Experimental Study for Structural Behaviour of Precast Lightweight Panel (PLP) Under Flexural Load

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Abstract. Precast lightweight concrete slab is first fabricated in workshop or industrial before construction and then transported to site and installed by skilled labour. It can reduce construction time by minimizing user delay and time for cast-in-situ to increase workability and efficiency. It is environmentally friendly and helps in resource reduction. Although the foamed concrete has low compressive strength compared to normal weight concrete but it has excellent thermal insulation and sound absorption. It is environmentally friendly and helps in resource reduction. To determine the material properties of foamed concrete, nine cubes and six cylindrical specimens were fabricated and the results were recorded. In this study, structural behaviour of precast lightweight panel (PLP) with dry density of 1800 kg/m³ was tested under flexural load. The results were recorded and analysed in terms of ultimate load, crack pattern, load-deflection profiles and strain distribution. Linear Voltage Displacement Transducers (LVDT) and strain gauges were used to determine the deflection and strain distribution of PLP. The theoretical and experimental ultimate load of PLP was analysed and recorded to be 70 and 62 kN respectively, having a difference of 12.9%. Based on the results, it can be observed that PLP can resist the adequate loading. Thus, it can be used in precast industry for construction purposes.

1. Introduction
Lightweight foamed concrete (LFC) is comprised of Ordinary Portland cement (OPC), fine aggregates and foamed agent without using any coarse aggregate. This helps in reduction in density. The density of lightweight concrete ranges from 1440 to 1840 kg/m³ which is approximately 80% of normal weight concrete. It is lightweight, free-flowing, easy to pump and does not required compaction [1]. It also has good thermal insulation and sound absorption as compared to normal weight concrete [2]. Although the Industrialised Building System (IBS) was introduced in Malaysia in early 1960s but the usage level of IBS in the local construction industry stands at only 15% [3] due to lack of knowledge about properties of lightweight concrete. Thus, this study was carried out to achieve better understanding of the structural behaviour of PLP subjected to flexural load.

2. Literature Review

2.1 Structural Behaviour of Panel.
Each construction has its own structure part which is responsible to sustain the loading and prevent it from failure. Structures are designed to sustain loads and types of building to be constructed. Thus, ultimate load, cracking pattern and deflection of structures have a relationship to the failure of structure. The ultimate flexural load of panel will be influenced by compressive strength, thickness [4] and density [5]. According to Mustaffa, higher density of foamed concrete also influences the attained ultimate load of slab under test. According to Mohamad et al., two types of crack patterns were discovered on a panel which are flexural crack and shear crack. Flexural cracks started to occur between the point of loading (mid-span) where the concrete experienced high local tensile stresses as loading applied to the slab followed by a shear crack propagated along the slabs. Further increasing the load, the flexural crack propagated upwards reaching top of the slab with increased deflection. Finally, the panels failed by crushing of concrete at the spot nearest to the point of loading [5].

According to the study on the use of additives to enhance properties of preformed foamed concrete [6], it was found that the compressive strength of foam concrete decreased with a reduction of density but the compressive strength increased with the use of additives. This is due to the reduction of water content with the formation of less porous interfacial zone and provided a better interlocking between the paste and the aggregates. The results showed that the mixes with density 1300 and 1600 kg/m$^3$ are not suitable for structural purposes due to the low compressive strength obtained. The tensile strength and splitting of conventional mixes is higher than mixes with additives. For a given density, the sand content is lower in mixes with additives and degraded the shear capacity.

A research was conducted to study the flexural behaviour of structural fibre composite sandwich beams in flatwise and edgewise positions [7] in which composite sandwiches with nominal thicknesses of 18 mm and 20 mm were tested under flexural load. In the flatwise position failed with sudden brittle type failure and the presence of fibre composite skins increased the ultimate strength prevented the sudden failure of the composite sandwich in edgewise. Strength is significantly improved by the introduction of the non-horizontal fibre composite skins, thus could be used in the inner portion of the laminated beams to carry shear.

3. Materials and Methods
The materials used in foamed concrete are Ordinary Portland cement, fine aggregate, water and foam. 2:1 sand-cement ratio was used while the foam-water was 1:20 and 0.55 water-cement ratio was taken. In order to test the mechanical properties of foamed concrete and flexural behaviour of panel, cube specimens of 100 x 100 x 100 mm, cylinder specimens of 300 x 150 mm and PLP specimens of 1400 x 500 x 200 mm dimensions were cast. The detailing of the panel is showed in figure 1.

