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ORIGINAL PAPER

Heat of Hydration and Alkali- Silicate Reaction in Oil Palm Shell Structural Lightweight Concrete

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Abstract
In this study oil palm shells (OPS) are used as coarse and fine aggregate in making of light weight concrete. OPS are used as aggregate by many researchers but using them as both coarse and fine aggregate in concrete. Concrete with OPS as fine and coarse aggregate are examined for alkali-silicate reaction using concrete motor bar test and concrete prism test. Heat of hydration in lightweight concrete is evaluated with coffee cup calorimeter test. Water absorption test shows OPS has water absorption rate of 20–24% which is very high which helps in internal curing of concrete to takes place which may change the heat of hydration in period of time. Expansion property of mortar or coarse aggregate concrete can be found in mortar bar test and prism bar test. This test reveals the expansion of mortar bar and prism bar is within the permissible limit. Heat of hydration in conventional concrete and OPS lightweight concrete showed the 10–15% time difference in setting time of concrete, difference in heat evolved during OPS lightweight concrete heat of hydration process is 18–22% less than conventional concrete.

Keywords Alkali-silicate reaction · Heat of hydration · Lightweight concrete · Oil palm shell · Water absorption

1 Introduction

OPS are waste material from palm oil industry. Malaysia, India, Nigeria etc. produces OPS waste as these are the leading places having palm trees. 58% of palm oil is exported to all the countries are by Malaysia. 15–4 million tons of OPS wastes are produced annually by Malaysia and Nigeria.

Concrete using OPS as coarse aggregate were coming after the extraction of palm oil from palm oil fruit (A). These shells are cleaned and sieve analysis is carried out, maximum size attained are 12 mm (B) as shown in Fig. 1. Making of concrete with OPS shows reduction of weight to 20–24% that of conventional concrete (CC). Concrete with reduced weight and density below 1900 kg/m^3 are said to be lightweight concrete (LWC). This not only reduces the weight but helps in minimize the size of the members in high-rise buildings [1].

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Concrete made with OPS leads to better internal curing of concrete. OPS has water absorption rate of 20–25% than that of conventional aggregate. While making lightweight concrete, OPS aggregates are immersed in water for 24 h and then used for making of concrete. OPS internal structure is porous in nature and absorbs more water than natural aggregate; this porosity helps the OPS aggregate to maintain the low density which has about 25–30% less than conventional aggregate [2] [3] [4]. Making the concrete with OPS as coarse aggregate shows concrete density ranges from 1800 to 1950 kg/m^3 which is 25–28% lower than conventional concrete [5].

Effect of Alkali-silicate reaction (ASR) in new materials needs to be studied in detail. Even in conventional concrete effect of ASR can be observed when there is reactive silica available in concrete. ASR causes cracking of concrete due to thermal stresses developed by the concrete. Due to presence of Hydroxyl ions in concrete pore solution pressure develops and increase in pH value causes concrete expansion and leads to cracking [6]. Alkali- aggregate reaction caused be reactive silica in aggregate which is a subset of causing ASR [7, 8]. Aggregates used in making of concrete should be free from active silica, and should not react with the pore solution in concrete.

Fig. 1 Palm oil fruit (A) and palm oil shells 12 mm in size (B)

OPS used in lightweight concrete as aggregate should be examined to find out whether there is active silica to react with pore solution in concrete to form ASR. ASR can be identified with the petrographic examination of aggregate as per ASTM C295. For examining of ASR motor bars or prism bars are made according to ASTM C1260, ASTM C 227. These are stored in natural environment for a period of 16 days to 90 days accordingly and examined for regular intervals for ASR in concrete. For ASR to occur there should be high alkali content in the concrete pore solution, and the aggregates used in concrete should be reactive and availability of water in concrete should be more.

Heat of hydration is an important parameter in concrete for setting and hardening process [9, 10]. OPS used in making of lightweight concrete has water absorption rate of 20–25% which leads to internal curing of concrete. This internal curing in concrete supplies continuous water for concrete and makes the hardening and setting process slow when compared to conventional concrete. Heat of hydration in lightweight concrete is examined with the help of coffee cup calorimeter for find out of hydration of concrete and setting time in concrete. Emission of heat is more in mass concrete which leads to increase in thermal stresses then the tensile stresses, so hardening process in important parameter in concrete to develop equal stresses and strength.

2 Experimental Study

The purpose of this research is to find the heat of hydration and Alkali –Silicate reaction in OPS lightweight concrete.

