223, 2005.
18. P. Sivakumar, J. Annie Peter, and N. P. Rajamane, "Prefabricated Buildings with different Innovative Construction Materials", The MasterBuilder, Aug.2009 Vol.11, No.8, pp.82-93, 2009.
19. T. D. Bush Jr., G. L. Stine, "Flexural Behaviour of Composite Precast Concrete Sandwich Panels with Continuous Truss Connectors", PCI Journal, March-April, pp.112-121, 1994.

IOP Conf. Series: Materials Science and Engineering **225** (2017) 012275 doi:10.1088/1757-899X/225/1/012275

20. A. Waleed, Y. Yavuz, M. S. Jaafar, and JNoorzaei J, 'Structural behaviour of ferrocement–brick composite floor slab panel', Construction and Building Materials, 24 (6), pp 2224–2230, 2010.
21. Xu Yi, Linhua Jiang, Jinxia Xu, Yang Li, "Mechanical properties of expanded polystyrene lightweight aggregate concrete and brick", Construction and Building Materials, vol. 27, pp. 32–38, 2012.

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