Influence of Palm Oil Fuel Ash on Physico-Mechanical Properties of Prepacked Aggregate Concrete

Hossein Mohammadhosseini[1, a], A.S.M. Abdul Awal[1, b*], Abdulhamid Vahedi[1, c]

[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia

[a]hofa2018@yahoo.com, [b*]abdulawal@utm.my, [c]hamidvahedi132@yahoo.com

Keywords: Prepacked aggregate concrete, palm oil fuel ash, hydration, physical and mechanical properties.

Abstract. Prepacked aggregate concrete (PAC) is a special type of concrete which is made by placing coarse aggregate in a formwork and injecting a grout either by pump or under gravity force to fill the voids. Utilization of pozzolanic materials in traditional concrete has become increasingly extensive, and this trend is expected to continue in prepacked concrete as well. Palm oil fuel ash (POFA) is one of the pozzolanic ashes, which has been recognized as a good pozzolanic material. This paper presents the results of some experimental tests on the performance behavior of POFA in developing physical and mechanical properties of prepacked aggregate concrete. Four concrete mixes namely prepacked concrete with 100% OPC as control, and PAC with 10%, 20% and 30% POFA were cast, and the temperature growth due to heat of hydration in all the mixtures was recorded. It has been found that POFA significantly reduced the temperature rise in prepacked concrete. The compressive and tensile strength, however, increased with replacement of POFA. The results obtained and the observation made in this study suggest that the replacement of OPC by POFA is beneficial, particularly for prepacked mass concrete where thermal cracking due to extreme heat rise is of great concern.

Introduction

Prepacked aggregate concrete (PAC) or two-stage concrete drives its name from the unique placement method by which it is made. The prepacked concrete unlike conventional concrete, is a method of concreting in which the coarse aggregate is first placed in the formwork and then filling the gaps between aggregates by injecting a prepared grout of sand, cement and water [1, 2]. Usually, the PAC grouting process can be carried out by two methods of gravity or pumping. In the gravity method, the grout penetrate through the aggregates from the top surface to the bottom of the formwork under its own weight and mostly useful for grouting concrete sections with a depth up to 300 mm[3]. In the pumping method, the mixed grout is pumped from the bottom of the mold into the aggregates through a pipe[4, 5]. The prepacked concrete has proved particularly useful for plain or reinforced concrete in a number of applications like under water construction, concrete and masonry repair, for applications where the reinforcement is very complicated, works where placement by normal traditional methods is difficult, large mass concrete where low cement content and low heat of hydration are required[1, 2].

When cement is hydrated the compounds react with water to acquire stable low-energy state, and the process is accompanied by the release of energy in the form of heat. The quantity of heat evolved upon complete hydration of a certain amount of unhydrated cement at a given temperature is defined as heat of hydration. The temperature of concrete mix due to hydration process is mainly controlled by materials, mix properties and by environmental factors. The heat of hydration is also related to the chemical composition of the cement. The major component of Portland cement is calcium; therefore the expansion of total heat will be affected by the amount of calcium in the cement. High cement content may be useful to obtain higher strengths of concrete in early ages, but the larger heat generated due to the chemical reactions causes undesirable durability problems like shrinkage and thermal cracks in the concrete[7, 8].

In this respect, to minimize the heat of hydration and avoid the high temperature effects on the properties of concrete, the use of pozzolanic materials as a conventional replacement or in higher volume in reducing heat of hydration of concrete is well established[9, 10].The first use of fly ash was made in 1950 at the Otto Holden Dam on the Ottawa River near Mattwa, Ontario[11] and it has been observed that concrete containing 30% fly ash obtained 30% lower temperature than that of plain concrete. The addition of higher volume of fly ash in concrete has been exposed to be helpful in many features of durability due to heat liberation [12] . Other types of pozzolanic materials like slag, silica fume and rice husk ash have been revealed to influence the concrete by lowering heat in massive concrete [7, 12-14].

Manufacture of concrete made by the prepacked method is different from normal traditional concrete, not only in the way of placement but also in that it contains a more amount of coarse aggregate and the grout components [2]. With the development of concreting techniques and materials, utilization of different pozzolanic materials in concrete construction has also been increased. One of the latest supplementary cementitious materials added to the ash family is palm oil fuel ash (POFA), a waste material obtained on burning of palm oil husk and palm kernel shell as fuel in palm oil mill boilers that has been recognized as a good pozzolanic material [15-17]. In view of the utilization of POFA as a supplementary cementing material to prepare grout in prepacked concrete, extensive research works have been carried out in the Faculty of Civil Engineering, Universiti Teknologi Malaysia in examining various properties of prepacked concrete. This paper presents experimental results on the effect of palm oil fuel ash in reducing heat of hydration and strength properties of prepacked concrete.

