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# STRUCTURAL PERFORMANCE OF OIL PALM SHELL LIGHTWEIGHT AGGREGATE CONCRETE WALL PANEL ON INSULATION CONCRETE CAPACITY

Eravan Serri[a,b*], Mohd Zailan Suleiman[a], Roslan Talib[a], Khairul Azmi Jabar[c]

[a]School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia
[b]Kolej Universiti Yayasan Sabah, 888867, Kota Kinabalu, Sabah, Malaysia
[c]Forest Products Division, Forest Research Institute Malaysia, 52109, Selangor Malaysia

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*Corresponding author
eravan06@yahoo.com

**Graphical abstract**


## Abstract

This paper presents of an investigation conducted the structural performance of oil palm shell lightweight aggregate concrete (OPSLAC) wall panel. Load-deflection characteristic on OPSLAC wall panel was conducted. Further, the effect of Stress-strain relationship and buckling effect on compression load was investigated. The variable selected are size of oil palm shell (OPS). Three wall panel specimens were prepared, and tests on compression load were conducted. The load-deflection result showed the changing on OPS shape used. The convex of OPS influence the bond within aggregate and cement paste. Further, the increasing of compression load is related to the formation and growth of micro cracks. As ultimate strength is approached, increased load and bulk paste micro cracks join to form continuous cracks parallel to the direction of loading on stress-stain curve. After 70% from the ultimate loading, the extent of cracking is so great that OPSLC cannot support additional load.

*Keywords*: Load-deflection, buckling, compression load, insulation concrete

## Abstrak

Artikel ini menerangkan tentang kajian yang dilakukan terhadap prestasi struktur panel dinding yang diperbuat daripada konkrit aggregat ringan tempurung kelapa sawit (OPSLAC). Ciri yang dikaji bagi panel dinding OPSLAC ini ialah pesongan beban. Selain itu, kesan hubungan tekanan-terikan dan kesan lenturan terhadap beban mampatan juga dikaji. Pemboleh ubah yang dipilih ialah saiz tempurung kelapa sawit (OPS). Sebanyak tiga spesimen panel dinding disediakan dan ujian terhadap beban mampatan dijalankan. Keputusan ujian pesongan beban menunjukkan pesongan beban dipengaruhi oleh bentuk OPS yang digunakan. Permukaan OPS yang melengkung mempengaruhi ikatan antara aggregat dengan pes simen. Selain itu, peningkatan beban mampatan adalah berkaitan dengan pembentukan dan perkembangan retakan mikro. Apabila kekuatan maksimum semakin hampir dicapai, beban yang semakin tinggi dan retakan mikro yang banyak pada pes simen akan menyebabkan retakan bersambungan yang selari dengan arah bebanan pada lengkungan tekanan-terikan. Selepas 70% daripada bebanan akhir, tahap retakan adalah sangat tinggi sehinggakan OPSLC tidak dapat menyokong bebanan tambahan.

*Kata kunci*: Beban-pesongan, lengkokan, beban mampatan, konkrit peneba

# 1.0 INTRODUCTION

Oil palm shell (OPS) lightweight aggregate concrete can be categories as sustainability construction building materials. From the waste materials of oil palm processing, OPS can be used as a coarse aggregate in concrete. And in terms of strength, most of previous researcher [1] found, that, OPS lightweight aggregate concrete (OPSLAC) are achieved for structural strength requirement. However, only several study that investigate the performance of OPSLAC on structural element. The structural application of OPSLAC that was reported by previous researchers mainly consist of reinforced beam [2, 3]. By using reinforcement ratio of 3.14%, prediction moment of OPSLAC beam increased about 4% to 35%. Apart from that, for 3.90% reinforcement ratio, ultimate moment capacity of 6% is recorded according to BS 8110 for flexural behaviour. The crack width is also in the range that is allowed by BS 8110 for services load value. Based on the experimental result, they finalizes that, the trend of OPSLAC beams is similar to normal weight concrete beam especially for ductility behaviour and moment curvature. In shear behaviour performance Alengaram *et al*. [4] found that shear strength for OPSLC beam is higher than normal weight concrete due to concave shape of OPS. This condition causes the soundness interlocking within OPS and cement paste to become weaker.

