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ABSTRACT

Incorporation of natural fiber can give useful enhancements to the concrete mechanical properties. Compressive strength and flexural strength development of lightweight foam (LFC) concrete reinforced with palm fibre cured in water was investigated at different ages. LFC was maintained at a plastic density of 900, 1000 and 1100 kg/m^3 with a variation of ±50 kg/m^3, and a constant water-binder ratio of 0.5 was used for all mixes. Palm fiber was introduced into the LFC at 0.5%, 1.0% and 1.5% by weight of cement. Tests results showed that the use of the palm fiber increases the density of lightweight concrete, the compressive strength and flexural strength of LFC increased as a result of increasing the percentage at which palm fiber was used to addition to the mixes. The results indicated that the use of palm fiber with LFC enhances the compressive strength and flexural strength mechanical properties of the concrete and the optimization of the palm fiber additions is required to get the best performance.

KEYWORDS: Palm fiber, Reinforce fibre, Compressive strength, Flexural strength, Lightweight foam concrete.

1. Introduction

The future needs for construction materials of foresight groups around the world have identified that are simple to use, light, durable, economic and environmentally sustainable. Although reinforced autoclaved aerated concrete panels are available, these are controlled by the requirements of factory autoclaving and, as a consequence, in size, although modern developments have allowed much larger sections to be manufactured. An alternative way, however, that has the potential to fulfil all these requirements is lightweight foamed concrete (LFC) [1]. Nowadays with the advancement of technology, LFC becomes an innovation product for the construction sector which offers advantages such as light densities ranging from 400 to 1600 kg/m^3. LFC is produced through a very economical and controllable cell-forming process known as preformed foaming. This process relies on a hydrolyzed protein foaming agent. In terms of composition, LFC comprises cement, fine sand, and preformed foam a combination that gives rise to unique properties, such as low density and a flowing and self-compacting rheology [2]. LFC is recognized for its high flowability, low cement content, low aggregate usage, and excellent thermal insulation. Furthermore, LFC is considered as an economical solution in fabrication of large scale lightweight construction materials and components such as structural members, partitions, filling grades, and road embankment infills due to its easy production process from manufacturing plants to final position of the applications [3]. In the other hand, the low elastic modulus of the aggregate and high cement usage in the production of LFC has generally increased the drying shrinkage of LFC. The inclusion of fibre into LFC is one approach to enhance its durability properties. The inclusion of low volumetric fractions of short fibre has been proven to reduce the impact of early age shrinkage on concrete durability [4].

Palm oil has become the world's leading vegetable oil in terms of consumption and production with 55.1 million tons produced worldwide in 2013. The biggest producer, with a 48.8% share in production in 2013, was Indonesia, followed by Malaysia (34.8%) and Thailand (3.5%) [5]. In 2016, Office of Agricultural Economics of Thailand forecasting that the total oil palm planted area was 4.5 million rais, and production was 11.68 million tonnes [6]. Approximately 8.1 million tonnes of solid waste by products in the form of fibers, kernels and empty fruit bunches were produced annually. The idea of reinforcing concrete with date palm surface fibres was studied by Kirker et al. [7], the increasing of the length and percentage of fibre-reinforcement in both water and hot dry curing, was found to improve the post-crack flexural strength and the toughness coefficients. In addition, the inclusion of the fiber increases the compressive strength, flexural strength and durability of the mortar and high strength flowable mortar mixes [8-10].

This research aims to study and develop fibre-reinforcement in lightweight foamed concrete made from oil palm fiber. The choice of material is expected to be widely used in the markets of Thailand, and to turn its abundant supply of oil palm industry byproducts that often create environmental problems into value-added product.

2. Materials and methods

2.1 Materials

Ordinary type I Portland cement (OPC) conforming to ASTM C150 [11] was used in this study. OPC had a specific gravity of 3.15, specific surface area (determined by the BET N_2 method) of 810 m^2/kg, and mean particle size of 22.65 μm. Chemical composition and physical properties of the OPC and mineral admixtures are given in Table 1. Natural fiber was palm fiber, which was cut to an average length of 10 mm. Raw fibers were pretreated by washing with water and boiling in water for 3 h to eliminate water-soluble chemicals. The specimen was kept saturated with water for 24 h. Natural river sand fine aggregate was used in this study. The fine aggregate had a specific gravity of 2.67, water absorption content of 0.71%, fineness modulus of 2.76, and bulk density of 1,640 kg/m^3. The particle size distribution met the concrete aggregate specifications of ASTM C33 [11]. A commercially available protein-type surfactant with a specific gravity of 1.02 was used to produce preformed foam. Mixing water was discharged into the mixer from the municipal water supply.