![Figure 1. Detailing of PLP](image)

Test Set-up and Procedure.
The flexural strength was performed on specimens of 1000 x 500 x 150 mm dimensions using the four-point loading procedure. PLPs were cast and were tested after 28 days curing. The test specimen was placed in the Magnus Frame, hydraulic jack of machine was loaded to the mid-span of the panel and the distance between two point loads was 400 mm as shown in figure 2.

A total of 24 electrical strain gauges of 30 mm length were placed on top, bottom, front and rear surface. Each surface consisted of 6 strain gauges. To measure the deflection of the panel three Linear Voltage Displacement Transducers (LVDT) were used. LVDT 1 was placed at the center while LVDT 2 and LVDT 3 were placed at the bottom of panel where the load was applied. All the strain gauges and
LVDTs were connected to data logger and computer for data recording purposes. The crack pattern was marked on the surface and noted at each load stage.

![Figure 2](image1.png)

**Figure 2. Test setup specimen and location of strain gauge and LVDT**

4. **Results and discussion**

The material properties of foamed concrete and ultimate load of PLP are shown in table 1.

| Properties of Foamed Concrete of PLP | Compressive strength | Tensile strength | Elastic modulus | Ultimate load |
|-------------------------------------|---------------------|-----------------|-----------------|---------------|
|                                     | 13.93 kPa           | 1.34 kPa        | 8.509 kN/mm²    | 62 kN         |
|                                     | (Experimental)      | (Theoretical)   |                 |               |

4.1 **Crack Pattern.**

Figure 3 shows the cracking pattern of PLP at different location. The load was applied on panel incrementally but it was stopped before failure but after the ultimate load occurred. The first crack occurred when 30 kN load was applied. The flexural crack started at the bottom and propagated to top of panel. All the cracks developed at the middle part of the panel where the concrete experienced highest tensile stresses. However, no shear crack occurred, this is due to the reinforcement and stirrups provided in the panel. The reinforcement provided had gripped the concrete together and reduced the cracking. The major crack happened at mid-span of the panel.

![Figure 3](image2.png)

**Figure 3. Cracking pattern of PLP**

4.2 **Load Deflection Profile**

The deflection happened before first crack meaning that the panel had deformed as the loads were applied. Load-deflection curves were approximately linear which can be assumed as elastically deformation but the curve become non-linear and deflection increased significantly until reaching ultimate load after first crack as shown in figure 4. The deflection for LVDT2 is higher compared to LVDT1 and LVDT3 at ultimate load. It can be observed that as the loads increase, the deflection of panel also increases as shown in figure 5. At initial stage, the deflection of right part of panel deformed more as compared to other parts but at the ultimate load, mid-span deflected most indicating critical area of panel.
4.3 Strain distribution

There are total of 12 strain gauges in front and rear surface. Each surface consists of two rows of strain gauges and each row has 3 strain gauges. It is distributed into three parts (left, right and middle) and labelled as top (left or right) and bottom (left or right) as shown in figure 6, while front (up or down) and rear (up or down) as shown in figure 7. load-strain curve at upper part tends to move to the negative along the applied load. Therefore, all the strain gauges at right part experienced compressive strain at ultimate load and this indicated that the right part of the panel undergoes compressive strain. In addition, some of the curve is not completed compared with the others. This is because the data had been removed since this inconsistence results is affected by the cracks which had passing through the location of strain gauge during testing.

5. Conclusion

This study was carried out to investigate the flexural behaviour of Precast Lightweight Panel (PLP) under flexural load. Based upon the results, the following were concluded:

i. The ultimate load tabulated according to BS 8110 is 70 kN which has a difference of 12.9% from experimental data, 62 kN. Although the loading sustained by PLP is not as much as normal weight concrete but it is able to be applied in low rise building which carry lesser loading.
ii. The first crack occurred on the panel at 50% of the ultimate load. The cracks mainly appeared at middle and bottom part of panel. Cracks which appeared are known as flexural or bending crack which start at the tension face and extend upwards. Steel reinforcements that had been introduced in the panel had effectively reduced the shear crack as no shear cracks had appeared.

iii. The larger the applied load, the larger the deflection of panel. The PLP proved to be ductile which experienced large deformation before failure.

iv. PLP behaved elastically before the first crack but it turned to non-linear afterwards. PLP failed due to tensile stress with excessive cracks appearing in the tension zone of the bottom surface.

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