Materials and Test Methods

Collection and preparation of palm oil fuel ash

Palm oil fuel ash (POFA), is a waste product received in the form of ash on burning palm oil husk and palm kernel shell as fuel in palm oil mill boiler. In this study, POFA was obtained from a factory in Johor, southern state of Malaysia. The collection of ash was done at the foot of the flue tower where all the fine ashes are trapped while escaping from the burning chamber of the boiler. After collection the raw POFA was dried in an oven at a temperature of 110 ^{o}C for 24 hours. Later, it was sieved through 300-μm sieve in order to remove large particles and other impurities and reduce the carbon content to prevent glassy phase of crystallization. To increase fineness, the ashes were then ground in a modified Los Angeles abrasion test machine having 10 stainless steel bars of 12 mm diameter and 800 mm long.

Concrete materials and mix proportions

The selection of coarse aggregate is of great importance with respect to the prepacked concrete. Because, the applied stresses in prepacked concrete are transferred first to the coarse aggregate particles and then to the hardened grout [1, 2]. According to ACI 304.1, the coarse aggregate used in prepacked concrete should be washed, free of surface dust and impurities, and chemically steady in order to attain a high bond with the grout [18].The coarse aggregate used in this study was angular and irregular crushed granite with specific gravity of 2.7, having 0.5% water absorption and size of 20-38 mm. A saturated surface dry mining sand with fineness modulus of 2.3, 100% passing through ASTM Sieve No. 14 having specific gravity and water absorption of 2.6 and of 0.70% respectively was used as fine aggregate. Ordinary Portland cement (ASTM Type I) was used in the study. RHEOBUILD 1100 (HG), a polymer based superplasticizer was used in order to improve fluidity of grout mixture.

The mix proportions of the grout were prepared at water-binder (w/b) ratios of 0.50 and cement to sand(c/s) ratio of 1/5. Superplasticizer was used in order to improve flowability of grout 1% by weight of the binder. In this study, the mixture proportions of the grout were determined according to the ASTM C938 [19]. A total of four mixes were made: one with OPC alone as control and the others with OPC replaced by weights of 10%, 20% and 30% POFA. The relative mix proportions of prepacked concrete mixes are given in Table 1.

Table 1:Mix proportions of PAC samples

Mix	W/B	S/C	Proportion by weight (kg/m^3)					
			Water	Cement	POFA	SP	Fine aggregate	Coarse aggregate
OPC	0.50	1.5	189	378	-	3.78	548	1321
10% POFA	0.50	1.5	189	340	38	3.78	548	1321
20% POFA	0.50	1.5	189	302	76	3.78	548	1321
30% POFA	0.50	1.5	189	265	113	3.78	548	1321

Preparation of test specimens

The casting of prepacked concrete occurs in two stages, placing the coarse aggregate in the mold and injecting the grout to fill the gaps between the aggregate particles. In this study UPVC tubes having 150 mm diameter were placed on a plywood formwork base, the details of which are shown in Figure 1 (a).To ensure uniform rise of grout across the section in the tube, a cone was attached to the platform under each tube. The cone was made from mild steel and contained a steel ball, placed at the bottom of the cone to act as a one way valve. After placing the coarse aggregate in the tube it was capped with a perforated plywood cap which allowed the entrapped air to escape from the tube while also restraining the top portion of the coarse aggregate from the lifting during grouting process.

Figure 1: Grouting methods of prepacked concrete: a) Pump b) Gravity

In the second stage, the grout was injected into the gaps of the coarse aggregate by pump and gravity methods. The mixing of the grout was prepared by an electric mixer which took about five minutes to get the desired grout of well consistency [1]. When the POFA was used in the grout, it was first blended with dry OPC before adding water. In the case of superplasticiser, it was added at the time of final mixing of the grout.