2.1 Materials

Cement used is ordinary Portland cement. OPS lightweight aggregate for fine and coarse aggregate which has specific gravity of 1.28, and density of 350–380 kg/m^3 depending of aging of aggregate. Properties of OPS are given in Table 1. Sodium hydroxide solution is used to make the alkali solution to immerse the prism bars for 16 to 90 days for examining of ASR. 100 mm diameter circular cup with varying diameter from bottom to top is selected and a standard thermometer with 100 degree maximum temperature indicator is chosen for calculating the heat of hydration in concrete.

The following points to be consider for better results

A) OPS aggregates are immersed in water for 24 h before the lightweight concrete is made
B) Special insulating boxes are taken to examine the OPS concrete for heat of hydration using calorimeter
C) Motor bars and prism bars are subjected to normal environment for 16 days and 90 days for ASR to observe in OPS lightweight concrete.

2.2 Sample Preparation

In order to find the OPS concrete for heat of hydration, 100 mm circular cylinder samples were prepared. The concrete sample is placed in the calorimetric cup. The calorimetric cup is made up of insulating material this is also known as coffee cup calorimeter. The calorimeter is covered with a lid,

Table 1 Mechanical and physical properties of OPS aggregate

Compacted bulk density (kg/m^3)	350–480
Water absorption (%)	20–24
Aggregate impact value (%)	21.3
Specific gravity	1.28
Aggregate abrasion value (%)	4.65
Fineness modulus	7.85
Max grain size (mm)	13.2
Thickness of OPS (mm)	0.2–2.7

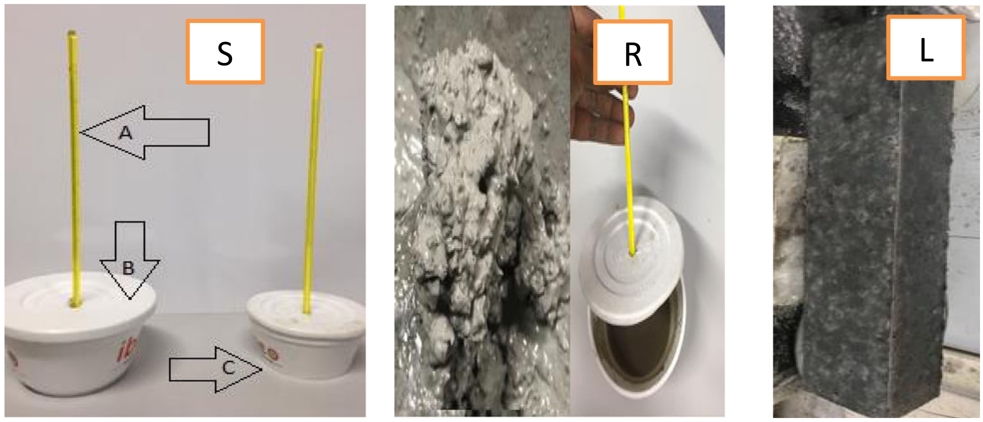

Fig. 2 S- Coffee cup calorimeter setup for heat of hydration test (A- Thermometer, B- Lid, C- Circular cup. R- calorimeter setup after concrete is placed. L- 100*100*500 Prism bar for ASR test

the lid has a small opening with 3 mm diameter. Thermometer with 80^{o} C was taken to measure the heat of hydration in concrete. Prepared concrete specimen is placed in the coffee cup calorimeter and lid is closed immediately without any loss of heat, the entire setup is shown in Fig. 2. Temperature raise in the thermometer is measured as the concrete sets through heat of hydration process. Minute to minute observation is noted in the raise in temperature in concrete, after 24–28 h of observation the temperature fluctuation stops. In the next stage hour to hour temperature is noted as there will not be much fluctuation in the temperature as the initial setting of concrete is done before this stage.

In order to find the ASR in concrete two types of sample preparation is made. For motor bars 200*10*10 mm bars are made and for prism bars 100*100*500 bars are made. As the concrete is lightweight and had density of 1800 kg/m^3 the aggregate to cement ratio is 1:1 and the water cement is maintained to 0.45–0.55 depends on the uniformity and gel formation in lightweight concrete. All the samples are subjected to cure in water for 28 days and then subjected natural environment for 16–90 days depends on the test. Tables 2 and 3 represents the fresh densities, dry densities, water, cement and coarse aggregate, and fine aggregate, water/cement contents. Densities are determined as ± corrections errors of the weighing machine.

