

## **EFFECTS OF OIL PALM STALK FIBRE BIOMASS WASTE ADDITION ON ENGINEERING PROPERTIES OF LIGHTWEIGHT FOAMED CONCRETE**

Md Azree Othuman Mydin\* & Nurshafikah Nadirah Alias

*School of Housing, Building and Planning,  
Universiti Sains Malaysia, 11800,  
Penang, Malaysia*

*\*Corresponding author: [azree@usm.my](mailto:azree@usm.my)*

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### **ABSTRACT**

The growth of agricultural waste in Malaysia has been one of the focal points today. Generally, the undue agricultural waste is discarded in the landfill without any consideration to the environment. Previous research has found that waste containing highly reactive silica can react with calcium hydroxide in concrete resulting in a compact concrete microstructure. Thus, this paper focuses on the potential utilization of oil palm stalk fibre (OPSF) as an additive in lightweight foamed concrete (LFC) for engineering properties enhancement. The engineering properties evaluated were compressive strength, bending strength, tensile strength, shrinkage and ultrasonic pulse velocity. Four different dosages of OPSF fibre of 0.15%, 0.30%, 0.45% and 0.60% were used as an additive to the LFC mix. The results revealed that the addition of 0.45% OPSF in LFC gave the best results of compressive strength, bending strength, tensile strength, shrinkage and ultrasonic pulse velocity of the LFC. OPSF's surface roughness was proved beneficial for fibre to matrix interfacial bonding since a coarser surface permits OPSF fibre and matrix interlocking in the hardened cement matrix.

**Keywords:** Lightweight foamed concrete, engineering properties, compression, flexural, tensile, porosity, water absorption

### **INTRODUCTION**

Lightweight foamed concrete (LFC) has become more prominent and widespread in expanding the production and range of applications. LFC is considered an economical alternative in the manufacturing of large-scale lightweight construction materials and components, such as structural elements, partitions, filling grades and road embankment infills, owing to its simple manufacturing process, which covers all stages from manufacturing plants to the final position of the applications [1]. For the past 30 years, LFC has principally been utilized for pipeline infill, bulk filling, trench restorations, backfill of retaining walls, insulation to foundations and sandwich filling for prefabricated components [2]. Though, there has been an increasing attention of using LFC as a lightweight semi-structural elements in building construction to take advantage of its lightweight and good insulation properties [3].

Nevertheless, LFC is identified to be a sensibly brittle in nature when exposed to bending and compression stresses, where its bending strength is about one-tenth of its compressive strength [4]. Consequently, LFC bending elements could not support such loads that typically transpire during their service life for these characteristics [5]. In most of the project utilizing LFC, the members were strengthened with continuous reinforcing bars in turn to endure bending and tensile stresses and recompense for the lack of ductility [6]. Additionally, steel reinforcement was employed to overcome high possibly shear and tensile stresses at a critical location in LFC components. Albeit the inclusion of steel reinforcement upsurges the strength of LFC, the development of micro-cracks desires to be controlled to produce LFC with regular tensile properties [7].

Thus, natural fibre is seen as a solution to develop LFC with improved bending and tensile strength, which is a new form of binder that can combine Portland cement in bonding with cement matrices [8]. These natural fibres are mostly discontinuous, randomly distributed throughout the cement matrices. The inclusion of natural fibres in LFC is to delay and control the tensile cracking of composite material. Fibres thus alter the intrinsic unbalanced tensile crack spread to slow controlled crack development [9]. Hence this study investigates the potential use of oil palm stalk fibre biomass waste as additive in LFC for engineering properties enhancement.

