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EXPANDED POLYSTYRENE FIBRED LIGHTWEIGHT CONCRETE (EPSF-LWC) AS A LOAD BEARING WALL PANEL

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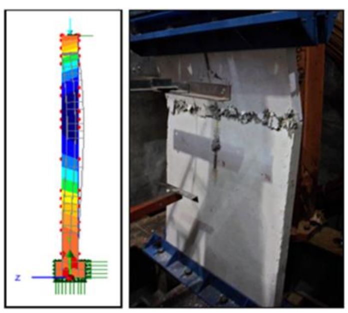
Graphical abstract



Abstract

This study was conducted to determine the optimum mix proportion of lightweight concrete (LWC) containing expanded polystyrene (EPS) and steel fiber which is designated as Expanded Polystyrene Fibred Lightweight Concrete (EPSF-LWC) for load bearing wall application. In order to produce LWC, EPS beads were chosen as lightweight aggregate because it gives advantages in term of energy absorbing capacity which suitable for structure that would be exposed to impact like shear wall. However, EPS beads possess zero strength. Therefore, steel fibre was added to improve LWC strength and also to reduce occurrence of micro and macro crack. In the mix design method, the percentage of EPS beads adding to the mix are differ while the percentage of steel fibre is same. The result showed optimum mix design was the one that contained 30% of EPS and 0.5 % of steel fibre and is designated as M8. The compressive strength EPSF-LWC of mix proportion designated as M8 is 19.51 MPa with density 1939 kg/m3. It is greater than 17 MPa as the requirement for structure component application that stated in the BS8110. Hence, reinforced and unreinforced EPS-LWC wall panels were constructed to determine the maximum loading that wall can sustain and deflection profile EPSF-LWC wall panel for the loaded to failure. The wall was set up under pinned-fixed end support condition. The sample was modelled using finite element analysis (FEA) for validation with experimental programme. The maximum loading capacity was found to be 908.20 kN and 853.40 kN for each reinforced (WR5) and unreinforced (WUR5) of EPSF-LWC wall panel. These loading were 31% to 35% less than finite element analysis. However, WR5 and WUR5 EPSF-LWC wall panel was deformed in single curvature profile for both experimental and FEA. Maximum deflection for WR5and WUR5 of EPSF-LWC recorded is 10.27 mm and 12.95 mm occurred at 0.7 heights (H) of wall panel. According to Euler buckling load theory, the location of maximum lateral displacement of wall panel sample is influenced by the type of fixity at end support of the sample.

Keywords: Expanded Polystyrene (EPS), Lightweight Concrete (LWC), Load Bearing Wall Panel

1.0 INTRODUCTION

Wall panel is widely used in the building construction such as partition or carrying load. It has been chosen as an alternative to conventional brick wall. Since wall panel itself provide gravity load due to self-weight, implementing lightweight concrete (LWC) wall panel may reduced this effect while provides additional advantage in terms of cost benefit. Therefore, many researches have been carried out in order to enhance the performance of lightweight concrete wall panel. The compressive strength, f_{cu} and density are significant in classifying as lightweight concrete. Normally, normal weight concrete f_{cu} ranges between 25 MPa to 45 MPa with density of 2400 kg/m^3. The LWC f_{cu} 50 % lower than normal concrete [1]. In producing

LWC, there are several methods which are no fine concrete, lightweight aggregate and aerated concrete [2]. However, this present research focuses on LWC by using lightweight aggregate namely as EPS. EPS is one of lightest materials and provides advantage of energy absorbing characteristic to resist high impact loads [3]. It also has hydrophobic characteristic, good insulation properties, closed cellular aggregates, high durability and shock absorbance ability [3, 4]. However, it has relatively low strength which not improve the concrete strength and furthermore compressive strength of EPS concrete decreases when density decreases [5, 6]. Therefore, additional material that can enhance the EPS concrete strength is required. It is reported that the utilisation of fiber is efficient in improving the ductility of concrete under all modes of loading. The desired properties of LWC with steel fiber can be observed in structural element like lightness, thermal and sound insulation, strength [7]. The addition of steel fibre is expected to improve the strength of EPS-LWC wall panel as well as advantages such as hindrance of macro cracks development, delay in micro cracks propagation while also gives higher ductility of micro cracks formation [8]. In the present research, it is hypothesized the presence of those materials of EPS and steel fibre increase the structural performance of EPSF-LWC wall panel.

