Compressive Strength and Dimensional Stability of Palm Oil Empty Fruit Bunch Fibre Reinforced Foamed Concrete

Siong Kang Lim[1*], *Hock Yong* Tiong[1] *and Kai Siong* Woon[1]

[1]Department of Civil Engineering, Lee Kong Chian Faculty of Engineering & Science, Universiti Tunku Abdul Rahman, Selangor, Malaysia

Abstract. Rapid drying shrinkage is an important factor in causing cracks of concrete. This research was aimed at studying the effects of Palm Oil Empty Fruited Bunch (POEFB) fibre on the drying shrinkage behaviour and compressive strength of foamed concrete (FC) under two different curing conditions. The adopted curing conditions were air curing and tropical natural weather curing. Two volume fractions of POEFB fibre were used, which were 0.25% and 0.50% based on dry mix weight with 1-2 cm in length. The dimensional stability of the control specimen and POEFB fibre reinforced FCs was obtained by cumulating the measured linear shrinkage or expansion due to different curing conditions. The results from the two different specimens were compared. The results showed that specimens reinforced with POEFB fibre and cured under tropical natural weather condition attained lesser variations of dimensional stability and higher 90-day strength performance index than the reference mix without POEFB fibre. This improvement was attributed to the ability of POEFB fibre to bridge the cement matrix, and irregular wetting process under tropical natural weather curing condition had enabled more production of Calcium Silicate Hydrate gels that gradually blocked the penetration of water into the specimens and increased the compressive strength. It is observed that 11.43% and 4.46% of improvement in 90-day strength performance index were obtained in natural weather cured 0.5% of POEFB fibre reinforced specimen, with corresponded to the reference mix and 0.25% of POEFB fibre reinforced specimens, respectively.

1 Introduction

It is commonly known that foamed concrete (FC) has the advantages of giving lighter dead load, higher thermal insulation characteristic and better acoustical properties than those normal weight concrete. However, FC possesses some weakness that limit it being extensively use in building, such as limited compressive, flexural and tensile strengths, and great dimensional instability, while maintaining its lightness. Several researchers [1-8] have successfully provided a viable solution by adding fibres as the reinforcing agent to enhance the mechanical properties and dimensional stability of lightweight concrete. Among the

* Corresponding author: sklim@utar.edu.my

type of fibres, metallic and synthetic fibres are being commonly used in their research. According to Brandt [9], opening and propagation of micro-cracks in a concrete can be effectively controlled by introducing short dispersed fibres in cement matrix. Whilst, long fibres (50-80 mm) are much able to control larger cracks and therefore contribute to higher final strength. However, the optimum quantity of fibres has to be investigated prior adding into cement matrix. The reasons are high volume of fibre content easily leads to conglomeration of fibre during the composite mixing, while too little fibre content is unable to provide sufficient reinforcing mechanism in cement matrix.

Instead of using metallic and synthetic fibres in lightweight concrete, some researchers have used natural fibres as alternative fibres in lightweight concrete [10-13]. These natural fibres include date palm, equisetum, coconut and jute fibres. Their use, as a construction material, in improving the properties of the composites, does not increase much of the overall composite cost. Besides, the flexibility of POEFB makes it easier to be mixed with cement matrix compared with using harder steel fibre in cement matrix [11]. However, the reinforcing effects from natural fibre in lightweight concrete are varied due to different characteristic among the natural fibres.

Currently, Malaysia is one of the largest palm oil producers in the world, and it contributes about 57.6% of the total supply of palm oil in the world. According to Roslan et al. [14], Malaysian palm oil industry produces approximately 19 million tonnes (wet weight basis) of Oil Palm Empty Fruit Bunch (OPEFB) in year 2010. Approximately 65% of OPEFB is incinerated and the bunch ash is recycled back as fertilizer [15]. Therefore, it will be more sustainable and environmental friendly if the fibre extracted from OPEFB, can be further explored and used as construction material. Although some studies and researches on POEFB fibre reinforced concrete have been reported, but the range of the studies and researches in POEFB fibre reinforced FC is extremely limited. For that reason, this research was initiated and focuses on the compressive strength and dimensional stability of FC incorporated with different content of POEFB fibre.

