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High Strength Concrete Incorporating Oil-Palm-Boiler Clinker as Coarse Lightweight Aggregate

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Abstract. Construction industry demands for high amount of raw material to produce concrete. The constant reduction of natural resources results in negative impact to the environment and lack of raw material. Promotion of utilization of agricultural wastes in production of concrete can minimize the environmental impact towards the sustainable development. In this study, the oil-palm-boiler clinker (OPBC) which is an agricultural waste from palm oil industry was used to substitute the crush granite in conventional concrete from 0 to 50% by volume in increments of 12.5%. Tests conducted in this study were compressive strength in different curing regimes, flexural strength and water absorption. The test results showed that concretes containing 37.5 to 50% OPBC can be categorized as semi-lightweight aggregate concrete with high strength. This aggregate has considerable potential for performing internal curing in concrete. Using OPBC in concrete reduced the flexural strength; however, the reduction was not significant. Although water absorption showed that concretes containing OPBC have slightly higher water absorption, however, all these concrete could be considered as good quality concrete.

1. Introduction

Due to the rapidly growing world population, the demand for and cost of building materials is tremendously ascending [1]. In order to cater to market demand and economic factors, the constant reduction of natural resources has resulted in the negative impact to the environment and shortage of raw materials. Some excessive wastes were disposed to dumping sites and this led to environmental pollution. Nowadays, many researchers focus on utilization of solid waste discharge from agriculture to full or partial replacement of raw material in the construction industry. Therefore, many researchers are interested to explore the use of waste and utilize it as full or partial replacement of raw material for sustainable development [2]. In the past, the unwanted materials that has been utilised in construction sector, such as oil-palm-boiler clinker (OPBC), oil palm shell (OPS), corncob rice husk, coconut shell, tobacco waste and coconut shell [3].

Malaysia is well known for its palm oil industry and is considered the second largest country in the world to produce palm oil [4]. However, the palm oil industry generates million tons of agricultural wastes yearly and is classified as the main source to contribute the environmental pollution in the country. This kind of waste is known as oil-palm-boiler clinker (OPBC) and is obtained from the



boiler of every palm oil mill through the process of incineration of oil palm shell and fiber. In Malaysia, OPBC is abundant with little selling value and easily to obtain from palm oil mill. Other than using OPBC as a landfill material, this agro waste has high potential to convert into construction materials. OPBC that are crushed and sieved into required sizes is found suitable to replace normal gravel aggregate in concrete mixture as OPBC is highly porosity, irregular shape with thorn. It also possesses good lightweight nature [5].

In construction industry, there is always special attention to the use of lightweight structures due to their significant advantages. For example, cable-stayed bridge with the length of long span and small scale structure is considered as lightweight structures [6]. The weight of concrete structures can be reduced significantly if structural lightweight concrete is used instead of conventional concrete. The common method for manufacturing structural lightweight concrete is to replace coarse aggregate with lightweight aggregate and the fine aggregate with normal sand. The OPBC as lightweight aggregate can be used to produce structural lightweight aggregate concrete due to OPBC possessing lightweight characteristics [5].

The main objective of this study is to evaluate the effect of the partial substitution of crushed granite with OPBC from 0 to 50% in increments of 12.5% in high strength normal weight concrete on the compressive strength with different curing regimes, flexural strength and water absorption.

2. Experiment

2.1. Materials and properties

The binder used was ordinary Portland cement (OPC) with the Blaine specific surface area and specific gravity of 3510 cm²/g and 3.14, respectively.

The coarse aggregate was OPBC and crushed granite. The OPBC in lump was sourced from palm oil producing mill in Dengkil. Figure 1 shows the OPBC in a lump. Prior to using the OPBC, it need to be washed for removing the dust, then crushed into 9.5 mm maximum nominal size by the crushing machine.

The fine aggregate was normal sand which sourced from a local mine. All the aggregates were used in dry condition. The physical properties of aggregates was shown in Table 1. The water sourced from normal tap water. To facilitate the dispersion of cement particles and improvement of concrete workability, a super-plasticizer (SP) was used in all mixes.



Figure 1. OPBC in a lump.

Table 1. Physical properties of aggregates.

Aggregate	Specific gravity	Compacted bulk density (kg/m ³)	Water absorption (%)	
			30min	24h
OPBC	1.9	1409	2.31	4.11
Granite	2.67	1453	0.53	0.72
Sand	2.65	1615	1.12	1.21

2.2. Mix proportions

All mixes were containing of OPC with 500 kg/m³. The crushed granite was replaced with OPBC from 0 to 50% by volume of total crushed granite. The percentages of replacements were from 0 to 50% with an increment of 12.5%. Table 2 shows the mix proportions for all mixes.

Table 2. Mix proportions of concretes (kg/m³).

Material	Mix code				
	C	C12.5	C25	C37.5	C50
OPBC	0	81	162	243	324
Granite	910	796	683	569	455
Sand	760	760	760	760	760
Cement	500	500	500	500	500
Water	170	170	170	170	170
SP	5	5	5	5	5

2.3. Test method

The casting ingredients were well prepared. First, all aggregates were placed into rotary drum mixer for two minutes. Secondly, OPC cement was placed into mixer with aggregate mixing for further three minutes. Thirdly, 70% water mixing with SP was poured into mix until well blended. Lastly, the balance water was added into the mix for five minutes. Then the mixture was to precede the slump test to determine the workability of the concrete.