## **EXPERIMENTAL METHODS**

### *Material Preparations*

LFC is a mixture of lightweight cellular mortar with the addition of stable foam. Ordinary Portland Cement (OPC), filler (fine sand), water and preformed surfactant are the main materials used to fabricate LFC. Type 1 Portland Cement (CEM1) was utilized in accordance to British Standard BS12 [10] and a portable foaming generator is used to produce the stable foam. In this assessment, a synthetic foaming agent was used produce the foam. Furthermore, the fine filler (sand) was utilized obtained from a local distributor. The suitable size of fine sand used was 1.18 mm using a sieving machine in accordance to BS882 [11]. Clean water free from any debris and other organic materials was used. The water-cement ratio was fixed at 0.45. Oil palm stalk fibre (OPSF) used in this research was collected from local farm in Seberang Jaya, Penang and undergo mechanical refinement process to produce 19mm in length OPSF. The volume fraction of the OPSF used were 0.15%, 0.30%, 0.45% and 0.60% of the total weight mix volume. Figure 1 shows the prepared LFC specimens. Tables 1, 2 and 3 show the physical properties, chemical composition and mechanical properties of OPSF correspondingly.

### *Mix Design*

For this research, five mixes were prepared. The density chosen was  $1000 \text{ kg/m}^3$ . The volume fraction of OPSF were 0.15%, 0.30%, 0.45% and 0.60%. For all the LFC mixes, the sand-cement ratio was fixed at 1:1.5, and the water-cement ratio was 0.38. Table 4 demonstrates the mix proportion considered in this study.



Figure 1: LFC specimens prepared in this study

Table 1: Physical properties of OPSF

| Element                    | Properties |
|----------------------------|------------|
| Length/mm                  | 19         |
| Diameter/ $\mu\text{m}$    | 31.8       |
| Runkel ratio               | 0.287      |
| Lumen Width/ $\mu\text{m}$ | 17.54      |
| Fibril Angle/degree        | 42         |
| Density/ $\text{g/cm}^3$   | 0.73       |

Table 2: Chemical composition of OPSF

| Composition   | Dry weight/% |
|---------------|--------------|
| Cellulose     | 28.7         |
| Hemicellulose | 16.8         |
| Holocellulose | 40.2         |
| Lignin        | 20.4         |
| Xylose        | 15.8         |
| Glucose       | 28.5         |
| Ash           | 2.5          |

Table 3: Mechanical properties of OPSF

| Element                   | Properties |
|---------------------------|------------|
| Tensile strength/MPa      | 80.8       |
| Modulus of elasticity/GPa | 5.63       |
| Elongation at break/%     | 14.34      |

Table 4: Mix proportions

| Specimen    | Mix Density/kgm <sup>-3</sup> | Mix Ratio<br>(s:c:w) | Cement/kg | Fine sand/kg | Water/kg |
|-------------|-------------------------------|----------------------|-----------|--------------|----------|
| Control mix | 1000                          | 1:1.5:0.4            | 45.74     | 68.61        | 18.29    |
| 0.15% OPSF  | 1000                          | 1:1.5:0.4            | 45.74     | 68.61        | 18.29    |
| 0.30% OPSF  | 1000                          | 1:1.5:0.4            | 45.74     | 68.61        | 18.29    |
| 0.45% OPSF  | 1000                          | 1:1.5:0.4            | 45.74     | 68.61        | 18.29    |
| 0.60% OPSF  | 1000                          | 1:1.5:0.4            | 45.74     | 68.61        | 18.29    |

### Test Methods

#### Compression test

The compression test was conducted according to BS12390-3 standard [12] via GoTech GT-7001-BS300 Universal Testing Machine. The sample size was 100 mm × 100 mm × 100 mm cube. The maximum load and compressive strength were recorded.

#### Bending Test

In order to accomplish this particular test, three-point bending test was opted in accordance to ASTM International C293 standard [13]. The sample size was 100 mm × 100 mm × 500 mm prism using GoTech GT-7001-C10 Universal Testing Machine to determine the bending stress.

#### Tensile Test

Tensile strength test of LFC was performed using GoTech GT-7001-BS300 Universal Testing Machine. The maximum load and splitting tensile strength were recorded in accordance to ASTM International C496 standard [14]. The specimen size was 100 mm in diameter × 200 mm in height cylinder.

#### Shrinkage Test

The shrinkage test was done according to ASTM International C878 standard [15]. The sample size was 75 mm × 75 mm × 275 mm prism. A spherical gauge plugs were attached at both ends of the specimens to facilitate length change measurements.