2 Experimental work

2.1 Materials

Ordinary Portland cement (OPC), quarry sand, water, synthetic foaming agent and POEFB fibre were used to prepare FCs. The OPC used in this experiment is produced by YTL Sdn. Bhd and it complied with the Type I Portland cement as per in ASTM C150 (2007) [16]. Quarry sand which was passed through 600 μm of sieve analysis, was used as fine aggregates in this study. The sand was oven-dried at 105°C for 24 hours before sieving in order to avoid inconsistency of its moisture content. Normal tap water and locally available synthetic foaming agent were used for production of the FCs in this study. POEFB fibre was torn and cut into 1-2 cm length. The fibre was oven dried at 105ºC for an hour to eliminate any moisture content which contributed to its mass and engineering property. Mechanical Properties of POEFB fibre are shows in Table 1.

Table 1. Mechanical Properties of Palm Oil Fibers.

Sample	Diameter, D (mm)	Area, A (mm^2)	Maximum Load (N)	Original length (mm)	Elongates (mm)	Tensile Stress (MPa)	Tensile Strain
1	0.300	0.071	6.791	50.000	4.650	96.071	0.093
2	0.300	0.071	9.655	53.000	7.632	136.596	0.144
3	0.400	0.126	11.360	48.000	7.728	90.401	0.161
4	0.330	0.086	12.292	56.000	9.072	143.718	0.162
5	0.250	0.049	7.727	52.000	4.316	157.415	0.083
6	0.220	0.038	5.181	46.000	7.222	136.288	0.157
7	0.320	0.080	11.057	47.000	9.870	137.477	0.210
8	0.270	0.057	6.736	47.000	4.982	117.649	0.106
9	0.310	0.075	10.107	46.000	4.738	133.905	0.103
10	0.270	0.057	12.202	43.000	5.590	213.117	0.130
11	0.380	0.113	14.548	48.000	7.440	128.272	0.155
12	0.270	0.057	10.984	46.000	9.292	191.838	0.202
13	0.370	0.108	16.625	47.000	9.447	154.616	0.201
14	0.320	0.080	10.053	49.000	6.762	125.002	0.138
15	0.300	0.071	15.285	50.000	8.900	216.242	0.178
16	0.360	0.102	11.843	51.000	8.262	116.353	0.162
Mean	**0.311**	**0.078**	**10.778**	**48.688**	**7.244**	**143.435**	**0.149**
Standard Deviation	0.049	0.024	3.159	3.219	1.882	36.577	0.039

2.2 Mix proportions and preparation

The details of the mixtures for this experiment are tabulated in Table 2. Series 1 was a laboratory trial mix, where a total number of thirteen mixes were prepared using water-cement ratio ranging from 0.54 to 0.60, with 0.02 incremental intervals. POEFB fibre was not added for control mix specimens. However, 0.25% and 0.50% of POEFB fibre were added into PF25 and PF50 mixes respectively, in order to study its effect on 28-day FC compressive strength under water curing condition. The mixes with optimum strength to 1000 kg/m³ density ratio [17] were selected for further investigation in Series 2. Series 2 focuses on the dimensional stability and 90-day compressive strength of the FC specimens as a result of two different curing conditions (air curing and tropical natural weather curing). Before exposing to different types of curing, all specimens in Series 2 had undergone the first 7 days initial water curing. Subsequently, the curing was continued with either air curing or tropical natural weather curing, for the remaining days until Day-90. Water curing was done with the temperature in the range of 25-28°C. For air curing, the specimens were placed in the laboratory at ambient room temperature (29-32°C) with 65% of average relative humidity. For tropical natural weather curing, the specimens were cured under Malaysian tropical climate. The temperature ranges 29-35°C and with 50-90% of relative humidity.

