Influence of Site Curing on Bond Properties of Reinforced Lightweight Concrete

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Abstract

An experimental investigation on structural lightweight concrete was conducted using oil palm shell (OPS) as coarse aggregate, which is a type of solid waste discarded in large quantities in palm oil mills. The compressive strength and the pull-out bond strength were determined in this study for up to 28 days under three curing conditions. These include two currently practiced site curing conditions and one laboratory full water curing. The full water curing condition was considered as controlled curing. The obtained 28-day air-dry density, compressive strength and pull-out strength were in the range of 1930-1995 kg/m^3, 25-28 MPa and 5.4-9.4 MPa respectively which satisfied the requirements for structural lightweight concrete. The developed compressive strength and pull-out strength under both site curing conditions were relatively lower than full water curing condition but still were higher than minimum requirement as per standard.

Keywords: Oil Palm Shell (OPS), Lightweight concrete, Pull-out test, Bond strength, Site curing

1 INTRODUCTION

Malaysia lies entirely in the tropics with equatorial climate of temperatures ranging from 21 to 32°C and an average rainfall of 2000 to 2500 mm annually. The state of Sabah is situated on the Borneo Island with vast coastal areas. The annual rainfall in Kota Kinabalu, the capital city of Sabah is approximately 2500 mm with air temperatures in the range of 22.9 to 32.2°C and relative humidity in the range of 71.6 to 91.0 percent. The prevailing wind in Kota Kinabalu is from the east with speeds ranging from 0.3 to 3.3 m/s.

Normally, curing is required to keep the concrete saturated or as nearly saturated as possible, so that the optimum products through the hydration of cement can be obtained [1]. Effective curing reduces the loss of water and increases the hydration of cement, which therefore reduces the porosity and increases the probability of the pores being blocked or narrowed down by continued formation of hydration products [2]. Good curing maintains relative humidity in concrete above 80% [3]. The curing temperature, duration of curing and method of curing play a crucial role in the development of strength in concrete.

Site curing practices are simulated due to the fact that laboratory curing condition fails to take into account the more robust conditions that exist in the field, especially at an early age. The method of curing used is dependant upon the site conditions and also on the size, shape and position of the concrete member. At construction sites in Malaysia, curing is normally done by spraying or sprinkling water three times a day for three continuous days or by covering the freshly placed concrete using plastic sheeting for three days. Curing compounds which are spray-applied are also used in construction, especially where the curing area is large or in areas where the availability of water is limited.

Currently, Malaysia is the largest producer of oil palm in the world with a solid waste production namely oil palm shell (OPS) of over 3.13 million tonnes annually [4]. Concrete using OPS as coarse aggregate has been found useful as structural lightweight concrete [5] and shows good potential in the construction industry especially in the construction of low cost houses. For structural applications, the bond strength of reinforced concrete is of paramount importance. It is therefore necessary to investigate the structural bonding properties of OPS concrete cured under practical site conditions so that its behaviour can be fully understood.

This paper discusses the structural bond properties using pull-out test on reinforced OPS concrete cured under different conditions currently. This investigation was conducted in the months from September to December 2004. The average rainfall in Kota Kinabalu for the months of September, October, November and December 2004 was 274.2 mm, 429.4 mm, 166.8 mm and 81.7 mm respectively, whereas the average temperature was 26.7 °C in September and 26.9°C from October to December 2004.

2 EXPERIMENTAL PROGRAM

2.1 Materials

The concrete mix was prepared using ordinary Portland cement (ASTM Type I), river sand, OPS, potable water and a Type-F naphthalene sulphonate superplasticiser. The OPS used were in saturated surface dry (SSD) condition, whereas the sand was in air-dry condition. The properties of OPS used are shown in Table 1 and the physical and chemical properties of cement are presented in Table 2.

