

Strength Development and Lateral Load Resisting Properties of Expanded Polystyrene Based Lightweight Concrete Panels

S. Sivakanthan, P.N. Karandeniya, B.E. Thevarajah and M.T.R. Jayasinghe

Abstract: The construction industry is rapidly moving toward sustainable development due to the rise of the scarcity of natural resources and the climatic impact on the environment. Several studies have been carried out related to the subject of Expanded Polystyrene (EPS) based lightweight concrete panel production and its usages in buildings. This paper mainly focuses on strength development and lateral load-bearing capacity of the EPS panels where these panels are used as a loadbearing wall in buildings. Lateral loading resistance properties and performance of lightweight wall panels were assessed by carrying out load tests on scale down wall specimens representing the actual wall construction. The strength development of EPS-based concrete panels was assessed by developing strength curves from compressive strength tests carried out for different curing conditions of the lightweight concrete. The outcomes of this study show that the flexural strength parallel to the wall panels is in the range of 0.58 to 0.70N/mm². Under wet conditions, it reduces to 0.45 N/mm². Also, there was an average of 0.4 N/mm² compressive strength difference between properly cured and non-cured EPS samples, which is approximately 20% of strength development in the six month period.

Keywords: Expanded polystyrene, Load bearing wall, Lateral load, Flexural strength, Strength development, Curing

1. Introduction

Today, the civil engineering constructions are mainly focused on sustainability developments while overcoming the issue with the scarcity of resources related to the construction industry due to the population growth. Climatic changes play a major role in the selection of construction materials and methods. Disaster resilience of the structures is being given high priority in view of the impending climatic change and the implications that had already occurred.

The construction industry is one of the main contributors to global greenhouse gas emissions with a much higher carbon footprint [1]. Rising temperature, excessive moisture in the atmosphere, and change in rainfall potential and rising sea levels can cause serious natural disasters such as floods and cyclones. The number of people who have died as a result of such hazards in tropical countries like Sri Lanka has recently increased dramatically. To prevent loss of lives and to reduce the damage to the belongings a disaster-resistant and environment-friendly structure is required. However, the construction of such a structure could be a massive burden to an average family considering the cost, construction time and availability of suitable materials [2]. In the meantime, material used should be

environment-friendly and structurally sound when considering sustainability.

Nowadays, expanded polystyrene (EPS) based lightweight concrete wall panels are used as loadbearing walls in single storey buildings as well as in two-storied buildings [3]. EPS based lightweight concrete panel system is a modern building construction product and a comparison study utilizing a typical single-story house and various building materials revealed that the foam concrete precast panel can be a strong competitor and hence has the potential to become a popular walling material [2]. Therefore, when considering construction using individual EPS panels, a wall can be built rapidly compared to using individual units like

Eng. S. Sivakanthan, AMIE(SL), AMSSE(SL),
B.Sc. Eng. (Hons) (Moratuwa),
Email: sivakanthan04@gmail.com
 <http://orcid.org/0000-0002-4194-9891>
Eng. P.N. Karandeniya, AMIE(SL), B.Sc. Eng. (Hons)
(Moratuwa),
Email: praveenkarandeniya@gmail.com
 <http://orcid.org/0000-0002-6423-8849>
Eng. B.E. Thevarajah, AMIE(SL), B.Sc. Eng. (Hons)
(Moratuwa) Email: tbryaneric@gmail.com
 <http://orcid.org/0000-0001-9221-1742>
Eng. (Prof.) M.T.R. Jayasinghe, C.Eng., MIESL, B.Sc.
Eng. (Hons), (Moratuwa), PhD (Cambridge),
Senior Professor, Department of Civil Engineering,
University of Moratuwa.
Email: thishan@uom.lk



clay bricks or cement blocks. Recycled expanded polystyrene is used with cement, sand, water, fly ash and admixtures instead of coarse aggregate, resulting in a lightweight concrete due to the low density of EPS [4]. In addition, EPS concrete is used for other specialized applications like construction material for marine structures, sub-base material for pavements and energy-absorbing material for the protection of military structures [5]. The use of these panels in Sri Lanka is under the research level category of load bearing walling material [6]. To implement these panels in practice, the feasibility of these panels must be analyzed.