Table 2. Mix proportions of various type of FC.

Specimen	w/c ratio	Materials [kg/ m^3]				
		Cement	Sand	Water	Foam	POEFB fibre
Ctrl[1]-54[3]	0.54	500	500	270	20.44	0
Ctrl-56	0.56	500	500	280	19.56	0
Ctrl-58	0.58	500	500	290	18.66	0
Ctrl-60	0.60	500	500	300	18.66	0
Ctrl-62	0.62	500	500	310	16.89	0
PF25[2]-54	0.54	500	500	270	20.44	2.5
PF25-56	0.56	500	500	280	20.00	2.5
PF25-58	0.58	500	500	290	16.89	2.5
PF25-60	0.60	500	500	300	13.33	2.5
PF50[2]-54	0.54	500	500	270	26.22	5.0
PF50-56	0.56	500	500	280	24.89	5.0
PF50-58	0.58	500	500	290	24.89	5.0
PF50-60	0.60	500	500	300	24.00	5.0

Note:
[1]Ctrl = control mix of FC for laboratory trial
[2]PF25 or PF50 = 0.25% or 0.50% (by dry mix weight) of POEFB fibre was being added into the FC mixture
[3]The last two digits = hundredths of respective w/c ratio

For all the specimens, cement to sand ratio was fixed at unity (by weight) and the foaming agent was diluted with water in a ratio of 1: 30 (by volume). The designated density of FCs in this study was fixed at 1300 ± 50 kg/m³. Therefore, a required amount of stable foam, produced by dry prefoamed method [18], was added into the slurry cement mortar mix in order to obtain the required density. 100 mm × 100 mm × 100 mm cubic mould and 100 mm × 200 mm × 400 mm prismatic mould were used to produce specimens for compression test and dimensional stability test. All specimens were demoulded 24 hours after casting.

2.3 Testing methods

Before casting, the fresh cement mortar and foamed concrete were tested for their flowability and consistency using flow table spread test and inverted slump test in accordance to ASTM C1437 (2007) [19] and ASTM C1611 (2007) [20], respectively. The diameters for four angles of the spread concrete were measured and the average reading was recorded. Compression test was conducted by using Instron 5582 Testing Machine in accordance with BS EN 12390-3 (2002) [21]. Dimensional stability was performed by measuring linear shrinkage and expansion of concrete block according to RILEM CPC9 (1994) [22]. Four strain measuring discs were affixed to the concrete surface (400 mm × 200 mm), two discs were affixed parallel to concrete specimen vertical side (100 mm × 200 mm) and the other two were affixed parallel to the horizontal side (100mm × 400 mm), using epoxy adhesive. Strain gauge meter was used to measure dimension changes of the specimens from the very first day of air curing or tropical natural weather curing until 90 days of age. These cumulative dimensional changes exhibited in this experiment show trends of contraction/expansion corresponding to variation of surrounding condition and temperature. The degree of deformation for the specimen can be calculated using Equation (1).

$$\Delta = \varepsilon \times L \quad (1)$$

Where, Δ is deformation, ε is strain or equals to measured scale, δ × strain factor (1.587 □ 10^{-5}), L is original length of specific surface [mm].

3 Results and discussion

3.1 Series 1 (laboratory trials)

Table 3 tabulated the results of average inverted slump cone spread values, stability, consistency, 28-day compressive strength and strength to 1000 kg/m³ density ratio (performance index). Referring to the inverted slump cone spread values in Table 3, the fluidity of FCs is significantly affected by the w/c ratio and percentage of POEFB fibre being added into the mixture. Higher w/c ratio increases the inverted slump cone spread values in each category of the trial mix. Whereas, incorporating higher content of palm oil fibre decreases the inverted slump spread value. This is due to the hydrophilic nature of the dried palm oil fibre, which absorbed portion of the water content required for cement hydration [12]. Since the required amount of water was not made available for cement hydration, therefore overall fluidity for PF50 and PF25 is lower than that of control mix.