2.0 EXPERIMENTAL PROGRAMME

2.1 Mix Proportion

Three (3) different series mix proportions were prepared to determine the optimum mix proportion for EPSF- LWC containing EPS and steel fiber (SF). Table 1 shows the details of the three (3) series of mix proportion. Series A contains of basic mix concrete Grade 30 which is cement (OPC), fine aggregate (passing 2.36 mm size), coarse aggregate (passing 10 mm size) and water and designated as M1. Series B was mixed with basic mix concrete proportion and EPS beads (3.0 mm diameter) and it was mixed according to different percentages of EPS which is 10 %, 20 %, 30 % and 40 %. There are four (4) batches which represent the four (4) level of EPS content and are designated as M2, M3, M4 and M5. For Series C, contains of basic mix concrete proportion, EPS beads and steel fibre (hooked ends 60 mm length). However, 0.5 % steel fibres are maintain for each different percentage of EPS beads. Samples were tested at different ages which are 3 days, 7 days, 14 days, 28 days and 60 days for compressive strength. Other tests which are tensile splitting and flexural strength were tested at 28 days of cured.

2.2 Preparation and Fabrication of EPSF-LWC Wall Panel

Based on the strength of EPSF-LWC, the M8 was chosen as the mix proportion in fabricating the EPS-LWC wall panel. Therefore, two numbers of EPFS-LWC wall panels were constructed which is reinforced with single layer reinforcement and the one without reinforcement. The size wall is 1500 mm (height), 1000 mm (width) and 75 mm (thickness).These dimension represent the half from the actual size of actual wall panel. The dimension details of EPS-LWC wall panel fabrication are shown in Figure 1(a and b). Size of reinforcement used is B7 with 100 mm spacing centre to centre for main wire and 200 mm spacing centre to centre for cross wires. The wall panels are named as WR5 for reinforced wall and WUR5 for unreinforced wall panel. The maximum design load per unit length was calculated by using Equation (1) below:

$$\eta_w \leq 0.4\, f_{cu} A_c + 0.75 A_{sc} f_y \qquad \text{(Eq. 1)}$$

where, f_{cu} is the concrete compressive strength, A_c is the total area of concrete, A_{sc} is the area of steel in compression, and f_y is the yield strength of steel reinforcement.