The main objective of this study is to determine the structural feasibility of EPS-based lightweight panels in terms of strength development and lateral load resisting properties with failure modes when used as load-bearing walls in a typical house building. Experiments have been conducted to evaluate the performance of panels.

2. Literature Review

2.1 Lateral Load Resisting Properties

The flexural strength of the wall is important to estimate the lateral load-carrying capacity of the wall. In most cases, the design of wall panels against uniform or non-uniform lateral loads is based on empirical data [7]. The available methods for identifying the qualities of lightweight concrete panels do not reflect the actual conditions [8] and are only applicable for a single panel. The failure criterion does not consider the joints and bond types. Therefore, during the design, to satisfy the bearing capacity, a more conservative factor of safety is used. This results in an uneconomical design and during unexpected disaster situations it may not be possible to predict the actual behaviour and capacity of the structure [8].

EPS concrete containing larger size and higher volumes of EPS aggregate show higher moisture migration, absorption and the reduction of strength properties [5]. Flexural strength of a wall material is important to evaluate the performance when subjected to lateral loads due to wind, floods, earthquakes or any other load that can cause out-of-plane bending in the walls [9]. The flexural strength of masonry can be determined by loading the wall panels laterally, with the load parallel to bed joints and perpendicular to bed joints. Since the flexural strength parallel to bed joints is generally low, there is a tendency for the failure to occur at very low lateral loads [10].

2.2 Connectivity of Sandwich Panels

The connectivity and transfer of loads between adjacent panels and components are mainly achieved along the horizontal and vertical tongue and groove joints [11]. Load transmission occurs through both connectivities. Therefore, they should have enough strength capacities to resist lateral loads. In addition, it has been proved that the interface between mortar and lightweight concrete corresponds to the weakest zone and failure occurs at the joints [12].

Normally the EPS wall panels are bonded together by a tongue and groove arrangement, with tile mortar adhesive paste or cement paste [13].

2.3 Curing Conditions

Curing is a very important procedure to obtain durable concrete. Past research studies concluded that curing affected the strength development of lightweight concrete [14]. Normally, water is used for concrete curing and there are curing agents as well. Curing makes a low degree of hydration in concrete with reducing temperature. Different types of curing conditions were analysed considering concrete strength [15].

3. Methodology

The process entails conducting an experiment and analysing the results to identify characteristics such as panel flexural and compressive strengths under varied conditions and exposure.

The experimental phase of the study entailed measuring the flexural strength of wall specimens under various exposure conditions, as well as the strength development of panels for wall construction with various curing conditions over a long period of time.

This analytical phase of the study focuses on the following:

1. Impacts of joints and exposure conditions on overall wall flexural strength.
2. Identification of failure modes of light weight walls under lateral loadings.
3. Compressive strength development of light weight panels under different curing conditions.

4. Experimental Procedure

A detailed experimental procedure was carried out to achieve the previously mentioned objectives.

Scale down wall specimens were built and tested to assess the flexural performance according to BS EN 1052-2:2016. With the results obtained, the flexural strength properties and failure modes of the EPS panel walls were assessed under several support and exposure conditions.

To assess the strength development, sample test specimens were prepared. Freshly cast panels were obtained for this purpose and the large panels were converted into 300x300 mm square specimens to check compressive strength with time.

In order to assess the performance, lightweight panels with 75, 100 and 150mm thicknesses were used as a construction material that consists of 50% of the total EPS, cement, sand, fly ash and cement fiber boards in current practice [6].

4.1 Materials and Properties

Using the material proportions mentioned in Table 1 an EPS-based concrete mix with a density of 650-750 kg/m³ was produced. Mechanically recycled EPS contributed for 50% of the total EPS content of the concrete mix. Table 2 shows the properties of cast lightweight panels after two weeks.