Table 3. Summary of Series 1 (initial laboratory trials).

Specimen	Inverted slump cone spread value [mm][a]	Stability[b]	Consistency[c]	28-day Compressive Strength [MPa][d]	Strength performance Index[e]
Ctrl-54	545	0.97	1.01	5.29	4.06
Ctrl-56	**584**	**0.95**	**1.08**	**5.80**	**4.47**
Ctrl-58	654	0.97	1.05	5.53	4.16
Ctrl-60	681	1.00	1.02	5.41	4.12
Ctrl-62	684	0.96	1.05	5.38	4.11
PF25-54	513	0.96	1.01	5.00	3.96
PF25-56	**539**	**0.96**	**1.05**	**5.77**	**4.43**
PF25-58	639	0.96	1.06	5.51	4.21
PF25-60	667	0.95	1.05	5.33	4.12
PF50-54	503	0.95	1.02	5.30	4.23
PF50-56	533	0.94	1.08	5.69	4.34
PF50-58	**673**	**0.93**	**1.05**	**6.37**	**5.00**
PF50-60	673	0.98	1.02	6.29	4.88

Note:
[a]Inverted slump cone spread values were obtained by averaging the spread diameter of four different angles.
[b]Stability = proportion of measured fresh density to measured hardened density.
[c]Consistency = proportion of measured fresh density to designated density, which is fixed at 1300 kg/m³.
[d]28-day strength was obtained by averaging the crush value of three specimens.
[e]Strength performance index = proportion of 28-day compressive strength [MPa] to its hardened bulk density
The mixes highlighted in bolded font were chosen due to their best strength to 1000kg/m³ density ratio.

Referring to Table 3, the best performance ratio for the Ctrl, PF25 and PF50 specimens were obtained at 0.56, 0.56 and 0.58 of w/c ratios, respectively. Theoretically, as the density of the concrete increases, its compressive strength would increases correspondingly. However, the hardened densities among the FC specimens are slightly different, although the targeted density was within 1300 ± 50 kg/m³. Therefore, mixes that have optimum strength to density ratio without compromising their stability and consistency were selected for further investigation [17].

3.2 Series 2

In Series 2, further investigation was concentrated on the dimensional stability, and 90-day compressive strength of the specimen with the highest strength performance index obtained in Series 1, namely Ctrl-0.56, PF25-0.56 and PF50-0.58. All the tests for FC were done in triplicate, but only the average values were reported.

3.2.1 Dimensional stability

The results of dimensional stability of POEFB fibre reinforced FCs that cured under air curing and tropical natural weather curing condition are shown in Figures 1 and 2, respectively. For air curing condition, the specimens shrunk with a decreasing rate with advancing age. This is due to the loss of water in concrete via evaporation, leading to specimens' shrinkage at early age. Subsequently, less water was available at the later age due to discontinuous water supply for specimens cured under air curing condition. Therefore, the shrinkage of air cured specimens increased gradually.

On the other hand, for specimens cured under natural weather condition, the dimensional stability was varying depending on outdoor humidity. Rain water was absorbed into the FC specimens through capillary pores during rainy season and it caused the specimen to expand. Conversely, internal water evaporated when the specimens exposed to hot scorching sun caused the specimens to shrink. This irregular wetting process during rainy days under tropical natural weather curing condition allowed continuity of hydration reaction in specimens and produced more Calcium Silicate Hydrate gels that gradually blocked the penetration of water into the specimens. As a result, tropical natural weather cured specimens had lesser volume changes at the later age, compared with air cured specimens, as shown in Figure 2. In addition, it was found that specimens incorporated with POEFB fibre encountered lesser dimensional changes than the control mix for both curing conditions. This result indicated that POEFB fibre has the bridging ability inside the cement matrix, reduced capillary pores, and therefore reduced the dimensional changes of the specimens.