#### Ultrasonic Pulse Velocity Test

The ultrasonic pulse velocity (UPV) test was performed by measuring the propagation velocity of a transmitted longitudinal ultrasonic pulse across the cross-sectional area. The transducers were placed for testing at a length of 0.5 m in accordance to BS12504-4 standard [16]. The sample size was 100 mm × 100 mm × 500 mm prism.

## RESULTS AND DISCUSSION

### Bending Strength

Figure 2 shows the result of the bending strength of LFC with the inclusion of different dosages of OPSF. The graph shows that 0.45% OPSF dosage contributed to the highest

bending strength, which is  $0.99 \text{ N/mm}^2$  at day 28. The bending strength is further increased to  $1.22 \text{ N/mm}^2$  at day 56. This trend shows that OPSF also plays an important role for long-term bending strength development. OPSF is a strengthening medium, given its decomposable characteristics. OPSF also poses high failure strain which can give greater compatibility between the fibres and the cement matrix [17]. The bending strength of LFC declines when surpassing 0.45% of OPSF dosage due to incomplete composite bonding between fibres and cement matrix of LFC. Additionally, the lowest bending strength was for the control sample which recorded readings of  $0.58 \text{ N/mm}^2$ ,  $0.68 \text{ N/mm}^2$  and  $0.77 \text{ N/mm}^2$  at day 7, day 28 and day 56 correspondingly.

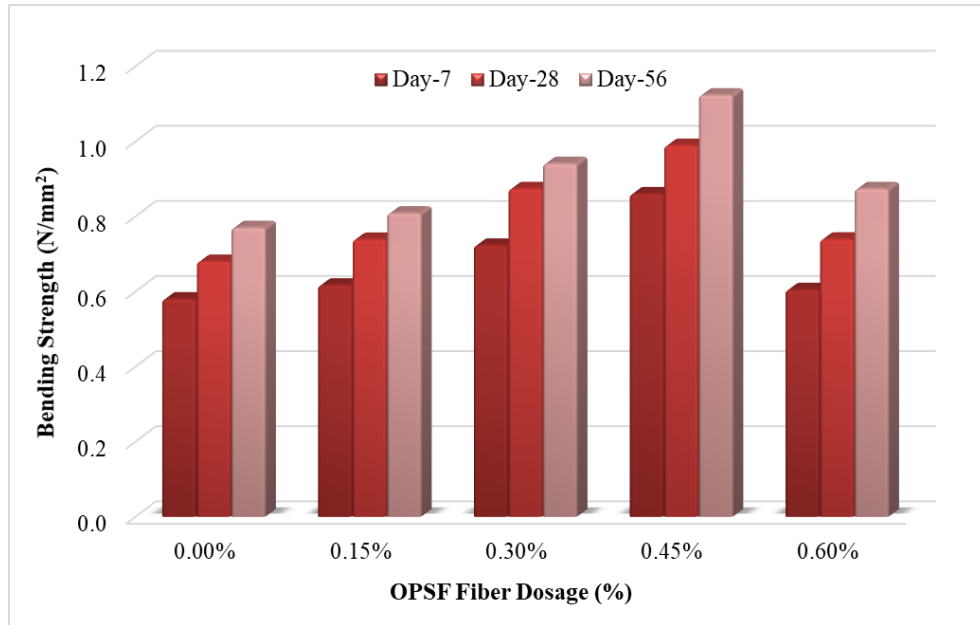


Figure 2: Bending strength of LFC with different OPSF dosage

### Compressive Strength

Figure 3 shows the result of the compressive strength with the addition of different dosages of OPSF. It can be clearly seen from Figure 3 that the control sample (without any OPSF addition) has lower compressive strength compared to the LFC with the inclusion of OPSF. The development of the compressive strength was studied from day 7 to day 56. The highest result of compressive strength was achieved with the addition of 0.45% OPSF compared to other dosages of OPSF, which was  $3.85 \text{ N/mm}^2$  at day 56. Hence, the OPSF fibre aided in stopping the propagation of micro-crack in the plastic state of LFC cement matrix when the load was applied. Moreover, the lowest result of compressive strength, the control specimen, was  $3.24 \text{ N/mm}^2$  at day 56. From Figure 3, it clearly shows that specimens with 0.45% of OPSF give the optimum compressive strength and the strength dropped when the OPSF dosage is further from 0.45% to 0.60%. The decrease in compressive strength when up to certain fibre content may be triggered by the creation of air void within the mixture with high fibre volume fraction [18].