Table 1 - Material Test Data for EPS Lightweight Panels

Material	Content(kg/m ³)
Cement	380
Fly ash	98
Sand	136
Water	282
EPS	22

Table 2 - Material Content Data for EPS Lightweight Concrete Mix

Property	Parameter
Dry density of lightweight concrete	629kg/m ³
Dimensions	600 mm x 2450 mm
Compressive strength	2.89 N/mm ²
Flexural strength	1.64 N/mm ²

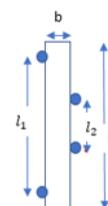
Portland cement conforming to ASTM C150 Type I and cementitious tile mortar adhesive conforming to BS 5980 class AA Type 1 were used for the joints between the panels. The flexural and compressive strengths of Cement

Paste and Adhesive Mortar were tested according to BS EN 1015-11(Figure 1), using the results of the three-point bending test, as given by Equations (1) and (2).

$$\text{Flexural strength} \quad F = \frac{1.5Fl}{bd^2} \quad \dots (1)$$

$$\text{Compressive strength} \quad F = \frac{F}{A} \quad \dots (2)$$

- F - Max applied load
- l - Spacing between supports
- b, d - Width and depth of specimen
- A - Effective area (Top face)



The load was applied gradually to avoid impact or shock due to sudden increases. As such, a uniform rate in the range of 10 N/s to 50 N/s was used so that the failure occurred within a period of 30 s, as specified by BS EN 1015-11. The results of these tests are summarized in Table 3.



Figure 1 - Testing for the Compressive Strength

Table 3 - Material Test Data for Cement Paste and Adhesive Mortar

Property	Cement paste	Tile adhesive mortar
W/C	2:5	1:3(Volumetric)
Compressive strength (N/mm ²)	35	21.25
Flexural strength (N/mm ²)	6.72	1.64

4.2 Construction of Wall Specimens

In order to replicate potential practical scenarios, three types of wall specimens were cast (refer Table 4). The joints in Type 1 (T1) specimens, consisted of cement paste, with and without steel dowel connectors. Specimens consisted of tile adhesive mortar, while no extra material was used in the Type 2 (T2) specimens (shown in Figure 2). Type 3 (T3) panel specimens were cast without joints (scale down full panel). Additionally Type 2 and Type 3 specimens were tested under both wet and dry conditions.



Table 4 – Wall Specimen Preparation Data

Type 1 (T1)	Specimen joints with cement paste	With connectors
		Without connectors
Type 2 (T2)	Specimen joints with tile adhesive mortar	Wet
		Dry
Type 3 (T3)	Specimen without joints	Wet
		Dry

The specimens were cured for 14 days and tested under both vertical and lateral loadings. The standard testing methods do not provide clear guidelines to test walls and, hence, the procedure outlined in BS EN 1052: Part 2: 2016 for masonry walls was used for the present study. Accordingly, the dimensions of the wall panels to determine the flexural strength, were decided based on the sizes recommended in the code. Because building and testing need a significant amount of resources, as well as other practical constraints such as labour component and laboratory space management, the number of specimens was limited to two, where an average value was calculated to determine the flexural strength according to BS EN 1052: Part 2: 2016 and the tests on two panels have yielded a wealth of helpful research data for masonry, and the same method has been utilized to generate the research findings described in this paper.