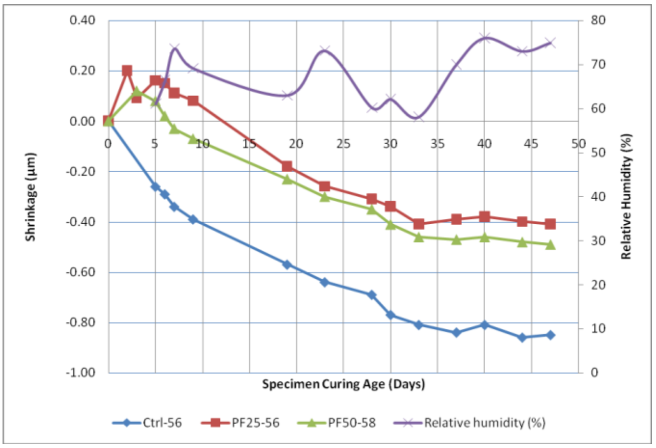

Fig. 1. Dimensional stability of POEFB fibre reinforced FC under air curing conditions.

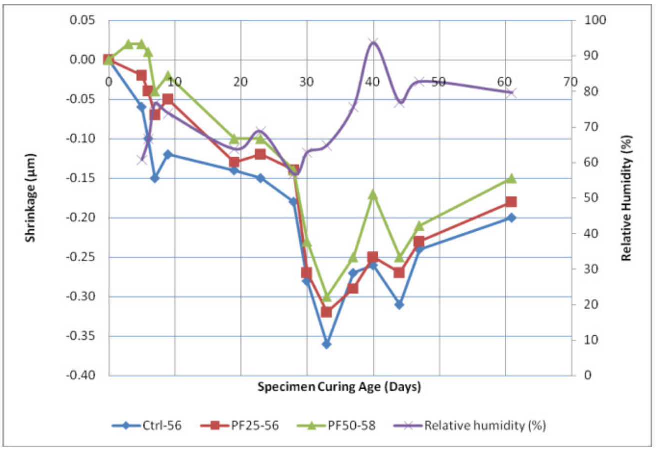

Fig. 2. Dimensional stability of POEFB fibre reinforced FC under tropical natural weather curing conditions.

3.2.2 Compressive strength

The compressive strength and strength performance index for Ctrl-56, PF25-56 and PF50-58, are shown in Figures 3 and 4, respectively. Table 4 shows the comparison of strength performance index among the FCs with and without POEFB fibre, in both air curing and tropical natural weather curing conditions. Based on the results, specimens with POEFB fibre obtained higher 90-day compressive strength than that of reference specimen, regardless of the type of curing condition being adopted. This is due to fibre inside the FC was functioned as reinforcing agent to bridge the cement matrix firmly than plain concrete [12].

It was found that tropical natural weather cured specimens achieved higher compressive strength and strength performance index than those of air cured specimens, regardless of the presence of POEFB fibre in the specimens. This could be due to the presence of water under tropical natural weather condition enables continuity of the hydration process and the production of more Calcium Silicate Hydrate gels, which reduced the porosity in hydrated cement paste. These findings are supported by the results shown in Figure 3, Figure 4, and Table 4.

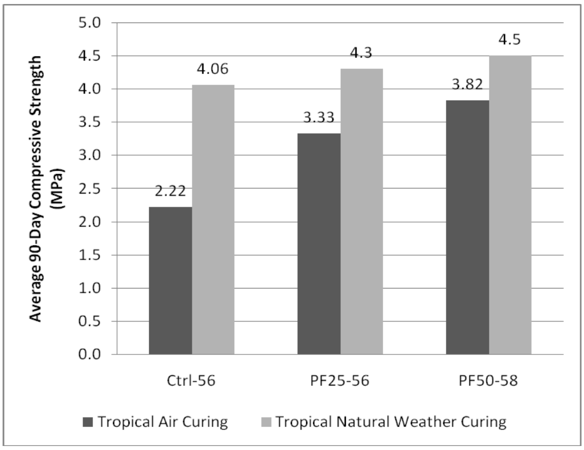

Fig. 3. Average 90-day compressive strength Ctrl-56, PF25-56 and PF50-58 under two different curing conditions.