OPS are available in various shapes such as curved, flaky, elongated, roughly parabolic and other irregular shapes. The shells also have varying thickness, depending on the species of the oil palm tree which the palm nut is obtained. Due to the porous nature of OPS, the bulk density of OPS is much lower compared to that of conventional gravel aggregates and therefore, the resulting concrete will be lightweight. OPS aggregates are tough in nature and have good shock absorbance nature as indicated by the aggregate crushing value (ACV) and aggregate impact value (AIV). Most lightweight aggregates have high water absorption values. Manufactured lightweight aggregates such as expanded clay, sintered pulverised fuel ash have water absorption values in the range of 9 to 15% [6]. OPS has a water absorption value of about 33%. However, this value is comparable to that of volcanic pumice aggregates which have an absorption of about 37% [7].

Table 1: Properties of OPS

Maximum size, mm	12.5
Shell thickness, mm	0.5 – 3.0
Bulk density (loose), kg/m^3	507
Bulk density(compacted), kg/m^3	593
Specific gravity (saturated surface dry)	1.17
Fineness modulus	6.08
Aggregate impact value, %	7.51
Aggregate crushing value, %	8
24-hour water absorption, %	33

Table 2: Physical and chemical properties of cement (ASTM, Type I)

Description	**Results**
Physical Properties:	
Fineness - Specific surface	3254 cm^2/g
Initial setting time	106 minutes
Final setting time	161 minutes
Soundness (Le Chatelier Method)	0.3 mm
Chemical Properties:	
Magnesia (MgO)	1.85%
Sulphuric anyhydride (SO_3)	2.42%
Chloride	< 0.01%
Total alkalies as Na_2O	0.61%
Tricalcium silicate (C_3S)	58.57%
Dicalcium silicate (C_2S)	14.16%
Tricalcium aluminate (C_3A)	8.87%

2.2 Mix Design and Acceptable Mix Proportion

The ability of lightweight aggregates to absorb water is by far the most significant feature in their performance in concrete production and hence, it is desirable to prevent the absorption from occurring during the mixing process [8]. This absorption of water was prevented by pre-wetting the OPS aggregates and the OPS aggregates were in saturated-surface-dry (SSD) condition during mixing.

The cost, strength, density, workability and durability requirements for different applications of lightweight concrete were taken into consideration during the design of the OPS concrete mix. The mix design for the OPS concrete in this investigation was based on conducting sufficient number of trial mixes and selecting an optimised mix. The trial mixes are presented in Table 3. Since OPS are available in many irregular shapes, poor workability was observed in the fresh concrete without addition of superplasticiser at a given w/c ratio. Therefore, the use of superplasticiser was necessary to achieve better workability. Based on the trial mixes, the optimum mix proportion was found to be mix C6 and this mix was used throughout the entire investigation. A comparative cost analysis between OPS concrete (Mix C6) and conventional concrete of Grade 25 is presented in Table 4.

The acceptable mix proportion was in the order of 1:1.66:0.60 and 1:2.14:1.62 (Cement: Sand: OPS) by weight and volume respectively. The cement content used for this mix was within the specified range of 285 to 510 kg/m^3 for lightweight concrete [9]. The final results of the fresh OPS concrete from the acceptable mix proportion are shown in Table 5.

Table 3: Trial mixes for OPS concrete

Mix No.	Mix proportion by weight (C:S:OPS)	Cement content kg/m^3	Super-plasticiser content, %	w/c ratio	Slump (mm)	28-day air dry density (kg/m^3)	28-day comp. (MPa)
A1	1:1.72:0.60	490	1.0	0.41	33	1920	14.5
A2	1:1.76:0.60	490	1.0	0.39	15	1945	17.0
B1	1:1.65:0.58	500	1.0	0.41	110	1975	15.5
B2	1:1.70:0.58	500	1.0	0.39	80	1950	20.0
C1	1:1.72:0.57	510	2.0	0.35	25	1990	24.5
C2	1:1.72:0.57	510	4.0	0.35	150	2000	24.5
C3	1:1.72:0.58	510	4.5	0.35	collapse	2000	25.0
C4	1:1.66:060	510	1.0	0.35	10	2000	28.5
C5	1:1.64:0.60	510	1.5	0.36	35	1950	28.5
C6	**1:1.66:0.60**	**510**	**1.4**	**0.38**	**60**	**1985**	**28.0**
D1	1:1.51:0.56	520	1.0	0.41	collapse	1940	20.5
D2	1:1.66:0.56	520	2.0	0.35	25	1970	24.0
E1	1:1.46:1.62	530	1.0	0.35	50	1955	26.5
E2	1:1.45:0.55	530	1.0	0.41	collapse	1935	21.0
F1	1:1.25:0.64	550	1.0	0.35	190	1950	27.5
F2	1:1.53:0.53	550	1.0	0.33	15	2010	28.5

