

INFLUENCE OF OIL PALM SPIKELETS FIBRE ON MECHANICAL PROPERTIES OF LIGHTWEIGHT FOAMED CONCRETE

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Abstract — As issues related to sustainable construction in Malaysia gains more importance, research on the utilization of waste by products especially from oil palm in concrete is vigorously implemented. Utilization of different parts of oil palm fibres in lightweight foamed concrete have garnered positive outcomes in terms of conservation of natural resources, lessening of environmental problem and can improve concrete's durability and mechanical properties. Lightweight foamed concrete (LFC) is well-known as a low-density concrete with a wide range of applications. It is good in compression but poor under flexural load, as it produces multiple microcracks and cannot withstand the additional stress induced by applied forces without supplementary reinforcing elements. Hence this study was performed to examine the potential use of oil palm spikelets fibre (OPSF) in LFC in order to improve its engineering properties. LFC specimens were strengthened with OPSF fibre at different percentages of 0.15%, 0.30%, 0.45%, and 0.60%. LFC density of 1000 kg/m³ was prepared with a constant cement-to-sand ratio of 1:1.5, and cement-to-water ratio of 0.45. The parameters that had been evaluated were flexural strength, compressive strength and splitting tensile strength. The results revealed that the addition of 0.45% of OPSF fibre gave the best compressive, bending and splitting tensile strengths result. OPSF fibre in LFC aided to evade the promulgation of cracks in the plastic state in the cementitious matrix.

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Keywords: lightweight foamed concrete, oil palm waste, spikelets fibre, flexural strength, compressive strength, tensile force

1.0 INTRODUCTION

Though lightweight foamed concrete (LFC) has been extensively studied, some limitations such as low flexural strength still restrict its wider applications. The strength of LFC is determined by different cementitious materials, cement dosage, mix proportion, water-cement ratio, foam volume, foaming agent, curing method, additive, and addition of waste by-product [1]. To a certain extent, the density controls the strength of LFC. Therefore, it is always to seek a balance between strength and density, for the purpose to maximize strength while reducing density as much as possible. Sometimes, this can be achieved through optimizing cementitious materials and selecting high-quality foaming agents and ultralight aggregates. The filler types and inclusion of oil palm biomass will influence the water-solid ratios when concrete density is constant, and the reduction of sand particle size will help to improve strength [2]. The pozzolanic effect of fibre biomass waste is to react with the secondary product, Ca(OH)₂ (calcium hydroxide, also known as portlandite), of cement hydration to form additional C-S-H gel (secondary C-S-H). During the pozzolanic reaction, the longer silicate chains are formed as the Ca:Si molar ratio of C-S-H drops. This secondary C-S-H reduces the porosity in bulk cement paste and improves the interfacial bond between aggregate particles and fibre, thus increases the strength, density, and ion diffusion resistance of LFC [3]. Lately, LFC has gained major attention among the industrial players and building material manufacturers owing its excellent thermal and mechanical properties such as high flowability, low self-weight, good thermal performance and sound insulation properties [4]. Besides, LFC is an environmentally friendly building material because of its minimal usage of aggregate and high potential to integrate waste material such as natural fibres. LFC is a mixture of cement paste (slurry) and homogeneous foam introduced using a suitable foaming agent, which can be regarded as self-compacting materials [5]. LFC has an air content of more than 25% by volume, thus, distinguishing itself from highly air entrained materials. Even though increasing consideration has been given to LFC worldwide, its application in the context of Malaysian construction industry is still in its infancy [6]. However, it has been utilized in several housing and void filling project in Malaysia. Hence this research was performed to inspect the potential utilization of OPSF in LFC to improve its mechanical properties.

2.0 MATERIALS AND METHODS

2.1. Materials

There were 5 main materials been used to fabricate LFC which were ordinary Portland cement (OPC), fine sand, surfactant, water, and the additive which was oil palm spikelets fibre. The OPC was supplied by YTL Castle Cement Marketing. All the cement used was in good condition and stored in a covered area. The fine sand utilized in this study was natural fine sand which was obtained from the local supplier. This fine sand had a maximum width of 2mm and a 600-micron sieve, and a passage of 60% to 90%. The suitability of the sand had to follow BS822:1992 [7]. To produce stable foam, a protein-based foaming agent was used, precisely Noraite PA-1. The foam was produced by a portable foaming generator machine, namely the Portafoam TM-1 machine. The water-cement ratio used for this research was 0.45, because this ratio can achieve reasonable workability [6]. Finally, the fibre used was oil palm spikelets fibre (OPSF), which was obtained from local farm in Seberang Jaya, Pulau Pinang after processing. The OPSF was placed under the sun to dry as shown in Figure 1. Next, Figure 2 shows the surface morphology details of OPSF. Table 1 shows the chemical composition and mechanical properties of OPSF used in this investigation.