Finally, after mixing the grout, the whole mass was transferred into the grout hoper and was stirred continuously while grouting was in progress to avoid any segregation in the grout mixture. The hand pump, connected to the grout hopper, was used to inject the grout through the aggregates into the tubes. As the tube was full, grout pumping was stopped and the time to fill the tube was recorded. The average time required to fill the 2000 mm long tube was about 120 seconds. In the gravity method, grout was injected to the cylindrical mold through a PVC pipe under gravity force, as shown in Figure 1 (b). After 24 hours of casting, the concrete specimens were demolded and immerged into water tank until test. All the tests were performed at an average room temperature of 27 ^{o}C with the relative humidity, RH of 80 ± 5 %.

Testing of physical and mechanical properties

The effect of POFA content at a different percentage on grout consistency were studied in order to investigate the flow characteristics of the grout according to ASTM C939-10[20].Measurement of bleeding was done according to ASTM C940-10a[21]. 800 ± 10 ml grout was poured inside a 1000 ml glass graduate for various POFA contents of 0%, 10%, 20% and 30% mix proportions to measure the bleeding of the grout mixture. Cube specimens with dimensions of 70×70×70 mm were made to determine the 28 days dry density of the different grout mixture. The compressive and splitting tensile strength tests were conducted with 150 mm x 300 mm cylinder specimens according to ASTM C39/C39M [22] and ASTM C496/C496M [23] respectively.

Measurement of heat of hydration

Heat of hydration is fundamentally the property of cement concrete or mortar in its hardening state. In this study, cubical plywood of sides 280 mm was internally insulated pact with 76 mm thick expanded polystyrene acting as the insulator. Concrete mix with 100% OPC and those with OPC replaced by 10%, 20% and 30% by weight were cast into the cylinder mold of 150 mm diameter and 300 mm height. Prior to casting, a thermocouple (Type K) was inserted into the center of each sample and then, the cylinder was filled only with coarse aggregates and grout injected into the mold through the drilled hole of the polypropylene foam lid and was connected to a computer driven data acquisition system. An insulated cubical box and the test arrangement are illustrated in Figure 2.When grout was poured into the mold; heat was liberated by hydration process and subsequently increased the temperature of the prepacked concrete mass. This rise in temperature and succeeding drop was observed with close interval during the first 24 hour and lesser frequency afterwards until the temperature dropped close to the initial reading. The measurement of temperature was continued up to 140 hours for all the mixes.

Figure 2: Test set up for the measurement of heat of hydration

Results and Discussion

Properties of palm oil fuel ash

Palm oil fuel ash is grey in color that becomes darker with increasing amounts of unburned carbon content. The particles have an extensive range of sizes but they are relatively spherical. The physical properties and chemical composition of OPC and POFA are presented in Table 2. It can be observed that POFA have higher Blaine fineness and lower specific gravity as compared to OPC. The chemical composition suggests that POFA contains low calcium oxide and may be classified between class F and class C according to the ASTM C618-12. It is interesting to note that the present-day classification system for grouping of ashes into class N, class F and class C is not adequate to appraise their total usefulness, particularly for agricultural ashes. Considering the origin and type this ash is, however, neither of class C nor of class F.

Table 2: Physical properties and chemical composition of OPC and POFA

	Physical properties				Chemical composition (%)							
	Specific gravity	Blaine fineness (cm^3/g)	Passing sieve 10 µm (%)	Soundness (mm)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	SO_3	LOI
OPC	3.15	3990	19	1.0	20.4	5.2	4.19	62.4	1.55	0.005	2.11	2.36
POFA	2.42	4930	33	2.0	62.6	4.65	8.12	5.7	3.52	9.05	1.16	6.25

Properties of grout

The basic properties of grout in the manufacture of prepacked concrete are its flow characteristics i.e. grout consistency and bleeding properties. The test results are displayed in Table 3.In the investigation of grout consistency, the effects of different percentage of POFA content with 1% superplasticiser on the fluidity of grout were studied. From the results, it is to note that as the POFA content increases the fluidity of grout also increases. At w/b and s/c ratios of 0.5 and 1.5 respectively, the 10% replacement presented a grout fluidity of 13.9 sec, whereas the 30% replacements exhibited a value of 12.1 for the same w/b and s/c ratios as compared to that of 15.3 sec for OPC grout. Table 3 reveals that, the bleeding of grout mixes containing POFA were relatively less than that of OPC grout. The bleeding capacity of grout which is the ratio of the bleed water to mixing water, for OPC grout with w/b ratio of 0.5, for example, was 10.38% whereas the bleeding capacity of the grouts containing 10%, 20% and 30% POFA for the same w/b ratio were 9.13%, 8.63% and 8.0% respectively. This shows that the POFA used in the grout mixes reduced the amount of bleeding significantly. The dry density of the OPC and POFA grout mixes is illustrated in Table 3. It was found that the density of the grout mixes containing POFA was lower than that of OPC mix. This is to be expected due to the lower specific gravity of POFA (2.42) particle compared to ordinary Portland cement (3.15). For instance, the lowest density of 2116 kg/m^3 was obtained for the grout containing 30% POFA which is 1.5% lower than that of 2145 kg/m^3 for grout with OPC only. Similar trends have been reported in normal concrete containing POFA[24, 25].