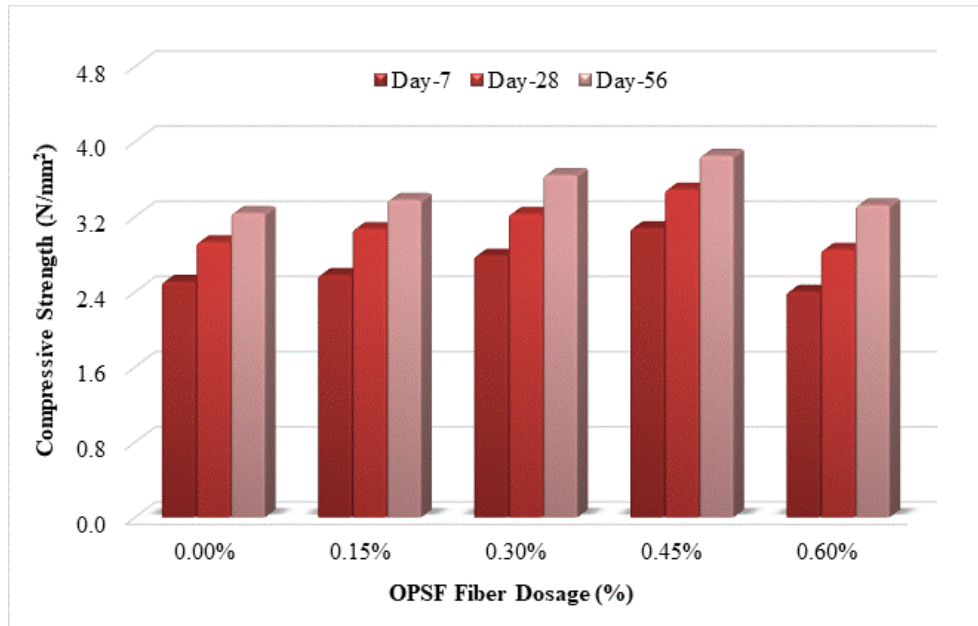


Figure 3: Compressive strength of LFC with different OPSF dosage

### *Tensile Strength*

Figure 4 demonstrates the result of the tensile strength of LFC with the addition of different dosages of OPSF. It can be seen from Figure 4 that LFC without addition of OPSF has lower tensile strength compared to the LFC with the inclusion of OPSF. Figure 4 visualizes that 0.45% OPSF dosage contributed to the highest tensile strength, which were 0.59 N/mm<sup>2</sup>, 0.71 N/mm<sup>2</sup> and 0.81 N/mm<sup>2</sup> at day 7, day 28 and day 56 correspondingly. Besides, the lowest result for the tensile strength for the control sample was 0.36 N/mm<sup>2</sup>, 0.42 N/mm<sup>2</sup> and 0.48 N/mm<sup>2</sup> at day 7, day 28 and day 56 respectively. It should be pointed out that the elongation at break for oil palm stalk fibre is low, resulting in high tensile strength. Elongation at break expresses the ability of the natural fibre to resist changes of shape without formation of crack [19]. Natural fibre such as oil palm fibre is considered stiff, therefore contributes to enhancing the tensile strength of LFC. The utilization of 0.45% of OPSF is considered as an optimal dosage for this type of concrete based on the increment of the tensile strength.