2.3 EPSF-LWC Wall Panel Testing

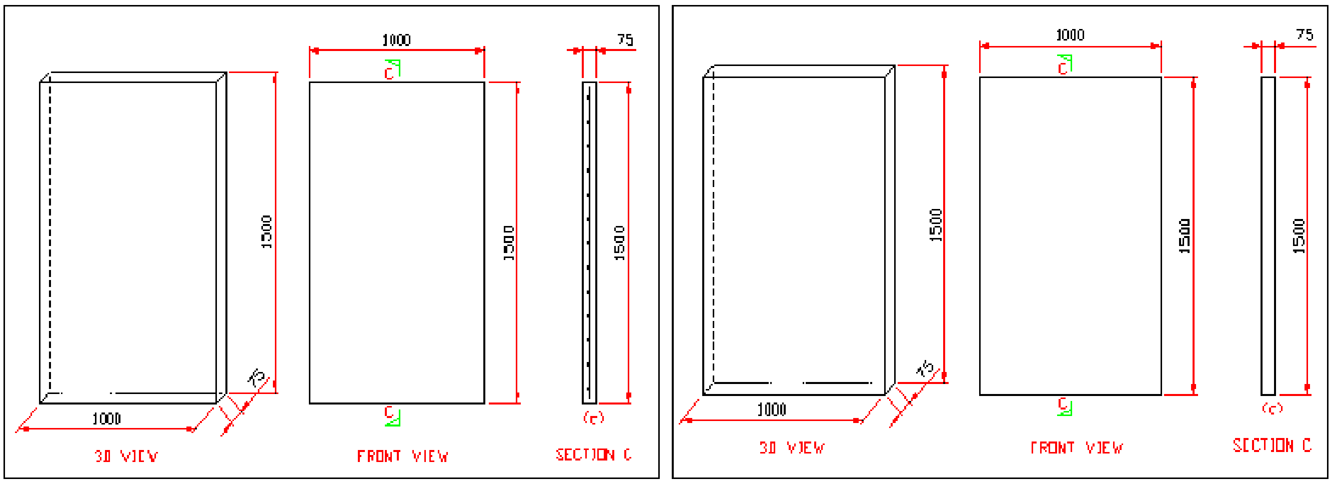
Five (5) units of Linear Variables Displacement Transducer (LVDT) were placed to measure displacement of the wall. The LVDTs were located at 0.1H (150 mm), 0.3H (450 mm), 0,5H (750 mm), 0.7H (1050 mm) and 0.9H (1350 mm) of wall height. The EPSF-LWC wall panel was tested using Universal Testing Machine (UTM) 2000 kN load capacity. The wall was placed vertically and tested under pinned-fixed end support condition and set up for axially loaded.

2.4 Finite Element Analysis

The finite element analysis (FEA) presented are modelled by using the LUSAS Modeller. The geometry of the wall panel is modelled in three dimensions solid continuum element, HX20 as a nonlinear analysis. The obtained results in terms of load versus displacement curves are compared with the experimental results reported. Further aspects such as the crack propagation and displacement profile at the failure load are also examined in order to emphasize additional peculiarities concerning the influence of steel fiber response of EPSF-LWC.

Table 1 The details of three (3) series of LWC

Materials	Mass (kg) per 1 m³								
	Series A	Series B				Series C			
	Mix 1	Mix 2 10% EPS	Mix 3 20% EPS	Mix 4 30% EPS	Mix 5 40% EPS	Mix 6 10% EPS	Mix 7 20% EPS	Mix 8 30% EPS	Mix 9 40% EPS
Cement (OPC)	376	338	301	263	225	337	299	261	224
Fine aggregate	1002	901	801	701	601	896	796	696	596
Coarse Aggregate	788	708	629	551	472	704	625	547	468
Water	233	210	186	163	140	209	185	162	139
EPS Beads	-	1.65	3.29	4.94	6.58	1.65	3.29	4.94	6.58
0.5 % Steel Fibre	-	-	-	-	-	41.3	41.3	41.3	41.3



(a) (b)

Figure 1 EPS-LWC Solid Wall panel (a:WR5, b:WUR5). All dimension in millimeter (mm)

Figure 2 Wall Panel Set Up for axial load

3.0 RESULTS AND DISCUSSION

3.1 Material Properties of EPSF-LWC

Table 1 shows the summary of the material properties result recorded. Series A represent LWC without EPS and SF. The LWC under series B recorded the lowest density ranges from 5.87 kg/m³ to 26.73 kg/m³. However the compressive strength, tensile strength and flexural strength are also lowest compared to those of Series C. It was found that, M8 from Series C is the optimum mix proportion with density of 1939 kg/m³ and compressive strength 19.51 MPa exceeded 17 MPa. In lightweight aggregate concrete cases, the compressive strength recommended should be above 17 MPa in order to be used as structural concrete [9]. It is a proof that steel fiber could increase the concrete strength and at the same time maintain the low concrete density.