3 Results and Discussions

3.1 Alkali-Silicate Reaction (ASR)

Checking of ASR in concrete contains new constituent materials is important to consider. Lightweight concrete contains oil palm shells has the same structural properties as conventional concrete as mentioned by swamy et and by different rearchers, but effect of ASR in lightweight concrete is not mentioned by any researchers. OPS are from natural resources and has silicon dioxide content more than 65% as mentioned by [11, 12]. So OPS aggreagtes should be tested for ASR. Method for determining the potential ASR reactivity is by motar bar test and the prism bar test as per standards. This test helps to find the reactive form of silica is available in the concrete by the expansion developed in the mortar bar during the period of time. IS code represents another test by chemical method to determine the potential reactivity of the aggregates, this test is carried out in 3 days but researchers around recommended this results are inadequate.

For ASR to test two types of samples were examined, acelerated mortor bar test of size 10*10*120 mm and concret prism test of size 100*100*500 mm. In accelerated mortar bar test the sample is demoulded after 24 h and immerced in water for 24 h and the length of the mortor bar is measared by the

Table 2 Mix proportion and density of concrete

Mix	Cement/aggregate ratio	Cement (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)	Water/cement ratio	Fresh density (kg/m^3)	Dry density (kg/m^3)
X 1	1:0.8	500	400	850	225	0.45	1975± 15	1815 ± 10
X 2	1:0.6	500	300	880	225	0.45	1905± 13	1809± 15
X 3	1:0.5	500	250	880	225	0.45	1855± 12	1805± 10

Table 3 Mix proportion for ASR motor bar

Mix	Cement/ fine aggregate ratio	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)	Water/cement ratio	Fresh density (kg/m^3)	Dry density (kg/m^3)
Y 1	1:0.5	450	275	202.5	0.45	927	860
Y 2	1:0.8	450	360	202.5	0.45	1012	955
Y 3	1:1	450	450	202.5	0.45	1102	1068

digital vernier callipers which has least count of 0.02 mm. The strain gurage which has a least count of 0.005 mm is used to measured the mortor bar test equipment as shown in Fig. 3. The prism bar specimnes are immersed in sodium hydroxide solution for 7 days and later again examin for the expantion of prism bars, the average expantion of samples readings are given in Table 4. Test samples and test equipments are shown in Fig. 3.

The ASR reaction in the two types of concretes is between silicious constituents in the concrete. The available silica in the pore solution of concrete and the reactive silica in the aggreagtes leads to ASR. During the hydration process potassium hydroxide and alkali-sodium were released and effects the constituents of the concrete which help in development of ASR in concrete. The pore solution reacts with hydroxil ions in the concrete and the concrete tends to expand the expanded concrete is measured with the motar bar eqipment as shown in Fig. 4 IS: 2386 (Part VII) – 1963. the excess of expantion in motar bar lead to crack in the concrete. The pore solution or cementious gel effects due to the following condtions

- Quantity of reactive silica present in the aggreagte.
- Free water availability to allow external sources to enter the concrete
- Prsence of hydroxyl ions, sodium and potassium in the pore solution in the concrete

The test results reveals the expaniton of mortor and concrete test specimens are in the permissible limit. The expation of mortar bar is 0.038 mm for 16 days and 0.039 mm for 90 days where as expantion in concrete specimen is 0.041 mm for 16 days and 0.0425 mm for 90 days. This shows the OPS lightweight concrete shows similar expantion in mortar bar and prism bar as compared to conventional concrete. So OPS can be used as coarse aggreagte and fine aggreagte in concrete and these can be used as alternate coarse aggreagte in concrete. OPS concrete microstructure is studied using LECA microscope which had zoom of 25 micro meters. Concrete specimen as shown in Fig. 4 shows the ASR in OPS lightweight concrete, which doesn't have any crack pattern along the aggreagte to the cement matrix. This is similar as in case of conventional concrete.