Figure 2 – Specimens Type 1 and Type 2

Table 5 - Details of the Tested Panels

Test	Panel dimensions (mm)			Nos.	
	W	H	T		
Parallel to joint					
T1	With dowels	400	800	150	2
T2	Wet	410	610	150	2
	Dry	400	590	150	2
T3	Wet	410	600	150	2
	Dry	400	600	150	2

W- Width, H- Height, T-Thickness

4.3 Flexural Strength Test

The characteristic flexural strength of wall specimen f_{xi} is expressed as a function of failure load and panel dimensions in BS EN 1052: Part 2: 2016, as given by Equation (3).

$$f_{xi} = \frac{3F_{i,max}(l_1-l_2)}{2bt_u^2} \dots (3)$$

Where,

$F_{i,max}$ - max failure load

l_1 - Spacing between supports

l_2 - Spacing between loading points

t_u -Thickness of panel, b - Width of the panel

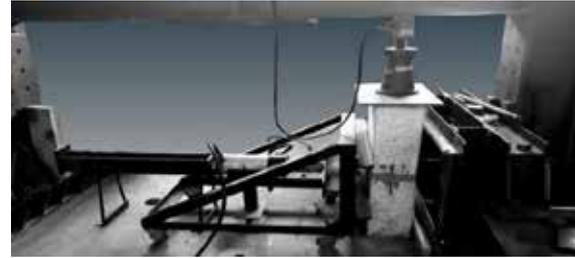


Figure 3 – Flexural Strength Test Apparatus

All the measurements were recorded including spacing between the bearing and loading rods and the dimensions of the panels (refer Table 5). From past research studies [16], it has been identified that maximum stress bearing stress on top of wall acting on a typical 2-story apartment building light weight wall is around 0.1488N/mm² (9kN). Therefore, a conservative constant vertical load 10kN was applied using a steel plate and hydraulic jack on the top surface of the wall to represent the expected typical load in a load bearing wall, to simulate the actual scenario. Later, a lateral load was applied at the specified constant increment rate of 1.25 kN/min with a hydraulic jack connected to a data logger for electronic measurements (Figure 3 and Figure 4). The load corresponding to the first crack and the load at failure were observed for each type of panels (Figure 9 and Figure 11), and the results are summarized in Table 6.

Table 6 - Results of Flexural Strength Test

Test		Load at first crack (kN)	Load at failure (kN)	Avg. strength N/mm ²
Parallel to joint				
T1(with dowel connectors)		6.1	12.5	0.58
T2	Wet	10.2	15.1	0.42
	Dry	11.8	19.2	0.65
T3	Wet	-	20.1	0.72
	Dry	-	21.5	0.74

$$\text{Avg. strength} = \frac{\text{Load at first crack} + \text{Load at failure}}{2} \dots (4)$$



Figure 4 - Panel Testing of Specimen Type 1 with Connectors

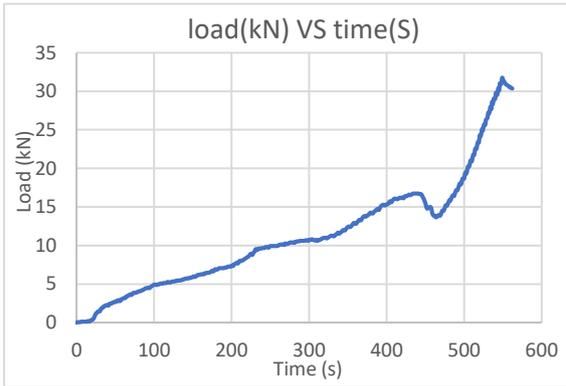


Figure 5 - Applied Load VS Time for Specimen Type 1 with Connectors

Figure 5 shows application of load with time for the T1 specimen with dowel connectors in the dry conditions.

In Type 1 with connectors, it shows three stages of failure and crack development. At the first stage, the crack propagation was observed at the joint and further increased the lateral load, resulting in the formation of a crack which was observed in the core part of the groove joint and continued through the core part. The stress at that stage was around 0.3 N/mm². Figure 6 and Figure 7 shows the propagation of cracks.