3.2 Ultimate Load

Table 2 shows the ultimate load the EPSF-LWC wall panel can sustain and the displacement results. The WR5 wall panel recorded higher ultimate load compared to the WUR5 wall panel which is 908.20 kN and 853.40 kN respectively and it is proven by LUSAS Modeller (Figure 3). This results is exceeded from the theoretical calculation. The percentage different of ultimate load between WR5 and WUR5 is only 6.03 % and it is only small different. This is because the addition of steel fibers increased the flexural and ultimate capacity of the EPSF-LWC wall panel. Besides, the position of steel fiber may transverse to the reinforcement will cause void. Concrete is a brittle material when exceeding its elastic region [10]. By analyzing the load and displacement relationship, it is obtained that WUR5 shows the brittleness effect where the displacement reduced due to slip of molecule bonded in the EPSF-LWC paste when experienced ultimate loading. The 31% to 35 % significant discrepancy of the both experimental results (WR5 and WUR5) to the finite element analysis can be due to the variability of the material properties used and set up to build the panels during the experimental tests.

Table 2 Ultimate Load and Displacement results

		EPSF-LWC Solid Wall Panel	
		WR5	**WUR5**
Load (kN)	Theoretical	728.60	581.70
	FEM	1321.50	1313.40
	Experimental	908.20	853.40
Displacement (mm)	FEM	0.37	3.18
	Experimental	10.27	12.95

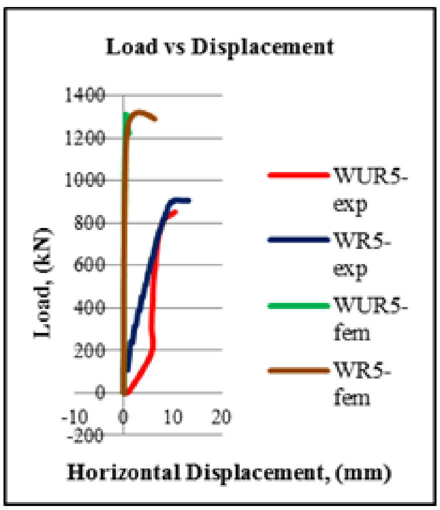


Figure 3 Load vs Displacement

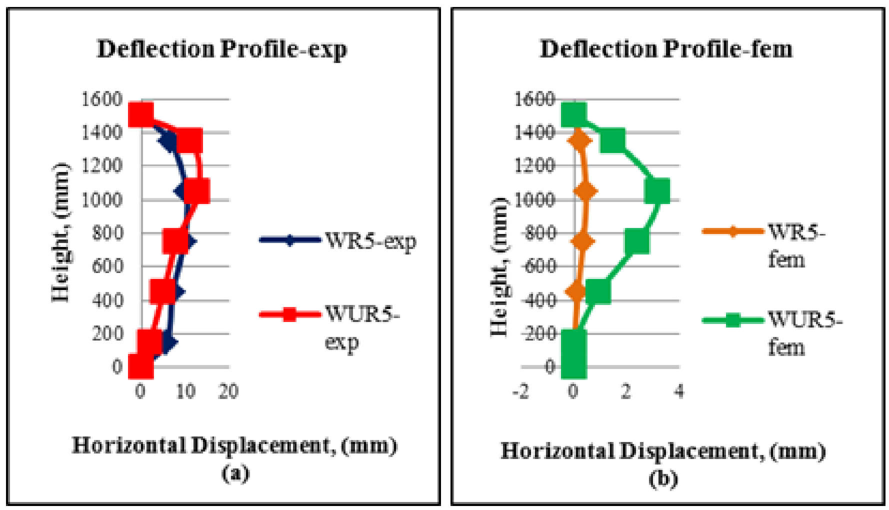
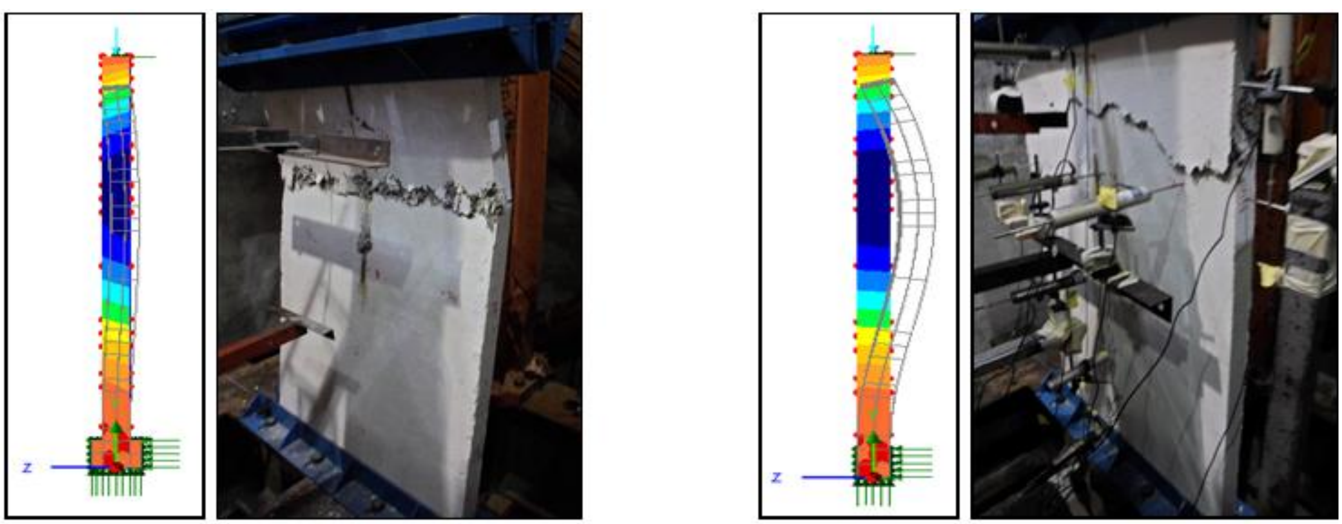