Figure 1 Raw OPSF

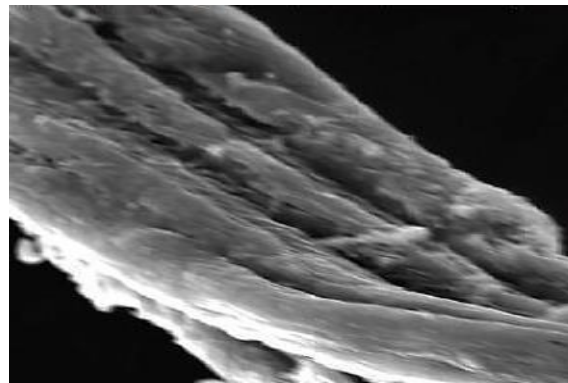


Figure 2 Surface morphology of OPSF

Table 1 Mechanical properties and chemical composition of OPSF

Composition (units)	Value
Cellulose (%)	27.7
Hemicellulose (%)	31.4
Lignin (%)	28.5
Extractives (%)	2.3
Density (g/cm ³)	0.94
Length (mm)	19
Diameter of fibre (µm)	12.45
Diameter of lumen (µm)	6.81
Tensile strength (MPa)	139
Elongation at break (%)	11.41
Young's modulus (GPa)	12.9

2.2. Mix Design

For this investigation, a total of five mixes and a density of 1000 kg/m³, were prepared accordingly. The percentages of the OPSF used were 0.15%, 0.30%, 0.45% and 0.60%. These four percentages were opted because during the pilot study, the authors had found that beyond 0.60% addition of OPSF, homogenous mix can't be obtained and the foam that was added in the mix quickly broken down. For entire mix, the sand-cement ratio utilized was 1:1.5 and the water-cement ratio used was kept constant at 0.45. Table 2 demonstrates the mix design of LFC of this study.

Table 2 LFC mix design

Density (kg/m ³)	OPSF (%)	Mix Ratio	Cement (kg)	Sand (kg)	Water (kg)
1000	-	1:1.5:0.45	37.47	56.20	16.86
1000	0.15	1:1.5:0.45	37.47	56.20	16.86
1000	0.30	1:1.5:0.45	37.47	56.20	16.86
1000	0.45	1:1.5:0.45	37.47	56.20	16.86
1000	0.60	1:1.5:0.45	37.47	56.20	16.86

2.3. Experimental Setup

Tests were carried out investigating the mechanical properties with the inclusion of OPSF which includes flexural test, compression test and splitting tensile test.

2.3.1 Flexural test

For the flexural test, prism of 100mm x 100mm x 500mm was utilized according to ASTM C293 / C293M [8]. Three-point flexural test was opted to obtain the flexural strength of LFC. Three specimens were prepared, and test and average result of flexural test was taken as final result. Figure 3 shows the setup for the flexural test.



Figure 3 Flexural test of LFC

2.3.2 Compression test

The specimen size for compression test is 100mm x 100mm x 100mm cube which was performed according to BS EN 12390-3 [9] standard. Figure 4 shows the arrangement of the compression test.



Figure 4 Compression test of LFC

2.3.3 Splitting tensile test

As for splitting tensile strength, cylinder of 100mm diameter x 200mm height was considered according to ASTM C496/C 496M [10] standard. Three specimens were prepared and test and the average reading from these three results of flexural test was taken as the final result. Figure 5 shows the setup for the flexural test. The cylindrical specimen was clamped properly to ensure equal distribution of tensile load during the test.



Figure 5 Splitting tensile test arrangement

3.0 RESULTS AND DISCUSSION

3.1. Flexural Strength

Generally, the flexural strength of LFC with the inclusion of OPSF fibre show trend of increment spite of the percentages of fibre included into LFC. Fig. 6 shows the result of flexural strength attained for the 1000 kg/m³ LFC considered in this study. The control mix showed the lowest flexural strength display only a slight increment along with the testing age from day-7 to day-60. Though, LFC specimens with the addition of OPSF fibre show a significant increment in flexural strength by the testing age. At day-28, the flexural strength of control LFC was 2.86 N/mm². The optimum percentage of OPSF fibre that gave the best result of flexural strength was 0.45%. The highest flexural strength accomplished at day 60 were 3.99 N/mm² with the presence of 0.45% percentage of OPSF. Nevertheless, undue OPSF percentage included into LFC (more than 0.45%) may lead to reducing the bonding between the cement matrix and the fibre [11,12]. Utilization of a 0.45% volume fraction of OPSF can be considered an optimal percentage for this type of concrete based on the increment of results obtained. High flexural strength attained is due to the reduction of porosity in LFC mixes.