3.2 Heat of Hydration

Hardening process in concrete is accompanied by the development of heat, the process so called heat of hydration. This heat of hydraition deos not effect the quality of the concrete but large masses like dams and in cold weather conditions this

Fig. 3 Shows the motor bar mould with test equipment and concrete prism of 100*100*500 mm size

Table 4 Strain guage readings for ASR in Mortor bar and Prism bar test

Sample	Aggreagte	Expantion after 7 days (mm)	Expantion after 90 days (mm)
X1	OPS Coarse	0.041	0.0425
X2	OPS coarse	0.045	0.0455
X3	OPS coarse	0.042	0.0422
Y1	OPS fine	0.038	0.039
Y2	OPS fine	0.036	0.037
Y3	OPS fine	0.036	0.0365

heat of hydration place an important role as reported by [5]. This heat of hydraition is represented in the form of time-temperature function, an analytical formulaiton is developed to represent the heat evolved in lightweight concrete. Test setup as shown in (Fig. 2), calorimeter setup used to represent the heat of hydration in concrete. Lightweight concrete is placed in calorimeter cup and closed with the help of lid, small openeing is inserted on top of the lid for thermometer of 100 °C to go trough the lid and place above the tip of the concrete. Concrete sample is placed in the calarimeter and immediately closed with the lid. As the heat of hydration starts immediately after the water is in contact with the cement. Exothermic process of concrete strats at this stage of contact, so the process of placing lid and thermometer insertion should be done instently after the wateris added to the cement. Second to sencond and minites to minutes change in temperature in thermometer reading is noted and observed.

As the source of heat for the calorimeter is by the heat of hydration process that comes form the lightweight concrete, as this heat of hydration develop in a relatively short time intervel the process of mixing and placing of lightweigt concret should be quick. By this procedure the concrete specimen placed in the calorimeter is caused to set without absorbing heat or dispressing heat to the surrouding. The temperature released

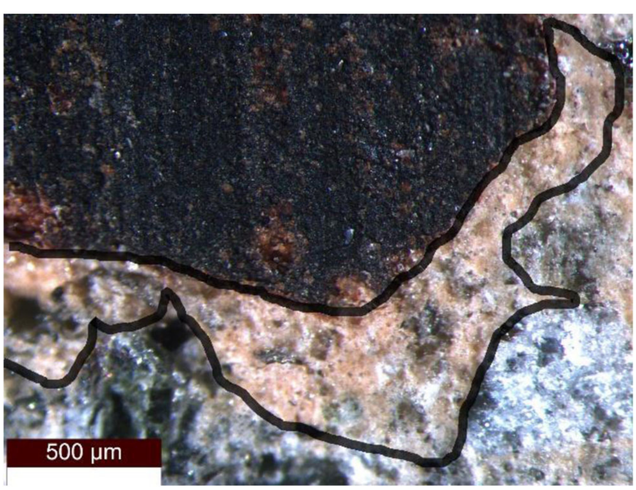

Fig. 4 An ASR reaction in OPS lightweight concrete

during this process is proportional the "adiabatic heat of hydration". This can be expressed as

$$V^*c^*R^*d\theta = V^*C^*dQ \tag{1}$$

$$\theta = S^*Q/R^*c \tag{2}$$

V volume of concrete,
c Cement content,
R density of concrete,
S specific heat,
Q heat of hydration

Calculations for heat of hydration for lightweight concrete is carried out with the formula 1 and 2, the properties of oil palm shell lightweight concrete that required to find the heat of hydration are cement content 500 kg/m^3, density of concrete 1820–1880 kg/m^3, specific heat 1.207, θ is raise in temprature that indicated by thermometer at different time intervel as shown in Table 5.

Two types of concrete are investigated for heat of hydration process and heat evolution. Concrete with conventional aggreagte (Conventional concrete) and concrete with oil palm shell as coarse aggreagte (Lightweight concrete). Conventional concrete has higher temperature readings through out the hydration process where as Lightweight concrete shows less temperature readings as shown in Table 5. Change in temperatures for both the concretes takes place in high fluctuations in the initial stage of setting, change in temperatures can be seen in the minutes to minutes observations. Fluctuations in calorimeter stoped after the initial setting of concrete is seen. Hour to hour examinations of concrete doesn't have much rise in temperatures but after 26–28 h the change in temperatures can be seen. This changes in calorimeter are due to the available water in the pores of the concrete is drying and concrete tends to set completely. Lightweight concrete had aggreagtes which are porus in nature and contains more water absorption rate then conventional aggragte, supply of water is continous form aggreagte to cement paste in lightweight concrete and the hydration of concrete is slow in

Table 5 Temperature and time readings for lightweight concrete and conventional concrete