Figure 4 Deflection Profile (a) experimental and (b) FEM



(a) (b)

Figure 5 Wall panel deflection and failure behaviour of (a) WR5 and (b) WUR5

3.3 Deflection Profile and Failure Modes

Lateral displacement increase linearly due to increase load applied for both experimental and FEA. Maximum lateral displacement for WR5 and WUR5 is 10.27 mm and 12.95 mm, it buckles at 0.7 height (H) of wall which is 1050 mm height. This result comply with the LUSAS Modeller finite element analysis and the Euler Buckling Theory whereas wall should buckles at 0.7 of height (H) for pinned-fixed ends support condition. Failure of wall panel also depends on the fixity and the reinforcement. Once the load applied to the wall, it will be transferred to the reinforcement. Then reinforcement was bended according to the load rate imposed. As shown Figure 4 and Figure 5 the walls buckle in single curvature for both experimental and finite element analysis since the ends supports condition is similar. The horizontal crack line clearly could be seen (Figure 5a) at the location of 1050 mm height of wall. The absence of the reinforcement in WUR5 finite element analysis did not disturb or change the deformation profile of wall panel in one-way action. However, the buckle shape could not obviously seen in the WUR5 experimental programe because the wall experience by buckling in shear. It also shows crushing at the top of wall near the location of load applied. Then the crack were propogated diagonally to the middle of wall. It is also found that number of crack occurred is minimal for both WR5 and WUR5 wall panel because of combination steel fibre in EPSF-LWC wall panel. The ability of steel fibre to prolong the minor crack reduces the crack propagation. In addition, the behaviour of EPS beads itself that has the elastic behaviour assist the phenomenon mentioned before.

4.0 CONCLUSION

As conclusions, the presence of EPS beads itself in the concrete mixture lower the strength and do not fulfill the requirement to be used as structural component. It was found that addition EPS in the LWC has made the concrete light in weight and the addition of steel fiber improve the strength. Besides, it also reduces the crack on tension and compression face in order to increase tensile strength, improve cracking deformation and increase the concrete strength. Predominantly, EPS-LWC wall panel with steel fibre offered significant advantage in terms of crack control. This ability is highly demanded in any of concrete structural element. This ability provides solution to the alleviate crack formations such as decrease serviceability interruption and reduce the possibility of corrosion to the steel reinforcement within the concrete.

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