Table 4 Material cost for 1 m^3 concrete

Constituents	OPS concrete of 25N/mm^2 (G25 concrete)	Conventional concrete of 25N/mm^2 sold at market (G25 concrete)
Cement (RM13/50kg bag)	RM 133	RM 210 (USD 55.26)
River sand (RM44/m^3)	RM 16	
OPS (free)	-	
Potable water (free)	-	
Superplasticiser (RM3.50/liter)	RM 25	
Total Cost	RM 174 (USD 45.79)	

Note: 1 USD = RM 3.80

Table 5: Fresh OPS concrete properties

Slump, mm	50 – 70
Fresh concrete density, kg/m^3	2010 – 2065
Air content, %	4.8 – 5.5

2.3 Test Specimens

For this study, 100 mm cube specimens for compressive strength determination and 100 mm diameter x 200 mm height cylindrical specimens for bond strength tests incorporating both deformed (type Y) bars of 10, 12 and 16 mm were prepared.

The specimens used for the bond strength test were similar to those used by El-Hawary [10]. Each specimen was reinforced axially with one central reinforcing bar measuring approximately 900 mm in total length. This length was provided to facilitate loading of the specimen in a 300 kN Shimadzu universal testing machine. Both ends of the specimen were provided with an unbonded length by attaching a plastic sheathing of 25 mm to the bar as shown in Fig. 1. The main purpose of the unbonded lengths was to protect the reinforcement form confining pressure of concrete at the supports.

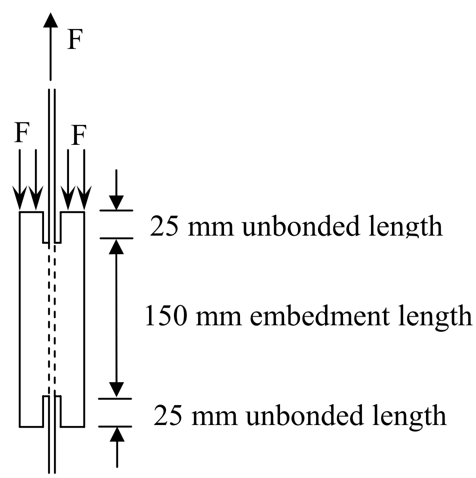

Fig. 1: Schematic diagram of bond test sample

2.4 Curing Regimes

The curing regimes employed in this study are presented in Table 6. Curing CS1 and CS2 simulate site curing conditions. CS1 curing is normally practised in Malaysia, whereas CS2 curing is the recommended curing practice by Barnbrook et al. [11], ACI 318 [12] and ACI 308 [13]. Curing CC is the full water curing (water temp. = 23 ºC ± 2 ºC) used as controlled condition. For all curing conditions, the specimens were immediately covered with plastic sheets upon casting to prevent excessive evaporation from the fresh concrete and then demoulded after 24 ± 3 hours.

Table 6: Curing regimes

Symbol	Duration of curing with place, day(s); From September – December 2004					
	Room (mould + plastic cover)	Water	Site (mould + plastic cover)	Site (plastic wrapper)	Site (cement bag with 1 layer of sand: water spray: 2 times/day)	Site (totally exposed)
CS1	-	-	1	2	-	25
CS2	-	-	1	-	6	21
CC	1	27	-	-	-	-

2.5 Hardened Concrete Density and Compressive Strength

The 28-day air-dry densities were determined as per ASTM C 567 [14] and compressive strength tests were conducted in accordance to BS 1881 [15], where the results are reported as an average of three samples.