Time (minutes)	Temperature (°C)		Time	Temperature (°C)	Temperature (°C)	Time	Temperature (°C)	
	LWC	CC	minutes	LWC	CC	hours	Lightweight concrete	Conventional concrete
1	27.1	28.3	18	28.6	30.9	6	30.2	32.5
2	27.3	28.6	20	28.7	31.3	8	30.3	32.4
4	27.5	29	30	28.9	31.8	10	30.4	32.3
6	27.6	29.2	40	29.2	32.1	12	30.4	32.3
8	27.8	29.4	50	29.6	32	14	30.4	32.2
10	28	29.7	60	29.9	32.2	16	30.5	32.1
12	28.2	29.9	120	30.1	32.2	18	30.6	31.6
14	28.3	30.1	240	30.2	32.3	20	30.6	31.5
16	28.5	30.5	360	30.1	32.4	22	30.5	31.4

lightweight concrete. Whereas in case of conventional concrete supply of water to the surrounding cement paste is limited and the hydration of concrete stop after the period of time.

Figure 5. represents the time-temperature funcition for heat of hydration of conventional concrete and lightweight concrete, in the graph ordinate represents temperature and abscissa represent time. As temperature raise in conventional concrete is due to the supply of water from aggregate is limited and seeting of concrete is very fast, 24 h setting time with temperature 32.1 °C is the maximum time and maximum temperature attain by the conventional concrete. Where as in case of lightweight concrete setting of concrete is takes place as the maximum temperature of 30.2 °C @ 36 h. By this we can conclude heat released in lightweight concrete is less as compared to convention concrete as the temprature and heat is directly proportional to each other as shown in Fig. 6. Figure 6 represents heat of hydration in Lightweight concrete and conventional concrete, maximum emission of heat in Lightweight concrete is 36.9 C/g where as in case of conventional concrete is 44.6 C/g. Heat Stresses developed in lightweight concrete is less when compared to conventional concrete. Hence development of cracks due to thermal stresses are neglegible in case of lighweight concrete.

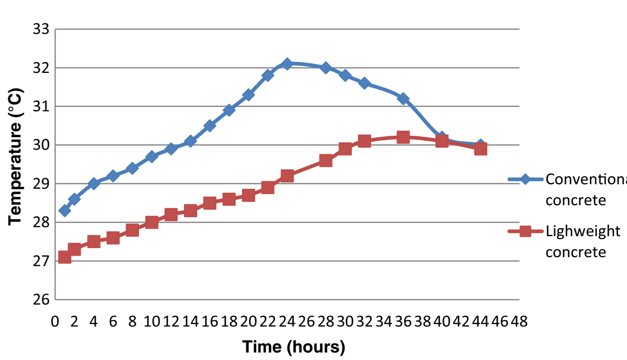

Fig. 5 Temperature vs time function for Conventional concrete and lightweight concret

4 Conclusions

Using of OPS in concrete helps the concrete undergoes low heat of hydraion then the conventional concrete. Using of OPS as coarse aggreagte in concrete hepls in reducion of weight up to 28% of the conventional concrete. Heat of hydration process ends @28–32 h which helps the concrete undergo minimum tensile and thermal stresses then the conventional concrete. Porous nature of OPS which had high amount of water then the conventional aggreagte helps the concrete to go heat of hydration process slow and helps to maintain the stresses in the concrete. Emission of heat in Lightweight concrete is 18–22% less when compared to Conventional concrete. ASR in lightweight concrete is adequate and can be used in constructions, the expantion of concrete is minimum even after the 90 days of the curing period. No traces were found on the top surface of the OPS lightweight concrete that resembles the ASR, so using of OPS in structural elements in construction can be made with out any hesitation.

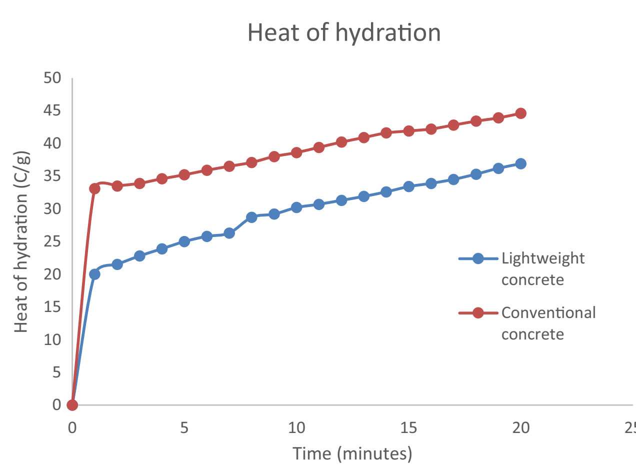

Fig. 6 Heat of hydraition in Lightweight concrete and Conventional concrete

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