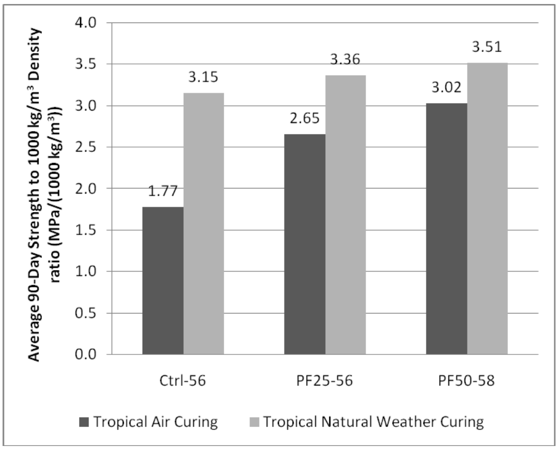

Fig. 4. Average 90-day strength performance index for Ctrl-56, PF25-56 and PF50-58 under two different curing conditions.

Table 4. Relationship of 90-day strength performance index and fibre content.

Curing Condition	90-day Strength Performance Index [MPa/ 1000kgm^{-3}]			PF25-56	PF50-58	PF50-58
				Corresponded to		
	Ctrl-56	PF25-56	PF50-58	Ctrl-56	Ctrl-56	PF25-56
Air	1.77	2.65	3.02	49.72%	70.62%	13.96%
Tropical natural weather	3.15	3.36	3.51	6.67%	11.43%	4.46%

4 Conclusions

Based on these experimental investigations, some conclusions were drawn and are listed as below:

(a) Foamed concrete (FC) reinforced with 0.50% of Palm Oil Empty Fruit Bunch (OPEFB) fibre (1-2 cm in length) shows better enhancement in compressive strength and dimensional stability under tropical air curing, compared to reference mix without POEFB fibre and 0.25% POEFB fibre reinforced FC.

(b) The inclusion of dried POEFB fibre inside FC requires higher water content in order to achieve a consistent mix compared with that of reference mix with higher water content.

(c) Tropical natural weather cured POEFB fibre reinforced FCs achieved higher compressive strength than those of air cured POEFB fibre reinforced FCs. This could be due to the presence of water under tropical natural weather condition enables continuity of the hydration process and the production of more Calcium Silicate Hydrate gels, which reduced the porosity in hydrated cement paste.

Effort and contribution by Ms Hew Yi Wen and Mr Li Siew Wu on these experimental investigations are highly appreciated.