2.6 Pull-out Test

The pull-out test was carried out using a Universal Testing Machine (Shimadzu – 300 kN) complete with a modified loading frame as shown in Fig. 2. The load was applied on the top of the concrete surface at a uniform rate without shock as per ASTM C 234 [16]. A dial gauge was positioned at the unloaded end (free end) of the sample and the dial gauge readings were noted during subsequent loadings at regular load intervals. The ultimate load was obtained by loading the specimen until failure. The bond strength was computed by the following formula:

$$\tau = F / (\pi \times d \times l) \quad (1)$$

where τ = bond stress (MPa), F = applied load (N), d = nominal bar diameter, l = embedment length (mm)

Fig. 2: Bond test set-up

3 TEST RESULTS AND DISCUSSIONS

3.1 Hardened Concrete Density and Compressive Strength

In general, lightweight concretes have densities less than 2000 kg/m^3 [6]. The 28-day air-dry densities for OPS concrete ranged from 1930 to 1995 kg/m^3, which make them lightweight. This density is approximately 16 to 20 percent lighter compared to the normal weight concrete of 2400 kg/m^3.

The compressive strengths for OPS concrete at the age of 28 days range between 25 MPa and 28 MPa, with full water curing giving the highest strengths as shown in Fig. 3. This is attributed to the substantial amount of water available for the hydration process to continue which resulted in higher strength gain. In the earlier stages (3 and 7 days) the strength development of specimens cured under CS1 was much better compared to CS2 curing. However, at the age of 28 days, the compressive strength of specimens cured under both site curing conditions exhibited similar compressive strengths, which shows that both site curing conditions provide similar levels of effectiveness. From all tested samples, it was observed that the compression failure in OPS concrete was mainly caused by the failure in the bond between the cement paste and OPS aggregate.

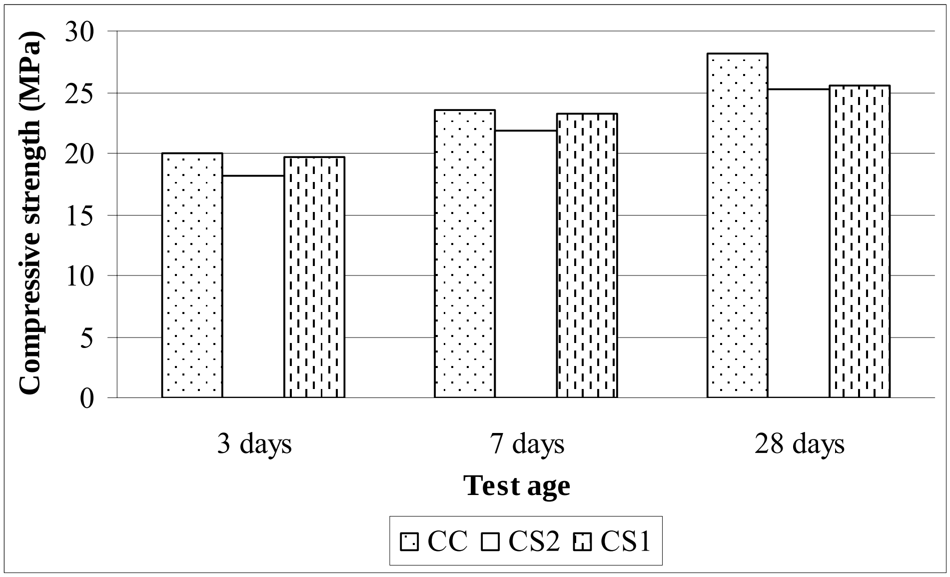

Fig. 3: Compressive strength of OPS concrete

3.2 Pull-out Test

The results for the pull-out tests under CS1, CS2 and CC curing are presented in Figs. 4, 5 and 6 respectively. At all ages of test, the samples cured under CC condition produced the highest bond strength. The 28-day bond stresses for samples cured under CS1 and CS2 conditions were approximately 9.5 % to 31.9 % lower compared to those cured under CC condition.