Figure 6 - First Crack Formation at the Joint in Type 1 Specimens



Figure 7 - Failure Crack Propagation at Core Section in Type 1 Specimens

At stage 2, there was a certain increment in the vertical load due to the bending of the specimen. At failure, the crack reached the face sheathing and another crack started to propagate from the base in T1 and T2 specimens. Lateral loading stress at that stage was assessed to be nearly 0.58N/mm². Later in stage 3, the provision of steel bars at the joint allowed further increase in applied lateral load as it can provide certain ductility to the specimen. In stage 3, the stress achieved was around 0.72 N/mm² with 6 mm deformation. However, the steel bar provided was the actual



Figure 8 - Crack Propagation in Type 3 Specimens

size used at the site condition, thus the effect from the steel bars can be over-stated for the scaled down specimens.

The same conditions applied to T2 and T3 test series as applied in the T1 testing. There was a strength increment in T2 while using tile mortar adhesive compared to the cement paste. Figure 8 shows the failure crack propagations. In addition, in the wet condition, there is a considerable reduction in the flexure capacity in both T2 and T3 specimens.



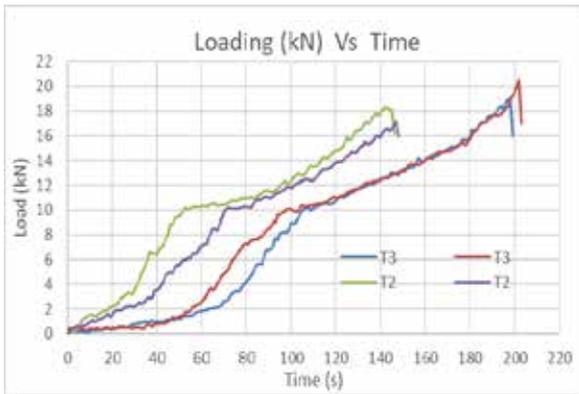


Figure 9 - Applied Load Vs Time for T2 and T3 under Dry Conditions

In part of the test series, the specimens were fully submerged for 24 hrs under water. The following Figure 10 shows the preparation of the specimen.



Figure 10 - T2 Specimens under Wet Condition

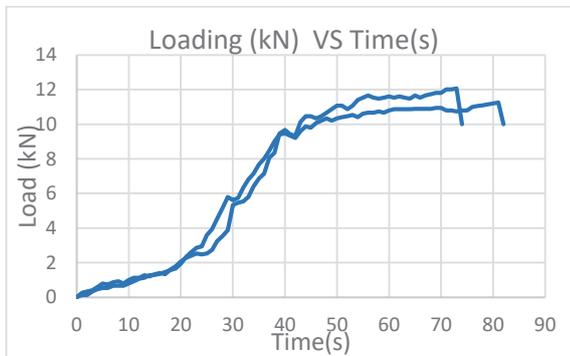


Figure 11 - Applied Load VS Time for T2 Specimens under Wet Condition

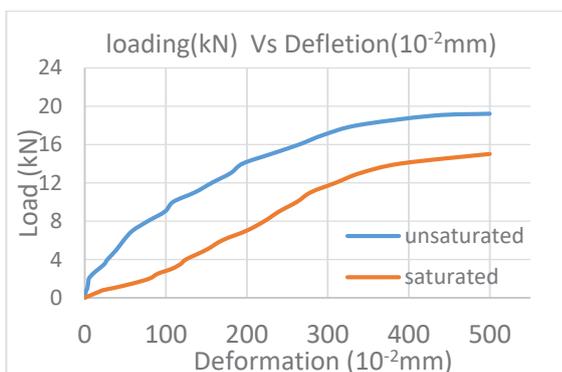


Figure 12 - Applied Load VS Deformation for T2 Specimens

The maximum deformation in the wall specimens (T2) was 4.2 mm and 3.8 mm in dry and wet conditions, respectively (refer Figure 12), and roughly 5.2 mm in typical panels (T3).

4.4 Development of Strength Curves

It is impractical to test for different curing conditions for a complete full EPS panel. The scale down specimens were used to perform the experiments. Therefore, full panels were converted into 1x1 ft blocks as in Figure 13 to perform tests.