To evaluate the bond strength of OPSLAC, a pull out test was conducted by Alengaram *et al*. [5] for that purpose. They found that the bond stress of OPSLAC (with 37 MPa compressive strength) is 85% of grade 30 normal weight concrete. This is more than 2 times higher based on British Standard specification for the same grade strength [6]. Therefore, this paper will explore the structural performance of wall panel OPSAC with load bearing capacity.

# 2.0 METHODOLOGY

## 2.1 Materials

Ordinary Portland cement ASTM type I with specific gravity of 3.10 and Blaice specific surface area of 3510 cm²/g; local sand with specific gravity, fines modulus, water absorption and maximum grain size of 2.67,2.66, 0.95% and 2.36 mm., respectively. Superplasticizer (SP) in the range 1% of cement volume was used. Potable water.

Old OPS was used as course aggregate, which is OPS that have been left outside for approximately half a year at the palm oil mill yard. Old OPS does not have fibre and less oil coating, which result in better bond within the OPS surface and mortar. OPS in different shapes and sizes were used and for crushed OPS, stone crushing machine was used to crush the OPS. Due to high water absorption of OPS, it was washed and kept in a saturated dry (SSD) condition before mixing.

## 2.2 Specimen

For structural laboratory experiment, 3 specimens were prepared for the test, and all of them were reinforced by the BRC A6. The variation in sizes of OPS differentiates the specimens with each other. Only mix design with 32% of OPS Vf is selected, due to its optimum thermal conductivity value with highest compressive strength. The details of mix design are shown in Table 1

**Table 1** Mix design for structural specimens

| MIx | OPS | | | | C | W | S | SP (%) |
|---|---|---|---|---|---|---|---|---|
| | Raw | Crushed | Partly crushed | Vf (%) | | | | |
| R-30 | 524 | - | - | 30 | 400 | 160 | 720 | 4 |
| R-32 | 566 | - | - | 32 | 375 | 150 | 675 | 3.8 |
| R-34 | 606 | - | - | 34 | 350 | 140 | 631 | 3.5 |
| C-30 | - | 537 | - | 30 | 400 | 160 | 721 | 4 |

Note* C: cement; W: water; S: sand; Vf; Volume fraction

Reinforced concrete load bearing wall is normally designed as columns and bending should be taken into account [7]. Thus, the design of the sample for OPSLAC wall panel follows Equation (1). Two layers of BRC A6 are used as reinforcement with sample dimension of 125 mm x 500 mm x 500 mm as shown in Figure 1 (A).

$$Pn = 0.85f'c(Ag-Ast)+Astfy \quad (1)$$

Where f'c is compressive strength, Ag is gross area of wall, Ast is areas of reinforcing steel and the strength by reinforcing steel is Astfy. With the rules Ast < 0.4% Ac following BS 8110. The 500 mm x 500 mm x 125 mm wall panel was casted horizontally into formwork (Figure 1B). The concrete were placed in 3 layers, with each layer subjected to vibrations of 15 seconds on the vibrating table. The specimens were then covered with nylon sheet and demoulded after 7 days. For the quality assurance checking, 3 extra cubes were prepared from each mixes to test its compressive strength at 28 days.


**Figure 1** (A) Specimens cast in a horizontal formwork; (B) Formwork with two layers of BRC A6

### 2.3 Test Set-up

The compression test was conducted using the TORSEE machine with capacity loading frame of 1000 kN. Plunger load was increased manually at pace rate of 5 kN per increment up to failure of test wall. The applied load was continuously monitored with the use of a 500 kN capacity load cell. In order to allow the monitoring of deflection to ultimate failure of test wall without damaging the LVDT, the LVDT was placed in contact with top of the wall instead of the bottom. All test data were collected and recorded using a high speed computerised data logger system using continuous recording mode at a recording speed of 5 Hz (Figure 2).


**Figure 2** (A) OPSLC wall panel set-up for compression test; (B) Data logger

## 3.0 RESULT AND DISCUSSION

### 3.1 Load-deflection Characteristic of OPSLAC Wall Panel

In accordance with the accepted conventions of engineering design, every structure must be capable of resisting dead loading and imposed loading. In a broad sense, dead loading comprises the weight of structure itself together with the weight of the remaining part of the building supported by structure. In the case of loadbearing wall, the dead load to resist at the base of the wall consists of weight of the wall itself and of that part of the floor and roof and of the partitions above, which must be estimated according to British Standard. For OPSLAC wall panel, the highest ultimate load is obtained by specimen R-32, which is 401 kN, followed by P-32, 398 kN and P-34, 390 kN.