Table 3: Properties of grout and prepacked concrete

Mix	Grout fluidity (sec)	Bleeding (%)	Density (kg/m^3)	28-day Compressive strength (MPa)		28-day splitting Tensile strength MPa)	
				Pump	Gravity	Pump	Gravity
OPC	15.3	10.38	2145	33.00	32.60	2.90	2.85
10% POFA	13.9	9.13	2130	35.10	32.90	3.25	2.95
20% POFA	12.8	8.63	2120	33.85	33.20	2.95	2.85
30% POFA	12.1	8.00	2115	28.70	24.95	2.75	2.60

Strength of prepacked concrete

The investigation of strength of prepacked concrete for pump and gravity methods was carried out at age of 28 days. The compressive strength data shown in Table 3 reveal that, using up to 20% POFA in the grout, the compressive strength of prepacked concrete was found to be higher than that of OPC for both pump and gravity samples. The highest 35.10 MPa compressive strength was obtained in the pumped prepacked concrete with 10% POFA, while sample with 20% POFA content showed 33.85 MPa and 33.20 MPa compared to that values of 33.00 MPa and 32.60 MPa for pump and gravity OPC PAC concrete respectively. Further increase in POFA content however, reduced the strength of concrete made by both pump and gravity method.

The splitting tensile strength of prepacked concrete filled with pump and gravity methods was also investigated at age of 28 days. The test results presented in Table 3 revealed that higher the amount of POFA lower was the tensile strength value. For example, the highest strength of 3.25 MPa was recorded for 10% POFA mix filled by pump, whereas a value of 2.90 MPa was obtained for PAC containing OPC alone for the same method. A Lowest tensile strength of 2.75 MPa was, however, recorded for specimen containing 30% POFA having 0.50 w/b ratios, which is around 5% lower than that of prepacked concrete with OPC alone.

Figure 3 reveals the relationship between compressive strength and splitting tensile strength of gravity and pump methods of prepacked concrete at the age of 28 days. A direct relationship between the compressive and tensile strength of two methods can clearly be observed in these figures. A linear regression method was applied to correlate the experimental data resulting in the Eq. (1) and (2), with a coefficient of determination R^2 = 0.91and R^2 = 0.80 respectively.

$$y = 1.3746x - 14.001 \quad (1)$$

$$y = 0.6368x + 0.9172 \quad (2)$$

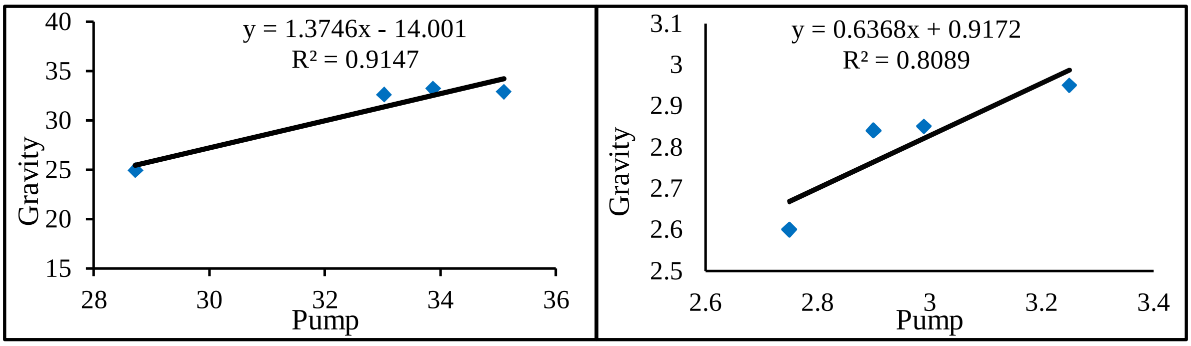

Figure 3: Relation between pump and gravity methods: a) compressive strength and b) splitting tensile strength