From the figure, it is observed that the bond stress increases with a decrease in bar size. This can be explained by the lower confining stress on the bar. As the bar size increases, the concrete cover to the reinforcement is reduced. Consequently, the confining pressure on the reinforcing bar from the surrounding concrete is also decreased, resulting in the decrease of bond stress. Similar trends were reported elsewhere [17, 18]. In addition, from the visual inspection of the tested samples, it was also observed that the occurrence of cavities caused by the bleeding water were greater on the concrete contact area with steel for larger diameter bars. This could have also contributed to the lower bond strengths for larger diameter bars. The 28-day ultimate bond stress for 10, 12 and 16 mm diameter bars ranged from 6.4 to 9.4 MPa, 6.3 to 8.7 MPa and 5.4 to 7.2 MPa respectively depending on the curing condition employed.

The relationship of typical bond stress and the corresponding slip values at the unloaded end are presented in Figs. 4, 5 and 6. Loaded end slip started soon after loading and this slip gradually increased as the load increased. Eventually, the samples failed by splitting of the concrete cover. It was observed that cracks progressed over the entire length of the sample before failure occurred. The failure was very sudden and was accompanied by the formation of longitudinal cracks. Splitting failure occurs when radial cracks form due to the bearing pressure developed by the projections of the steel bars on the surrounding concrete, leading to splitting of the concrete cover.

In general, the bond strength of OPS concrete was approximately 21% to 33% of the compressive strength. This shows similarity in the values of the present results to those obtained by Paramasivam and Loke [19] and Orangun [20] conducted on other lightweight weight concretes. The results obtained were also comparable to those obtained by Mo and Chan [21].