Table 1 Chemical composition of OPC (%wt.).

Materials	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	SO_3	LOI
OPC	20.22	4.49	61.42	3.20	0.54	1.03	0.28	4.18	4.07

2.2 Mix proportions.

The mix proportions of the 900, 1000 and 1100 kg/m^3 plastic density foamed concretes with a variation of ±50 kg/m^3, which are summarised in Table 1, were calculated by equating the design plastic density value to the cement, fine aggregate and water in the mix. Twelve LFC mixtures were prepared by progressive incorporation of palm fiber, with binder contents of 360-440 kg/m^3. Palm fiber was adding at 0.5%, 1%, and 1.5% by weight of OPC. The binder/sand ratio was 1:1, In Europe, foamed concrete is generally produced with a sand/binder proportion of 1:1 to 4:1 [3]. To ensure that sufficient free water was used in the mix to 'wet' the surface area of the fine particles [1], a water/binder (W/B) mass ratio of 0.5 was used for all mixtures. Foaming agent was diluted with water at a mass ratio of 1:30, as recommended by the manufacturer. This diluted foaming agent was added and mixed until a uniform LFC was obtained. DxFy denote x in which the plastic density of foamed concrete and y is the palm fiber addition, respectively.

Table 2 Mix proportions of the 900, 1000 and 1100 kg/m^3 LFC used to prepare the test specimens.

Design plastic density (kg/m^3)	Symbol	Materials (kg/m^3)			
		Cement	Palm fiber	Fine aggregate	Water
900	D900F0	360	-	360	180
	D900F0.5	360	1.8	360	180
	D900F1.0	360	3.6	360	180
	D900F1.5	360	5.4	360	180
1000	D1000F0	400	-	400	200
	D1000F0.5	400	2.0	400	200
	D1000F1.0	400	4.0	400	200
	D1000F1.5	400	6.0	400	200
1100	D1100F0	440	-	440	220
	D1100F0.5	440	2.2	440	220
	D1100F1.0	440	4.4	440	220
	D1100F1.5	440	6.6	440	220

2.3 Test procedures

The plastic density of the LFC was measured in accordance with ASTM C138 [11], with the goal of achieving values within a target range. For the compressive strength and flexural strength tests 100 mm cubes and 75 x 75 x 250 mm prisms were prepared, respectively. The samples were water cured until the test day. Three samples were tested on each testing day and their average was taken as the final value. The compressive strength test was carried out at 3, 7, 14 and 28 days with BS EN 12390-3 [12]. During the same testing period, flexural strength was subjected to center-point loading in accordance with ASTM C293 [11].

3. Results and discussion

3.1. Plastic density

The fresh density value is required for mix design and casting control purposes. Densities of the design mixture were 900, 1000 and 1100 kg/m^3. The acceptable variation between the design and the achieved densities was fixed at ±50 kg/m^3 [1-2]. Figure 1 shows the results of the fresh density of LFC mortars, in which palm fiber was added at 0%, 0.5%, 1% and 1.5%. When palm fiber was added at 0-1.5% by weight of cement, density increased by 0-6% with a plastic density of 900 kg/m^3, 0-15% with a plastic density of 1000 kg/m^3, and 0-24% with a plastic density of 1100 kg/m^3. Addition of the palm fiber affected the plastic density of the LFC specimen significantly. This significant change was due to the variable adding palm fiber was higher in the volumetric quantity of LFC [3]. This effect can also be attributed to the reduction of air in the mix when palm fiber was included [9].