**Figure 3** Failure of OPSLAC wall panel specimens (R-32, P-32, P-34)

For all tested wall panel, there are two distinct stages of deflection namely pre-cracking and buckling. During the pre-cracking deflection stage, the deflection for all specimens increased slowly with corresponding uniform compression load in linear line. In this stage, the strengthening of OPSLAC matrix is still strong even though a little movement occur in cement matrix due to the impact of the compression pressure from the load. Meanwhile, the increasing of load and the corresponding deflection occurred in geometrical relationship up to the initiation of the first cracks for all OPSLAC wall panel.

As static load increase, the gradient of the curve for all specimens become less steep towards the ultimate point. Right after the ultimate point, there is a sharp increase of static load causing the fracturing of the OPSLAC wall panel. At this stage, the reinforcement has already bent and then, the cracking at the wall surface happen as shown in Figure 3. The condition is also called buckling strength. After wall panel reached the ultimate load, the wall panel collapsed due to unstable structure position. The graph for reaction of all specimens is presented in Figure 4.

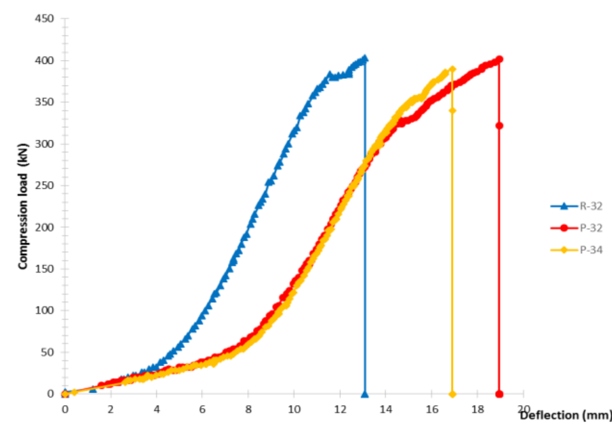


**Figure 4** Load-deflection curves of OPSLAC wall panel

### 3.2 Stress-strain Relationship

Failure of OPSLC occurs as a result of the development of a network of micro-cracks that grow in length with increasing load to the point where the concrete cannot support further load. The OPS particles can both initiate and arrest crack growth. The latter feature is beneficial in reducing the brittleness of OPSLAC. Before external load is applied to concrete, fine cracks exist in concrete at the interface of OPS and cement paste due to mechanical property differences and the occurrence of shrinkage of thermal strains. These pre-existing micro cracks are responsible for the low tensile strength of OPSLAC. As internal load is applied, existing micro cracks are stable up to about 30% of the ultimate load, at which point interfacial cracks begin to increase in length, width, and quantity. When 70%–90% of ultimate strength is reached, cracks penetrate into the bulk paste leading to continuous larger cracks until the OPSLAC cannot support additional load.

The shape of the compressive stress-stain curve of OPSLAC is related to the formation and growth of micro cracks. The relationship of the stress-strain curve is illustrated in Figure 5. From 0 to 30% of ultimate strength, the stress-stain line is in curve pattern, and then up to 30% to 70% from ultimate strength, the line becomes linear. When micro cracks penetrate into bulk cement paste, deviation from linearity increases at faster rate. As ultimate strength is approached, increased load and bulk paste micro cracks join to form continuous cracks parallel to the direction of loading. At some point, the extent of cracking is so great that OPSLC cannot support additional load, and subsequently the stress required for additional strain decreases.

Based on the above micro cracking process, it is clear that the ultimate strength of OPSLAC is strongly related to the strength of the cement paste. There are several factors that affect the paste strength of OPSLC. Probably the most important factor is paste density, which in turn depends highly on the water-cementations materials ratio (w/cm). As the w/cm is intersected, the density of the paste decreases, and so does its strength. The nature of the cementations materials also affects paste strength.