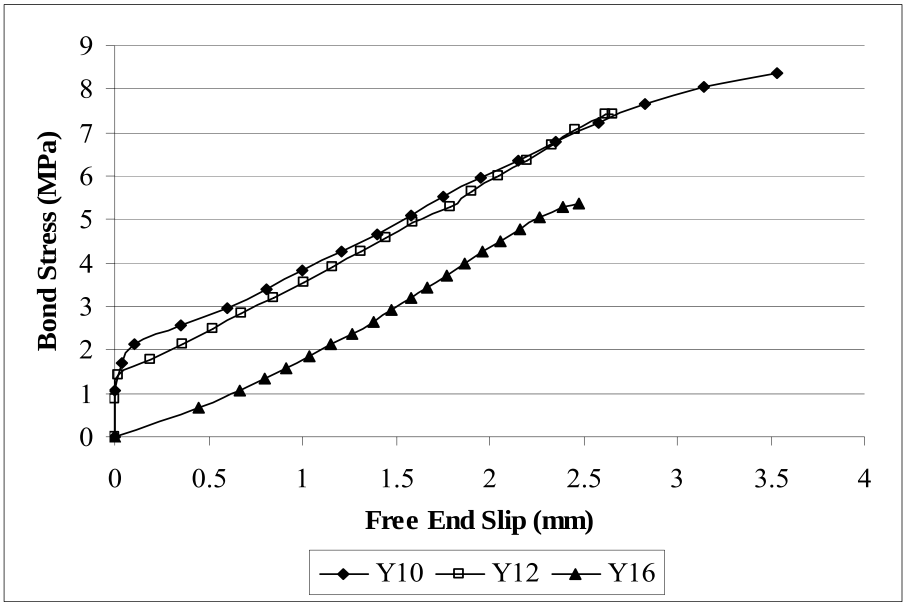

Fig. 4: Typical bond stress – slip relationship under CS1 curing

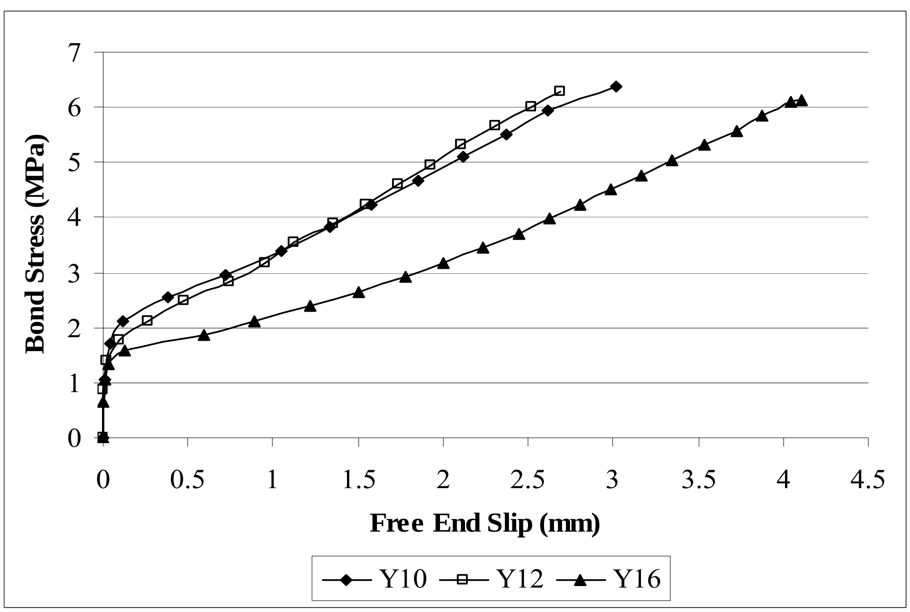

Fig. 5: Typical bond stress – slip relationship under CS2 curing

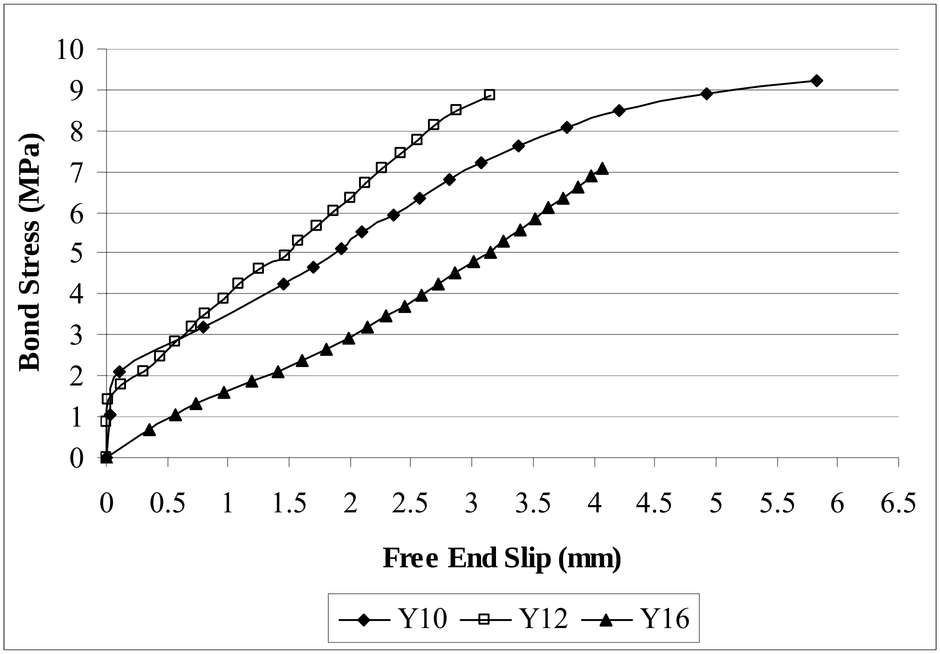

Fig. 6: Typical bond stress – slip relationship under CC curing

4 CONCLUSIONS

From this short term investigation, the following conclusions are drawn:

i) The 28-day air-dry densities for OPS concrete ranged from 1930 to 1995 kg/m^3 and this is within the range for lightweight concrete.

ii) The compressive strengths for OPS concrete at the age of 28 days ranged between 25 MPa and 28 MPa, with full water curing giving the highest strengths. In terms of compressive strength, both CS1 and CS2 curing provided the same level of effectiveness.