References

1. A. D. Oğuz, G. Rűstem, C. A. Abdulkadir, Effects of steel fibres on the mechanical properties of natural lightweight aggregate concrete, *Materials Letters*, **59**(27), 3357-3363 (2005)
2. B. Chen, J. Liu, Contribution of hybrid fibres on the properties of the high-strength lightweight concrete having good workability, *Cement and Concrete Research*, **35**(5), 913-917 (2005)
3. A. Sivakumar, M. Santhanam, Mechanical properties of high strength concrete reinforced with metallic and non-metallic fibres, *Cement and Concrete Composites*, **29**(8), 603-608 (2007)
4. B. Chen, Z. Wu, N. Liu, Experimental Research on Properties of High-Strength Foamed Concrete, *J. of Materials in Civil Engineering*, **24**(1), 113-118 (2012)
5. K. Aghaee, M.A. Yazdi, K.D. Tsavdaridis, Mechanical properties of structural lightweight concrete reinforced with waste steel wires. *Magazine of Concrete Research*, **66**(1). 1 - 9 (2014)
6. R. Yu, D. van Onna, P. Spiesz, Q. Yu, H. Brouwers, Development of ultra-lightweight fibre reinforced concrete applying expanded waste glass, *J. Cleaner Production*, **112**, 690-701 (2016)
7. H. Hardjasaputra, G. Ng, G. Urgessa, G. Lesmana, S. Sidharta1, Performance of lightweight natural-fiber reinforced concrete, *MATEC Web of Conferences*, **138**, 01009 (2017)
8. J. Li, J. Niu, C. Wan, X. Liu, Z. Jin, Comparison of flexural property between high performance polypropylene fiber reinforced lightweight aggregate concrete and steel fiber reinforced lightweight aggregate concrete. *Construction and Building Materials*, **157**, 729-736 (2017)
9. A. M. Brandt, Fibre reinforced cement-based (FRC) composites after over 40 years of development in building and civil engineering, *Composites Structures*, **86**(1-3), 3-9 (2008)

10. A. Kriker, G. Debicki, A. Bali, M. M. Khenfer, M. Chabannet, Mechanical properties of date palm fibres and concrete reinforced with date palm fibres in hot-dry climate, *Cement and Concrete Composites*, **27**(5), 554-564 (2005)
11. A. Majid, L. Anthony, S. Hou, C. Nawawi, Mechanical and dynamic properties of coconut fibre reinforced concrete, *Construction and Building Materials*, **30**, 814-825 (2012)
12. C. Sumit, P. K. Sarada, R. Aparna, K. B. Ratan, A. Basudam, S.B. Majumder, Improvement of the mechanical properties of jute fibre reinforced cement mortar: A statistical approach, *Construction and Building Materials*, **38**, 776-784 (2013)
13. N. Zahra, F. Mehdi, E. Ghanbar, H. Yahya, Manufacture of lignocellulosic fibre-cement boards containing foaming agent, *Construction and Building Materials*, **35**, 408-413 (2012)
14. A. Roslan, F. K. Mohammad, A. N. A. Borhan, S. M. Arif, A study on the Malaysian Oil Palm Biomass Sector – Supply and Perception of Palm Oil Millers, *Oil Palm Industry Economic J.*, **11**(1), 28-41 (2011)
15. M. S. Rosnah, W. H. Wan Hasamudin, M. T. Ab Gapor, H. Kamarudin, Thermal properties of oil palm fibre, cellulose and its derivatives, *J. of Oil Palm Research*, **18**, 272-277 (2006)
16. America Society of Testing and Materials, ASTM C 150-05: Standard Specification for Portland Cement, *ASTM International*, Conshohocken, Pennsylvania, United States (2007)
17. H. Kurama, I. B. Topcu, C. Karakurt, Properties of the autoclaved aerated concrete produced from coal bottom ash, *J. of Materials Processing Technology*, **209**(2), 767-773 (2009)
18. K. Ramamurthy, E. K. K. Nambiar, G. I. S. Ranjani, A classification of studies on properties of foam concrete, *J. of Cement and Concrete Composites*, **31**, 388-396 (2009)
19. America Society of Testing and Materials, ASTM C1437: Standard Test Method for Flow of Hydraulic Cement Mortar, *ASTM International*, Conshohocken, Pennsylvania, United States (2007)
20. America Society of Testing and Materials, ASTM C1611: Standard Test Method for Slump Flow of Self Consolidating Concrete, *ASTM International*, Conshohocken, Pennsylvania, United States (2007)
21. British Standard Institute, BS EN 12390-3: Testing hardened concrete – Part 3: Compressive strength of test specimens, *BSI*, London (2002)
22. RILEM CPC9, Technical recommendations for the testing and use of construction materials: Measurement of shrinkage and swelling of concrete, 1975, *E & FN SPON*, London (1994)