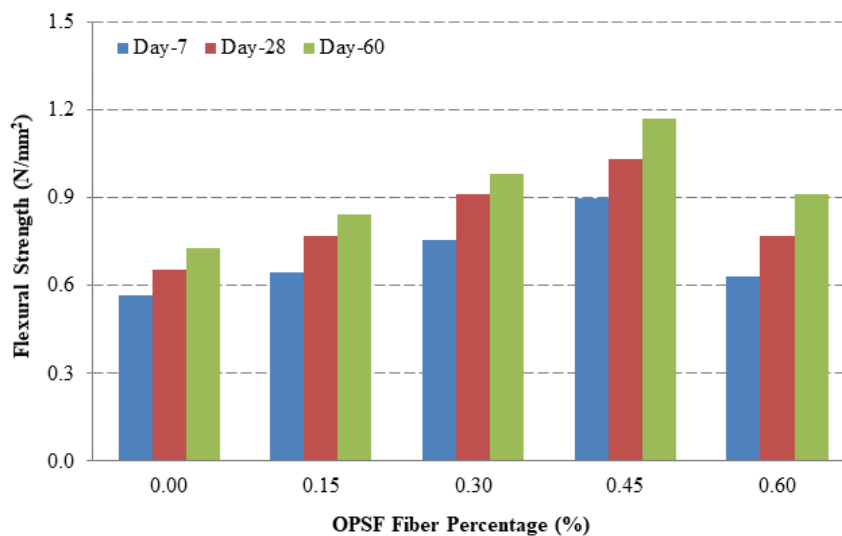


Figure 6 Bending strength of LFC with different percentages of OPSF

3.2. Compressive strength

Fig. 7 shows the results of the compressive strength with different percentages of OPSF. Same as flexural strength, the optimum percentage of OPSF that gave the best compressive strength was 0.45%. The highest compressive strength achieved at day-28 was 3.59 N/mm², with the addition of 0.45% of OPSF fibre compared to control sample which only achieved compressive strength of 2.86 N/mm². Above 0.45% of OPSF addition, non-uniform scattering of fibres was detected, which resulted in the lessening of the compressive strength. At the optimum level of fibre addition, OPSF and the LFC cementitious matrix reached maximum compaction, which lead to excellent mix consistency [13,14]. As LFC encompasses of large void size in the matrix, micro cracks will take place at the transition zone between the LFC matrix [15,16].

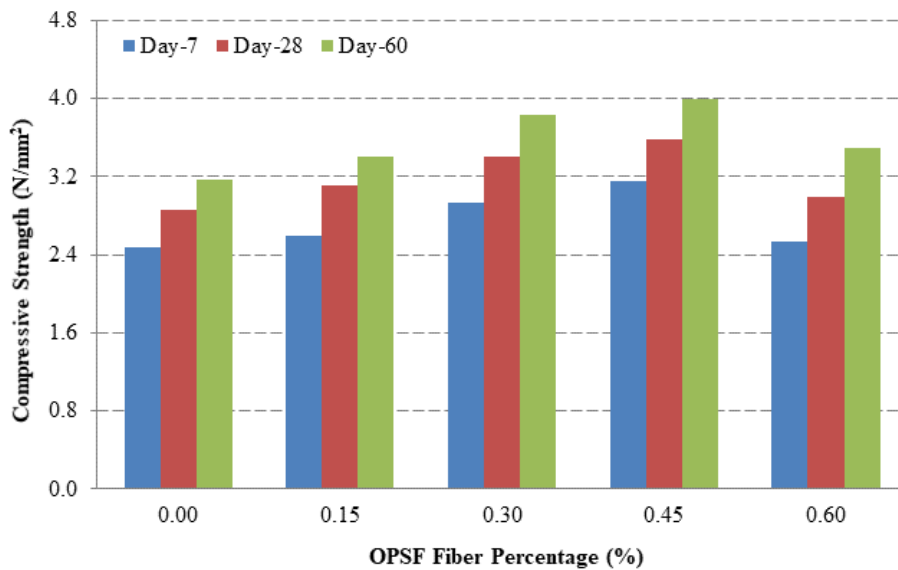


Figure 7 Compressive strength of LFC with different percentages of OPSF

3.3. Splitting Tensile Strength

Figure 8 visualized the results of splitting tensile strength of LFC with different percentages of OPSF. The highest splitting tensile strength attained at day-28 was 0.72 N/mm² with the addition of 0.45% OPSF compared to control specimen (with no fibre inclusion) which only reached compressive strength of 0.41 N/mm². Beyond the optimum level of OPSF inclusion, agglomeration of fibres was observed, which results in the drop of tensile strength (at 0.6% volume fraction of OPSF fibre). The data attained in this study specifies that the addition of OPSF boosts the tensile strength of LFC irrespective on any percentages of OPSF fibre [17, 18].