Table 7 - Details of Panels used

Type	Size (mm)	Weight (kg/m ²)
EPS light weight panel	2440x610x75	50-53
	2440x610x100	60-65
	2440x610x150	80-90

EPS panels as in Table 7 with 75, 100 and 150mm thicknesses were taken just after casting.



Figure 13 - EPS Panel Blocks



Figure 14 - Fully Submerged Curing



Figure 15 - Gunny Bag Curing



Figure 16 - Membrane Curing

In fully submerged curing, EPS blocks were fully submerged in water (Figure 14) and some blocks were covered using wet gunny bags as shown in Figure 15 for gunny bag curing. For the membrane curing (Figure 16), “Masterkure 181” was used to cover the surfaces to prevent moisture escaping. In addition, a set of control samples were maintained without any curing to compare the results.

4.5 Laboratory Test for Strength Development

The compressive strength of specimens was measured using cured EPS blocks in the laboratory (Figure 17). For each curing condition, compressive strength was measured at 3, 7, 14, 28, 56, 84 and 168 days [17]. The test results were taken in metric tons (refer Table 7, Table 8 and Table 9).



Figure 17 - Compressive Strength Testing of Panel Specimens

Using the test results, strength development curves of the EPS panels were developed for different curing conditions and different panel thicknesses.

From Equation (1) $f = F/A$

$A = \text{thickness} \times \text{length}$

In addition, the units were converted into MPa to get the strength of EPS panels.

- A - No Curing (Reference)
- B - Gunny Bag Curing
- C - Submerged Curing
- D - Membrane Curing

Table 8 - Failure Loads Values of the 75mm Panels

Time	Failure loads (10 ³ kg)			
	A	B	C	D
7 days	1.6	1.8	2.1	2.3
14 days	3.1	3.5	3.2	3.8
1 month	5.1	6.2	4.7	5.2
2 months	5.9	6.8	6.1	6.5
3 months	6.0	6.9	6.5	6.7
6 months	6.9	7.8	7.7	7.9

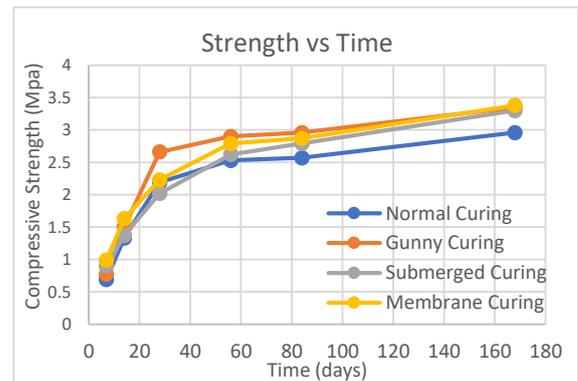


Figure 18 - Strength Development Curves for 75 mm Panels

Table 9 - Failure Loads Values of the 100 mm Panels

Time	Failure loads (10 ³ kg)			
	A	B	C	D
7 days	3.6	4.7	4.5	3.8
14 days	4.1	4.9	4.6	5.4
1 month	4.7	5.9	5.1	5.8
2 months	5.1	6.2	5.3	6.5
3 months	6.1	6.8	6.7	6.9
6 months	7.4	8.5	8.4	8.7

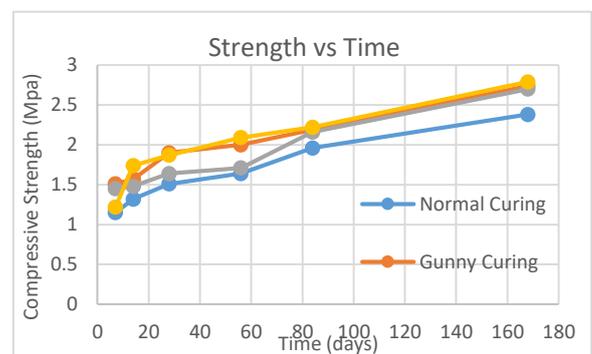


Figure 19 - Strength Development Curves for 100 mm Panels



Table 10 - Failure Loads Values of the 150 mm Panels

Time	Failure loads (10 ³ kg)			
	A	B	C	D
7 days	4.1	4.9	4.5	4.1
14 days	4.5	5.2	5.1	5.4
1 month	8.2	8.8	8.4	8.6
2 months	8.3	8.9	8.6	8.7
3 months	8.4	9.3	9.0	9.2
6 months	9.5	10.6	10.3	10.9