iii) The 28-day bond stresses for samples cured under CS1 and CS2 conditions were approximately 9.5% to 31.9% lower compared to those cured under CC condition.

iv) The bond stress increases with a decrease in bar size. The 28-day ultimate bond stress for 10, 12 and 16 mm diameter bars ranged from 6.4 to 9.4 MPa, 6.3 to 8.7 MPa and 5.4 to 7.2 MPa respectively depending on the curing condition employed.

v) The bond strength of OPS concrete was comparable to that of other lightweight concretes.

vi) Loaded end slip started soon after loading and this slip gradually increased as the load increased. Eventually, all samples failed by splitting of the concrete cover.

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References

1) Neville, A. M. (1999), Properties of Concrete, 4th Edition, Longman, Malaysia.

2) Bushlaibi, A. H. and Alshamsi, A. M. (2002), "Efficiency of curing on partially exposed high-strength concrete in hot climate", Cement and Concrete Research, 32, 949-953.

3) Price, W.F. (1998), "Curing concrete", Concrete, 32(8), 9-10.

4) Mannan, M.A. (2001), "A study on the use of oil palm shell in lightweight concrete", PhD Thesis, Universiti Malaysia Sabah, Malaysia.

5) Mannan, M. A. and Ganapathy, C. (2004), "Concrete from an Agricultural Waste-Oil Palm Shell (OPS)", Building and Environment, 39(4), 441-448.

6) Newman, J. B. (1993), "Properties of structural lightweight aggregate concrete", In: Clarke J. L., Structural Lightweight Aggregate Concrete, Blackie Academic & Professional, Glasgow, 19-44.

7) Hossain, K. M. A. (2004), "Properties of volcanic pumice based cement and lightweight concrete", Cement and Concrete Research, 34(2), 283-291.

8) Pankhurst, R. N. W. (1993), "Construction", In: Clarke, J. L., Structural Lightweight Aggregate Concrete, Blackie Academic & Professional, Glasgow, 75-105.

9) Mindess, S., Young, J. F. and Darwin, D. (2003), Concrete, 2nd Edition, Prentice Hall, United States of America.

10) El-Hawary, M. M. (1999), "Evaluation of bond strength of epoxy-coated bars in concrete exposed to marine environment", Construction and Building Materials, 13(7), 357-362.

11) Barnbrook, G., Dore, E., Jeffrey, A. H., Keen, R., Parkinson, J. D., Sawtell, D. L., Shacklock, B. W. and Spratt, B. H. (1975), Concrete Practice, Cement and Concrete Association, Wexham Springs.

12) ACI Committee 318 (1992), Building code requirements for reinforced concrete, ACI-318, American Concrete Institute, Detroit.

13) ACI Committee 308 (1989), Recommended practice for curing concrete, ACI-308, American Concrete Institute, Detroit.

14) ASTM C 567, Standard test method for unit weight of structural lightweight concrete. Annual Book of ASTM Standards.

15) BS 1881: Part 116: 1983 Method for determination of compressive strength of concrete cubes. British Standard Institution, London.

16) ASTM C 234, Standard test method for comparing concretes on the basis of bond developed with reinforcing steel, Annual Book of ASTM Standards.

17) Short, A. and Kinniburgh, W. (1978), Lightweight Concrete, 3rd Edition, Applied Science Publishers Limited, London.

18) Kankam, C. K. (2004), "Bond strength of reinforcing steel bars milled from scrap metals", Materials and Design, 25(3), 231-238.

19) Pramasivam, P. and Loke, Y. O. (1978), "Study of Sawdust Concrete", The International Journal of Lightweight Concrete, 2(1), 57-61.

20) Orangun, C.O. (1967), "The Bond Resistance between Steel and Lightweight-Aggregate (Lytag) Concrete", Building Science, 2(1), 21-28.

21) Mo, Y. L. and Chan, J. (1996), "Bond and Slip of Plain Rebars in Concrete", Journal of Materials in Civil Engineering, 208-211.