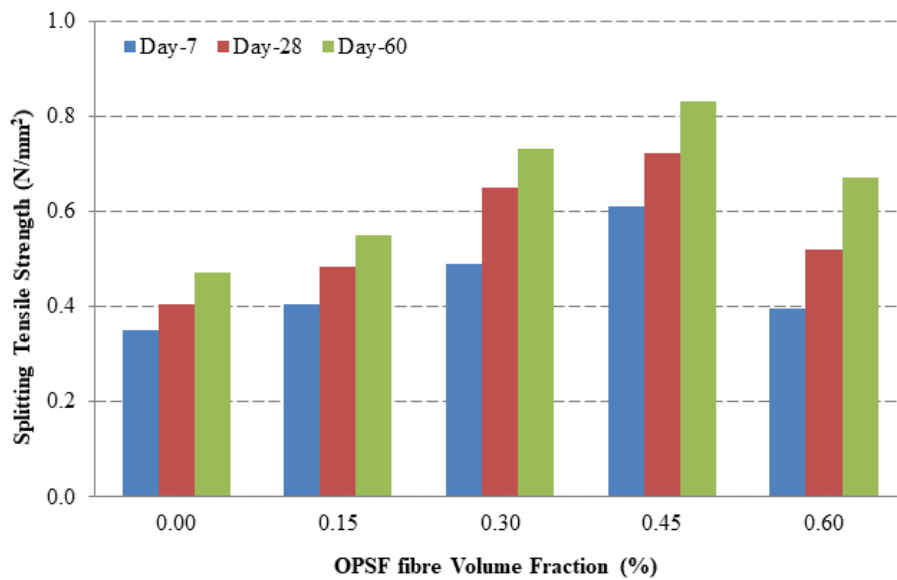


Figure 8 Splitting tensile strength of LFC with different percentages of OPSF

3.4 Performance Index (PI)

The axial compressive strength and dry density of LFC has correlated relationship. In theory, higher density of LFC will lead to higher compressive strength [19,20]. The density of LFC for this research was control to within 1000 kg/m^3 . As the density for each sample was varying, the performance index of LFC was considered to enhance the precision of the results attained from the experimental work. Figure 9 displays the performance index (PI) of the LFC considered in this study. It can be seen that parallel tendency was reached by performance index, in which the performance index is unswervingly proportionate to the specimen's age of curing. The 60-day PI was attained by LFC with 0.45% inclusion of OPSF, which was 4.20 N/mm^2 per 1000 kg/m^3 .

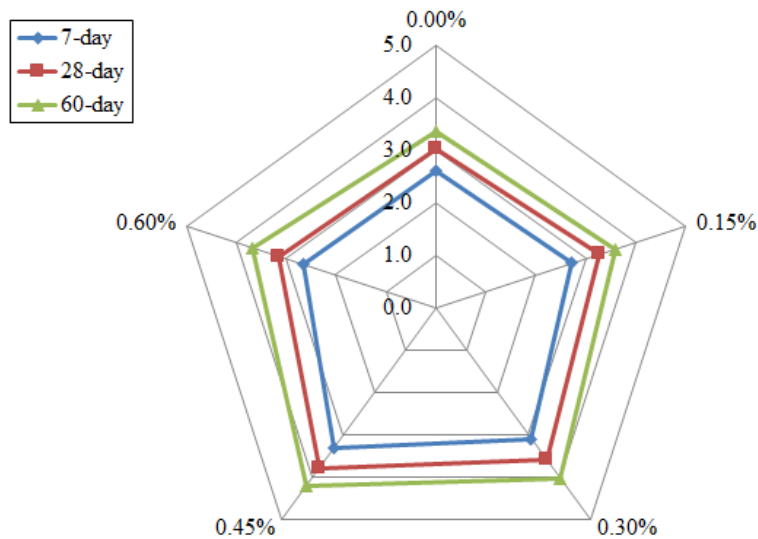


Figure 9 Performance index of LFC of different OPSF percentages

4.0 CONCLUSION

From the results obtained from this study, it can be summarized that the strength of LFC improved with the inclusion of OPSF. Though, the different percentages of OPSF included in LFC gave a different result on the mechanical properties of LFC. Overall, 0.45% of OPSF in LFC gave an outstanding flexural strength, compressive

strength and splitting tensile strength compared to other percentages considered in this study. OPSF-matrix interface bonding, which is regarded as a coarser surface, is helpful given its surface roughness. Hence, it empowers the OPSF fibre, and matrix mechanical interlocking, thus refining the mechanical properties of LFC.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper

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