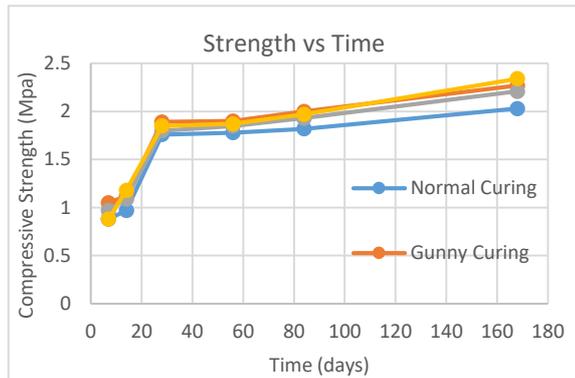


Figure 20 - Strength Development Curves for 150 mm Panels

According to the graphs in Figure 18, Figure 19 and Figure 20, very low strength of the EPS panels can be identified in the first two weeks after casting. Therefore, for construction, it is not advisable to use the EPS concrete panels just after casting. Furthermore, long-term strength development was observed in the samples tested.

Fly ash content of EPS could be the reason for this long-term strength development. In the 1st month there was no significant strength difference between cured EPS panels and the reference EPS sample. With time, the cured EPS panel strength increased from reference EPS sample. After 6 months (188 days), there was an average of 0.4 N/mm² strength difference between cured and non-cured EPS samples.

Out of three different curing conditions, membrane curing had slightly higher strength than others, most of the time. After 6 months, 75 mm, 100 mm and 150 mm panel thicknesses achieved average strengths of 3.3 N/mm², 2.7 N/mm² and 2.2 N/mm², respectively. Therefore, there was a high strength achievement with reduction of the panel thickness.

It must be noted that the present study was conducted for EPS based light weight panels with a cement fibre board, which is the mostly used form of panels for construction and the

board of these panels might affect the strength of EPS panel blocks as well.

5. Conclusions

Based on the findings, EPS-based lightweight panels can be recommended for traditional houses as an alternative to traditional materials such as brick and blocks. According to a previous study [6], it possesses a flexural strength of roughly 1.64 N/mm² when used as a single panel. The all-wall specimens parallel to the joints have flexural strengths ranging from 0.58 to 0.74 N/mm². It is almost less than half the capacity of a single panel. It also decreased to 0.45 Nmm² in the wet condition. It has a higher load bearing capacity than the BS5628-1-1992 recommended value of 0.4 N/mm² for masonry work under lateral loading parallel to joints. This could withstand lateral loads better than traditional materials when used as a single panel, however its capacity is reduced when used as a wall with integrated panels, similar to conventional masonry.

There was an average of 0.4 N/mm² strength difference between cured and non-cured EPS samples when considering experimental results in curing conditions analysis and strength developments over a 6-month period, which is approximately 20% strength development. There is a significant strength growth difference of around 28% across three distinct curing settings in the early stages of the curing period (30 to 60 days from the panel cast). As a result, the strength (load-bearing capability) of EPS panels can be improved by applying long-term curing procedures.

Acknowledgement

The authors wish to thank Eng. M.B.J.N. Fernando, the Managing Director of Ekala pre-stressed concrete industries for providing materials for the experiment works. Also, special thanks go to all the staff members of the Department of Civil Engineering, University of Moratuwa and colleagues for their immense support in the success of this research work.