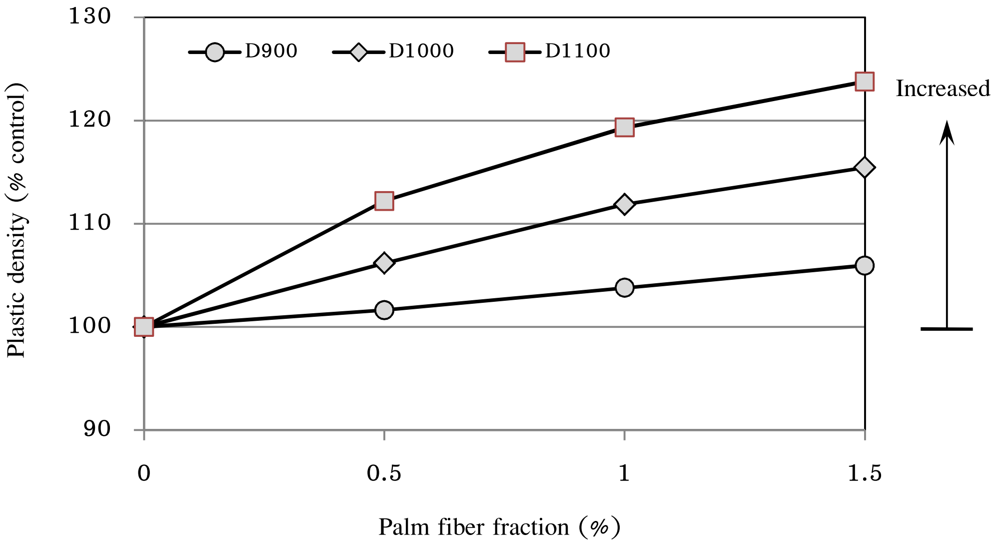

Figure 1 Plastic density of LFC mixtures.

3.2 Compressive strength

The compressive strength results are shown in Figure 2-4. The compressive strength of a specimens 100-mm cube continued to increase over the 28-day curing period. A plastic density of 900 kg/m^3 shows the compressive strength ranged from 8.60 to 10.01 ksc at 3 days, from 9.43 to 11.42 ksc at 7 days, from 10.99 to 13.46 ksc at 14 days, and from 11.13 to 14.12 ksc at 28 days the palm fiber addition increased from 0% to 1.5%, respectively (Figure 2). A plastic density of 1000 kg/m^3 shows the compressive strength ranged from 9.89 to 11.11 ksc at 3 days, from 10.45 to 12.34

ksc at 7 days, from 11.76 to 14.67 ksc at 14 days, and from 12.78 to 16.89 ksc at 28 days the palm fiber addition increased from 0% to 1.5%, respectively (Figure 3). And a plastic density of 1000 kg/m^3 shows the compressive strength ranged from 14.34 to 17.56 ksc at 3 days, from 15.43 to 20.56 ksc at 7 days, from 16.56 to 23.49 ksc at 14 days, and from 17.45 to 24.98 ksc at 28 days the palm fiber addition increased from 0% to 1.5%, respectively (Figure 4).

It is observed that compressive strength has a direct relationship with density where a reduction in density exponentially and adversely affects the compressive strength [3]. As expected, the compressive strength increased with increasing plastic density, due to the increase in paste volume and the lower pore volume associated with increasing plastic density [2].The addition of palm fiber at 0%, 0.5%,1% and 1.5% in the matrix exhibited improvement in the compressive strength. It can be concluded that the increase of palm fiber increase the compressive strength due to the reduction of porosity in the LFC [8-9]. On the other hand, high compaction between the fibers and the cement matrix was likely achieved leading to good homogeneity in mix [10].