Heat of hydration of concrete

The time–temperature histories of different prepacked concrete mixes are displayed in Table 4 and, the growth of temperature due to heat liberation during hydration process obtained at the center of insulated PAC specimens of all the concrete mixes is shown in Figure 4. It can be seen that initially, the temperature increased almost equally in all mixes. However, with the increase in time the effect of the replacement of OPC with POFA can absolutely be noticed. The PAC with grout containing POFA reduced the total temperature rise and furthermore, it delayed the time to reach the peak temperature.

Table 4: Characteristics of heat of hydration of OPC and POFA prepacked concrete

Properties	OPC	10% POFA	20% POFA	30% POFA
Initial temperature ℃	28	28.2	28.1	27.8
Peak temperature ℃	45.2	43	42.1	40.2
Time since mixing to peak temperature (hr)	19.5	22	24	26
Relative reduction in peak temperature (%)	0	5	7	11

A peak temperature of 45.2 ^{o}C was recorded for PAC having OPC grout at 20 hours after grout injected, while 43 ^{o}C and 42.1 ^{o}C were observed for 10% and 20% POFA concrete respectively. A peak temperature of 40.2 ^{o}C was, however, recorded for 30% POFA concrete at 28 hours after grout injecting. Both the OPC and POFA grouts ultimately exposed a slow drop in temperature until a relatively steady state was reached during the test. The reduction in the heat of hydration of mixes can be due to the lower amount of calcium oxide (CaO) in OPC due to the replacement of POFA. In terms of peak temperature and the time to reach at this temperature, grouts containing POFA performed better that that of containing OPC alone. A similar tendency has been reported by Awal and Shehu[7], who observed a reduction of temperature in normal concrete containing high volume POFA from that in OPC normal concrete. The obtained results are also in agreement with Chandara et al.[14], who found out that, total heat of hydration of blended cement pastes containing POFA is lower than OPC paste. Therefore, to reduce the heat of hydration and to avoid the thermal cracks in massive prepacked concrete, utilization of POFA can be a good solution.

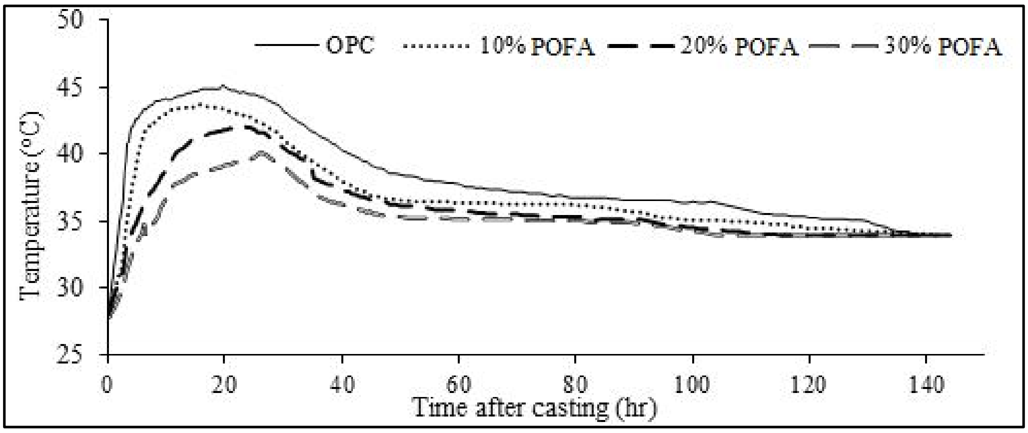

Figure 4: Development of temperature in prepacked concrete mixes

Conclusions

The physico-mechanical performance of prepacked aggregate concrete containing palm oil fuel ash has been outlined in this paper. It has been found that the highest grout consistency based on the flow cone test was obtained for grout with 30% POFA. Also the higher replacement of ordinary Portland cement by POFA resulted in lower bleeding and density of the grout. Incorporating POFA, both the compressive and tensile strength of prepacked concrete was found to increase and these values were higher in the pump-method than that in the gravity-method.