References

1. Onat, N. C. and Kucukvar, M., "Carbon Footprint of Construction Industry: A Global Review and Supply Chain Analysis," *Renewable and Sustainable Energy Reviews*, vol. 124.
2. Dissanayake, D. M. K. W., Jayasinghe, C., and Jayasinghe, M. T. R., "A Comparative Embodied Energy Analysis of a House with Recycled Expanded Polystyrene (EPS) Based Foam Concrete Wall Panels," *Energy and Buildings*, vol. 135, Jan. 2017, pp. 85-94
3. Naji, S., Celik, O., Alengaram, U. J., Jumaat, Z., and Shamshirband, S., "Structure, Energy and Cost Efficiency Evaluation of Three Different Lightweight Construction Systems Used in Low-rise Residential Buildings," *Energy and Buildings*, Vol. 84, Aug. 2014.
4. Kaya, A., and Kar, F., "Properties of Concrete Containing Waste Expanded Polystyrene and Natural Resin," *Construction and Building Materials*, Vol. 105, Feb. 2016, pp. 572-578.
5. Babu, D. S., Ganesh Babu, K., and Tiong-Huan, W., "Effect of Polystyrene Aggregate Size on Strength and Moisture Migration Characteristics of Lightweight Concrete," *Cement and Concrete Composites*, Vol. 28, No. 6, Jul. 2006, pp. 520-527.
6. Fernando, P. L. N., Jayasinghe, M. T. R., and Jayasinghe, C., "Structural Feasibility of Expanded Polystyrene (EPS) Based Lightweight Concrete Sandwich Wall Panels," *Construction and Building Materials*, Vol. 139, May 2017, pp. 45-51.
7. Kelman, I., and Spence, R., "A Limit Analysis of Unreinforced Masonry Failing Under Flood Water Pressure," *Masonry International*, Vol. 16, No. 2, 2003, pp. 51-61.
8. Čuk, M., Stih, S., and Jerman, B., "Finite Element Analysis of Sandwich Panels with Longitudinal Joints and Large Openings", *Strojniski Vestnik - Journal of Mechanical Engineering*, Apr. 2013, pp. 275-284.
9. Manalo and Allan, " Structural Behaviour of a Prefabricated Composite Wall System Made from Rigid Polyurethane Foam and Magnesium Oxide Board," *Construction and Building Materials*, Apr. 2013, pp.642-653.
10. Jayasinghe, C., and Konthesingha, "Effect of Tie Beams on Lateral Strength of Masonry", *Transactions, Institution of Engineers, Sri Lanka*, 2008.
11. Bertero, V., and Brokken, S., "Infills in Seismic Resistant Building," *Journal of Structural Engineering*, Vol. 109, No. 6, Jun. 1983, pp. 1337-1361.
12. Assaad, J., Chakar, E., and G.-P. Zéhil, "Testing and Modeling the Behavior of Sandwich Lightweight Panels against Wind and Seismic Loads," *Engineering Structures*, Vol. 175, Nov. 2018, pp. 457-466.
13. Vishnu, P., and Thilakarathna, P. S. M., "The Feasibility of Using Lightweight EPS Based Panels For Staircases of Apartments," P. 7, 2017.
14. Al-Khaiat, H., and Haque, M. N., "Effect of Initial Curing on Early Strength and Physical Properties of a Lightweight Concrete," *Cement and Concrete Research*, vol. 28, no. 6, 1998, pp. 859-866.
15. Tan, K., and Gjorv, O. E., "Performance of Concrete Under Different Curing Conditions," *Cement and Concrete Research*, Vol. 26, No. 3, 1996, pp. 355-361.
16. Hasalanka, H. H. H. and Jayasinghe, P. M. T. R. *Assessing the Structural Feasibility of a Two Storied House Constructed Using Lightweight Concrete Panels*. Unpublished BSc thesis, University of Moratuwa. 2017.
17. Chen, B., and Liu, J., "Properties of Lightweight Expanded Polystyrene Concrete Reinforced with Steel Fiber," *Cement and Concrete Research*, Vol. 34, No. 7, 2004, pp. 1259-1263.