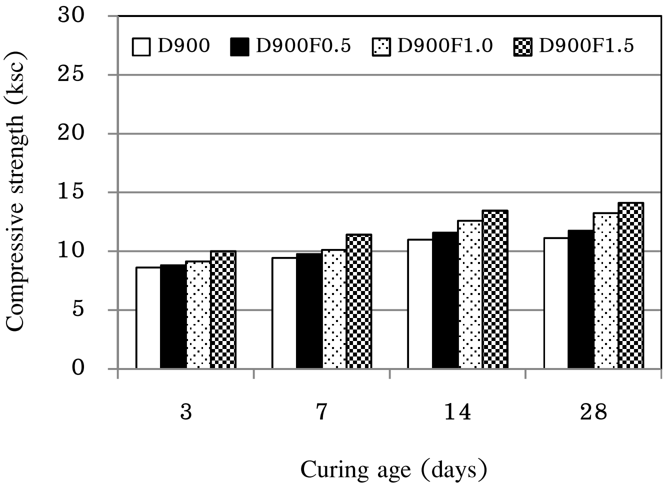

Figure 2 Compressive strength development for LFC at density of 900 kg/m^3

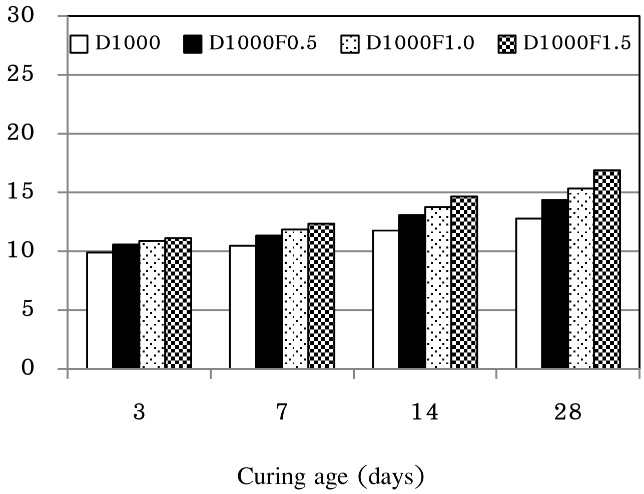

Figure 3 Compressive strength development for LFC at density of 1000 kg/m^3

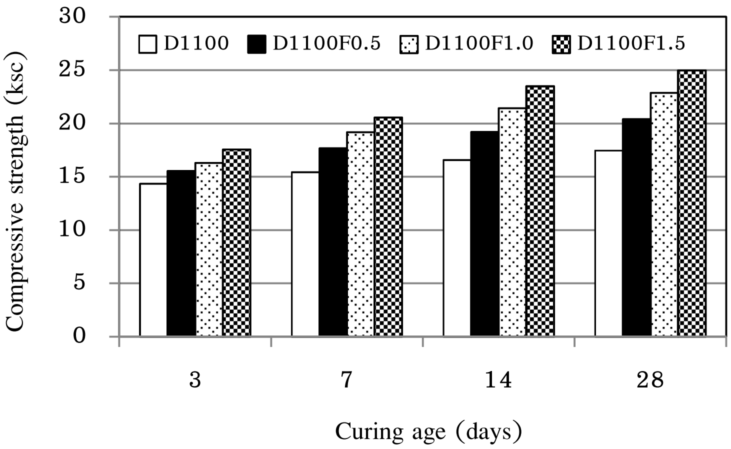

Figure 4 Compressive strength development for LFC at density of 1100 kg/m^3

3.3. Flexural strength

The flexural strength results showed a trend of development similar to that of the compressive strength results. Flexural strength continued to increase over the 28-day curing period are shown in Figure 5-7. A plastic density of 900 kg/m^3 shows the flexural strength ranged from 1.70 to 1.95 ksc at 3 days, from 1.72 to 2.20 ksc at 7 days, from 1.95 to 2.50 ksc at 14 days, and from 2.11 to 2.77 ksc at 28 days the palm fiber addition increased from 0% to 1.5%, respectively (Figure 5). A plastic density of 1000 kg/m^3 shows the flexural strength ranged from 2.59 to 3.25 ksc at 3 days, from 4.08 to 5.87 ksc at 7 days, from 4.95 to 6.76 ksc at 14 days, and from 6.03 to 8.26 ksc at 28 days the palm fiber addition increased from 0% to 1.5%, respectively (Figure 6). And a plastic density of 1000 kg/m^3 shows the flexural strength ranged from 4.31 to 5.56 ksc at 3 days, from 4.95 to 7.20 ksc at 7 days, from 5.51 to 8.05 ksc at 14 days, and from 6.61 to 9.63 ksc at 28 days the palm fiber addition increased from 0% to 1.5%, respectively (Figure 7).

It is observed that the flexural behaviour of a LFC with palm fiber, which revealed an increase in flexural strength with an increase in palm fiber content at 0.5%, 1% and 1.5%. The improvement in flexural strength is due the fibers can benefit foamed concrete in tensile strength through reducing the non-load cracking of foamed concrete mass at early ages. The advantage of fiber is to reinforce the foamed concrete mass and transform the basic material character from brittle to ductileelastic-plastic in foamed concrete. The contribution of fiber is to improve flexural strength, enhance toughness characteristic, and enrich capabilities and post cracking [3]. According to Shareef and Ramli [8], Ramli and Dawood [9], Ozerkan et al [10], indicated that inclusion of fibers improves the flexural strengths.