### *Shrinkage*

Figure 5 demonstrates the result of the shrinkage for LFC with different dosages of OPSF. The shrinkage of LFC with the inclusion of OPSF was found to upsurge significantly until day 28 of the testing age. It can be seen from Figure 5 that all shrinkage in the LFC with the inclusion of OPSF slightly increases after day 28 until day 60. This is due to the concrete specimens' condition during the first seven days, which were not fully hardened, while on day 28 onwards, the concrete specimens hardened totally, therefore reducing the shrinkage in the concrete. OPSF responds as an aggregate that gives the dense configuration of the microstructure, which diminishes the size of the voids, hence refining the shrinkage [19]. Based on Figure 5 the control mix experienced highest shrinkage. Markedly, high reading of shrinkage is not good for

concrete since it can cause cracks in the future.

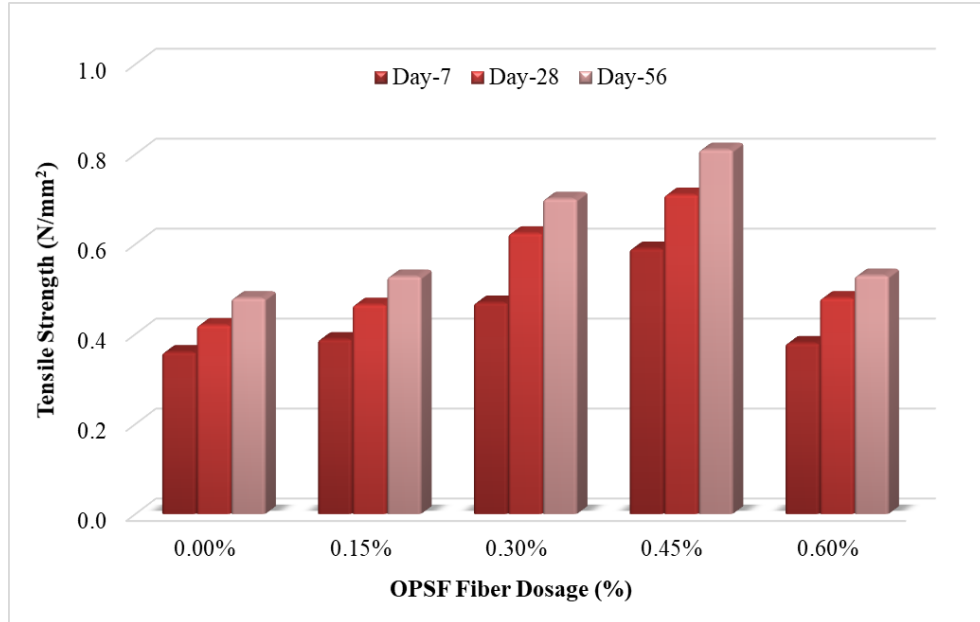


Figure 4: Tensile strength of LFC with different OPSF dosage

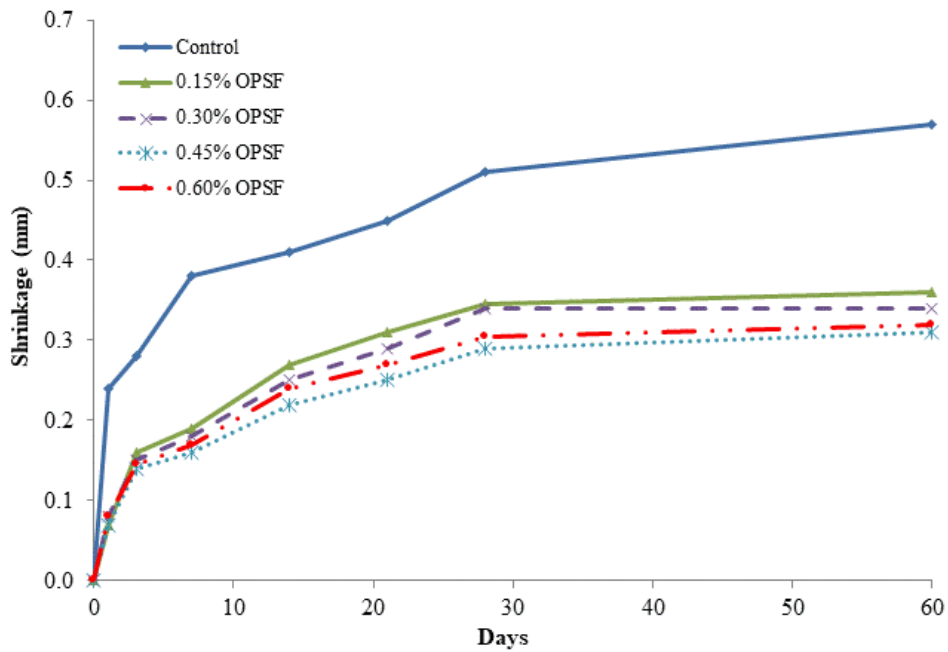


Figure 5: Shrinkage of LFC with different OPSF dosage

### *Ultrasonic Pulse Velocity*

An ultrasonic pulse velocity test was conducted to establish the quality of LFC. Figure 6