Factor involving both the paste and aggregate will affect the strength of the paste-aggregate interface. The bonds between OPS increased with higher surface per unit volume. Also, rough and angular surface texture such as crushed OPS increases interfacial bond strength [8]. Other factors that affect the strength of concrete include degree of mixing of the constituent materials and consolidation of the OPSLAC [9]. That is why specimens R-32 and P-32 obtained higher strength compared to P-34, due to increasing volume fraction of OPS used.

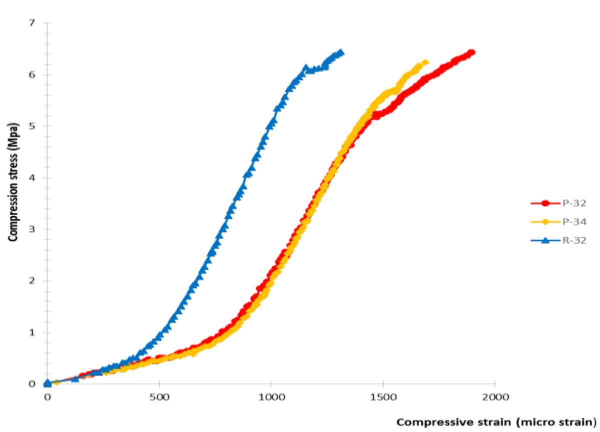


**Figure 5** Stress-strain curves of OPSLC wall panel

### 3.3 Buckling

Another parameter that needs to be considered for load bearing wall in compression load is buckling. Buckling happened due to reaction on axial load during compression. Based on Figure 6, P-34 specimens produced the highest deflection. However, it produced the lowest compression load capability. The minor deflection start at 34 kN load, and the curves show that the deflection slowly increased until the ultimate deflection at 6 mm. Different with specimen R-32, the minor buckling starts at 150 kN and linearly increase until 375 kN, before flattering till 403 kN and failed with 3.1 mm deflection. Specimen P-32 produced the highest minor deflection effect, which is at 240 kN, and increased slowly until ultimate deflection at 402 kN.

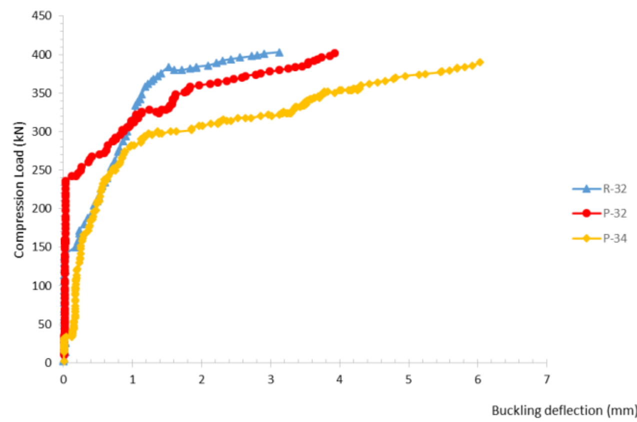


**Figure 6** Buckling deflection

## 5.0 CONCLUSION

The conclusions of this paper are presented as the following:

1. On structural performance, three specimens were selected (R-32, P-32 and P-34) for compressive strength test. Specimen P-32 obtained the highest load which is 402 kN, followed by R-32 and P-34. It can be seen that, again Vf plays an important role in determining the compressive strength.
2. The OPSLC wall panels with a dimension of 500 x 500 x 125 mm thick have the ultimate load in the range of 390–403 kN for all three wall panels. Specimens R-32 obtained the highest strength, followed by P-32 and P-34.
3. The shape of the compressive stress-stain curve of OPSLAC is related to the formation and growth of micro cracks. As ultimate strength is approached, increased load and bulk paste micro cracks join to form continuous cracks parallel to the direction of loading. After 70% from the ultimate loading, the extent of cracking is so great that OPSLC cannot support additional load, and subsequently the stress required for additional strain decreases.

4. On the buckling characteristics, specimen P-34 produced the highest deflection, which is the minor deflection stated at 34 kN, and deflection slowly increased until the ultimate deflection reached 6 mm. Specimen P-32 produced the highest minor deflection effect, which is stated at 240 kN, and increased slowly until ultimate deflection at 402 kN.

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