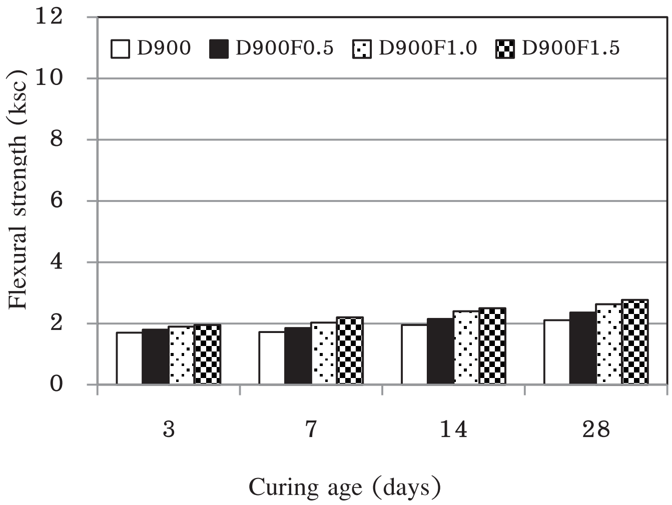

Figure 5 Flexural strength development for LFC at density of 900 kg/m^3

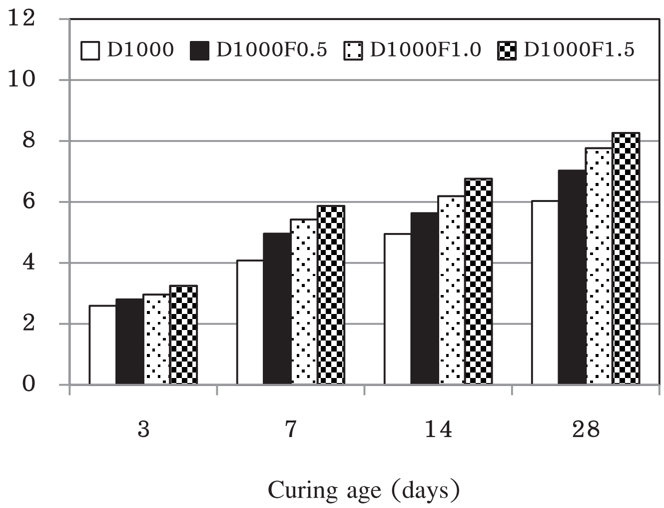

Figure 6 Flexural strength development for LFC at density of 1000 kg/m^3

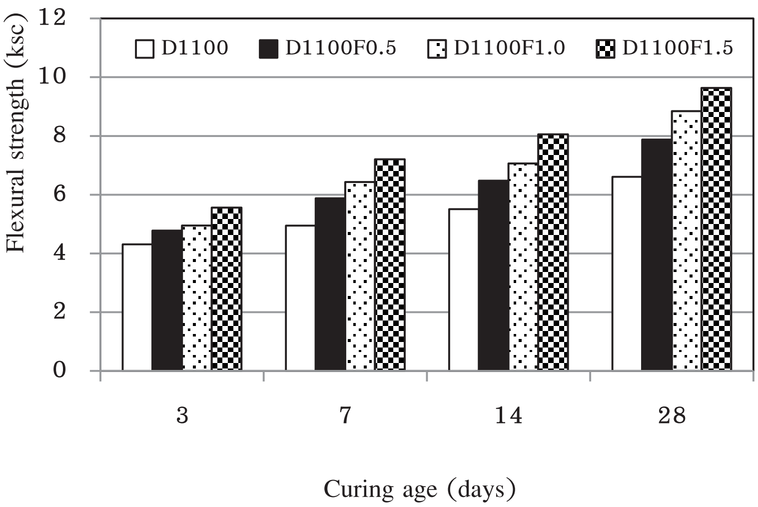

Figure 7 Flexural strength development for LFC at density of 1100 kg/m^3

4. Conclusions

(a) The use of palm fiber in LFC has increased the plastic density. The density increased by 6-24% for palm fiber addition of 0.5–1.5% by weight of cement.

(b) The compressive strength results show that the use of 0.5-1.5% of the palm fiber addition increase the strength after 28 days compared to the control mixture by about 5.6-26.9%, 12.2-32.2% and 16.9-43.2% for the plastic density at 900-1100 kg/m^3.

(c) Addition of 0.5–1.5% palm fiber in LFC that increased the flexural strength. For the plastic density at 900-1100 kg/m^3, flexural strength increased by 11.8-31.3%, 19.9-36.9% and 35.5-45.6% compared to the control mixture after 28 days.

(d) Palm fiber is suggested to be used in the production of LFC to enhance the mechanical properties. This characteristic can be very beneficial to construction industry and can improve efficient management of waste that otherwise can cause environmental problems.

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