The experimental results in this study further demonstrate that palm oil fuel ash has good potentials in controlling and reducing heat of hydration of prepacked concrete. Although, the maximum strength was obtained for 10% POFA replacement, higher volume replacement of OPC by POFA is advantageous for mass prepacked concrete where thermal cracking due to extreme heat rise is of great concern.

Acknowledgements

The authors wish to acknowledge the help and co-operation received from the technical staff of Structure and Materials laboratory of the Universiti Teknologi Malaysia (UTM) in conducting the experimental work.

References

[1] Awal, A.S.M.A., Manufacture and Properties of Prepacked Aggregate Concrete, M. Eng. Sc.Thesis. University of Melbourne, Australia, 1984.

[2] Najjar,M., Soliman, A., and Nehdi, M.,Critical overview of two-stage concrete: Properties and applications, Construction and Building Materials, 62 2014 47-58.

[3] Champion, S. and Davis, L.,Grouted concrete construction,Reinf Concr Rev, 1958 569-608.

[4] Abdelgader, H.,How to design concrete produced by a two-stage concreting method,Cement and Concrete Research, 29 1999 331-337.

[5] O'Malley, J., and Abdelgader, H.,Investigation into viability of using two-stage (pre-placed aggregate) concrete in Irish setting,Frontiers of Architecture and Civil Engineering in China, 4 (1) 2010 127-132.

[6] Neville, A.M., Properties of Concrete, 4th ed., Longman Group Ltd, 1995.

[7] Awal, A.S.M.A., and Shehu, I.,Evaluation of heat of hydration of concrete containing high volume palm oil fuel ash,Fuel, 105 2013 728-731.

[8] Orchard, D., Concrete Technology, Vol. 1 ed., Applied Science Publisher Ltd, 1973.

[9] Ballim, Y., and Graham, P.,The effects of supplementary cementing materials in modifying the heat of hydration of concrete,Materials and Structures ,42 2009 803-811.

[10] Langan, B., Weng, and Ward, M.,Effect of silica fume and f ly ash on heat of hydration of Portland cement,Cement and Concrete Research, 32 2002 1045-1051.

[11] Sturrup, V., Hooton, R., and Clendenning, T., Durability of fly ash concrete, in 1st International conference on fly ash, silica fume, slag and other mineral by products in concrete, Montebello, 1983.

[12] Malhotra, V.,CANMET investigations dealing with high-volume fly ash concrete,Advances in concrete technology,1994 445-82.

[13] Mehta, P., and Pirtz, D.,Use of rice husk ash to reduce temperature in high-strength mass concrete,ACI J Proc, 75 (2) 1978 60-63.

[14] Chandara, C., Mohd Azizli, K., Ahmad, Z., Hashim, S., and Sakai, E.,Heat of hydration of blended cement containing treated ground palm oil fuel ash,Construction and Building Materials, 27 2012 78-81.

[15] Tangchirapat, W., Saeting, T.,Jaturapitakkul, C., Kiattikomol, K., and Siripanichgorn, A.,Use of waste ash from palm oil industry in concrete,Waste Management, 27 2007 81-88.

[16] Hussin, M.W., and Awal, A.S.M.A.,Palm oil fuel ash- a potential pozzolanic material in concrete construction,Journal of Ferrocement, 27 (4), 1997 321-327.

[17] Bamaga, S., Hussin, M., and Ismail, M., Palm Oil Fuel Ash: Promising Supplementary Cementing Materials,KSCE Journal of Civil Engineering, 17 (7) 2013 1708-1713.

[18] ACI 304.1, Guide for the use of preplaced aggregate concrete for structural and mass concrete applications, American Concrete Institute, ACI Committee, 2005.

[19] ASTM C938, Standard practice for proportioning grout mixtures for preplaced-aggregate concrete, ASTM International, 2010.

[20] ASTM C939, Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method), ASTM International, 2010.

[21] ASTM C940, Standard Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory, ASTM International, 2010.

[22] ASTM C39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, ASTM International, 2014.

[23] ASTM C496, Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, ASTM International, 2011.

[24] Tangchirapat, W., Jaturapitakkul, C., and Chindaprasirt, P.,Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete, Construction and Building Materials, 23 2009 2641-2646.

[25] Johari, M., Zeyad, A., Bunnori, N., and Ariffin, K.,Engineering and transport properties of high-strength green concrete containing high volume of ultrafine palm oil fuel ash,Construction and Building Materials, 30 2012 281-288.