shows the ultrasonic pulse velocity result of LFC with different dosages of OPSF. From Figure 6, we can conclude that the concrete does not contain large voids or cracks, which would no doubt affect its structural integrity. The 0.45% OPSF dosage contributed to the best result of ultrasonic pulse velocity of 2374 m/s. The control specimen only recorded a reading of 2205 m/s for the ultrasonic pulse velocity. Concrete with an ultrasonic pulse velocity reading between 3500-4000 m/s is in the range reflecting good to a very good type of concrete. LFC poses low ultrasonic pulse velocity reading due to its lower density compared to normal strength concrete.

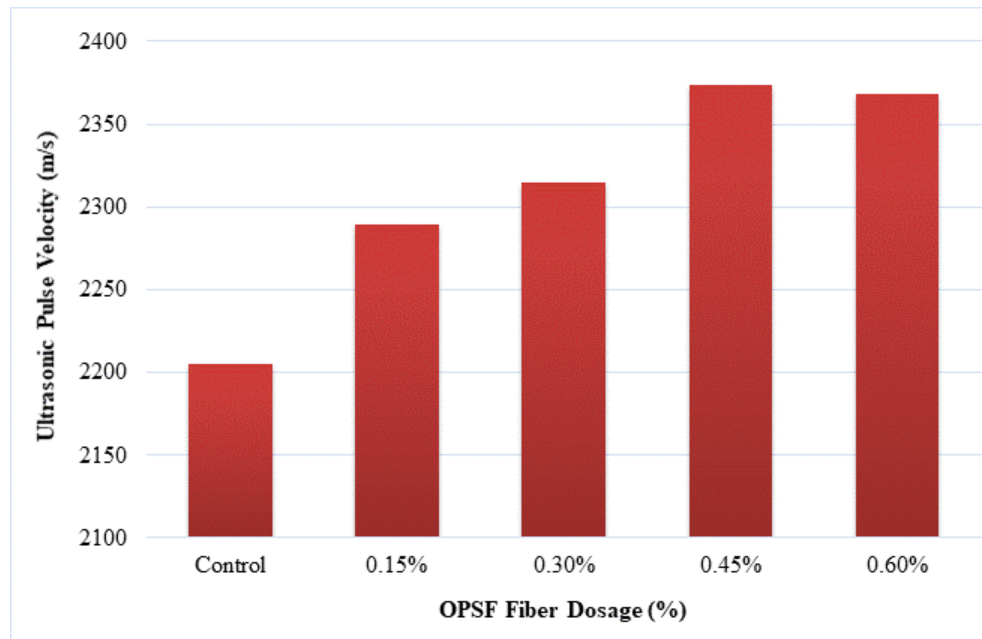


Figure 6: Ultrasonic pulse velocity of LFC with different OPSF dosage

## CONCLUSION

The conclusions that can be withdrawn from this research are 1) OPSF of 0.45% was the optimum dosage in LFC that gave excellent compressive strength, bending strength, tensile strength, drying shrinkage and ultrasonic pulse velocity, 2) OPSF aided in stopping the promulgation of micro-crack in the plastic state of LFC cement matrix when the load was applied, 3) OPSF poses high failure strain which can give greater compatibility between the fibres and the cement matrix and finally 4) OPSF responds as an aggregate that gives the dense configuration of the microstructure, which diminishes the size of the voids, hence refining the shrinkage.

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