In order to investigate the effect of different curing regimes on the compressive strength at the age of 28 days, the 100 mm cubes were performed under different curing regimes after 24 hours of casting. The different curing regimes are described in Table 3. Besides, the prisms of 100 mm x 100 mm x 500 mm beam for flexural strength and 100 mm cubes for water absorption tests were conducted after 27 days of water curing.

Table 3. Curing regimes.

Curing code	Description
AC	Specimen to be kept in air in a laboratory condition with RH% of 73 ± 5 and temperature of 29 ± 3 °C after demoulding
3W	Specimen kept in water for 2 days after demoulding and then kept in air under laboratory condition
5W	Specimen kept in water for 4 days after demoulding and then kept in air under laboratory condition
7W	Specimen kept in water for 6 days after 1 day demoulding and then kept in air under laboratory condition
FW	Specimen kept in water for 27 days after demoulding

3. Results and discussion

3.1. Compressive strength

Table 4 shows compressive strength at the age of 28 days under continuous moist curing and different curing regimes of all mixes. It was reported by Khoshkenari et al. [7] that the density of semi-lightweight aggregate concrete is between 1840 and 2240 kg/m³. Therefore, the mixes of C37.5 and C50 in this study are considered as high strength semi-lightweight aggregate concrete. However, the mixes of C, C12.5 and C25 are under category of high strength conventional concrete. The high strength conventional concrete inclusion of 50% OPBC (mix of C50) showed the satisfactory workability without reducing compressive strength compared to mix of C37.5 under continuous moist curing. The control concrete mix (mix of C) and concrete containing low volume OPBC (mixes of

C12.5 and C25) shows a slight decrease on the compressive strength at the age of 28 days under AC condition. However, at higher OPBC contents (mixes of C37.5 and C50), the compressive strength has the same (or higher than) compressive strength at the age of 28 days as for the full water curing condition. In addition, these two mixes have equivalent strength to the control mix in AC condition. The test results clearly show the potential for using high volume OPBC in concrete mixture for improving compressive strength when proper curing is not provided for concrete.

All partial early curing exhibits a considerable effects on the compressive strength at the age of 28 days. The effectiveness is more significant for concrete containing a higher volume OPBC. Increasing the period of water curing gives improvement of concrete strength. Similar to AC curing conditions, improvement in the compressive strength of C37.5 and C50 concrete mixes is more than for the other concretes. This shows that OPBC aggregates provides internal curing leading to further improvement of the compressive strength.

Compared to full water curing, the highest improvement of compressive strength is exhibited in the 7W curing condition. Therefore, 7-day wet curing in concrete is recommended in most codes of practice [8]. However, it can be seen from Table 4 that for the 3W curing regime, the compressive strength is the same as the standard curing for control mix and for mixes containing low volume OPBC, while it is even higher for concretes containing high volume OPBC.

In general, it can be concluded from Table 4 that when crushed granite as coarse aggregate in the control mix is substituted by OPBC in high volume (more than 37.5%), water curing is not necessary. This may be a great advantage for using these wastes as coarse aggregate in concrete in that we know that the curing cost is about 0.1 to 0.5% of the concrete members in construction expenses [9].

Table 4. Slump, density and compressive strength of concretes under different curing regimes.

Mix No.	Slump (mm)	Oven dry density (kg/m ³)	The 28-day compressive strength (MPa)				
			FW	Partial early curing			
				AC	3W	5S	7W
C	160	2308	71.7	68.8	71.7	80.6	80.6
C12.5	140	2298	74.4	72.9	76.2	74.7	84.9
C25	130	2242	72.0	72.1	72.1	76.3	78.0
C37.5	85	2225	68.1	67.7	72.0	75.0	77.1
C50	75	2202	68.1	71.9	72.2	73.3	77.0

3.2. Flexural strength

The flexural strength at the age of 28 days of all concrete mixes is shown in Table 5. Compared to control mix, the concrete mixes containing OPBC show a lower flexural strength. For the compressive strength of concrete exceeding 25MPa, the flexural strength generally appears about 8 to 10% of 28-day compressive strength [10]. The ratio of flexural strength to compressive strength of concrete containing OPBC in this study is in the range of 9.3-10% within the usual range. Previous studies have revealed that this ratio for high strength lightweight concrete is about 9-11% [11]. Therefore, the ratio for concrete containing OPBC in this study is within this range.

Table 5. The flexural strength and compressive strength of concretes (MPa) at age of 28 days.

Mix No.	f_{cu}	f_r	$\frac{f_r}{f_{cu}}$ %
C	71.7	7.87	11
C12.5	74.4	6.94	9.3
C25	72	6.98	9.7
C37.5	68.1	6.83	10
C50	68.1	6.66	9.8

3.3. Water absorption

Measurement for the quality of concrete based on initial water absorption (water absorption in 30 minutes) has been recommended by the CEB-FIP as poor, average and good for the ranges of 5% and above, 3-5% and 0-3%, respectively [12].

Figure 2 showed the initial and 24-hour water absorption for concrete mixes at the age of 28 days. This figure shows that increasing substitution of OPBC coarse aggregate in the mixture shows slightly increasing water absorption. This is due to water absorption of OPBC is much higher than that of crushed granite by about six times. The texture surface of OPBC aggregate is very porous compared to crushed granite. The water is absorbed into porosity of OPBC grain and hence increases the water absorption. However, it is noted that the initial absorption for concrete mixes is lower than 3%, which can be considered as good quality concrete by CEB-FIP [12]. The results show that even 24 hours water absorption of OPBC mixes are still less than 3%.

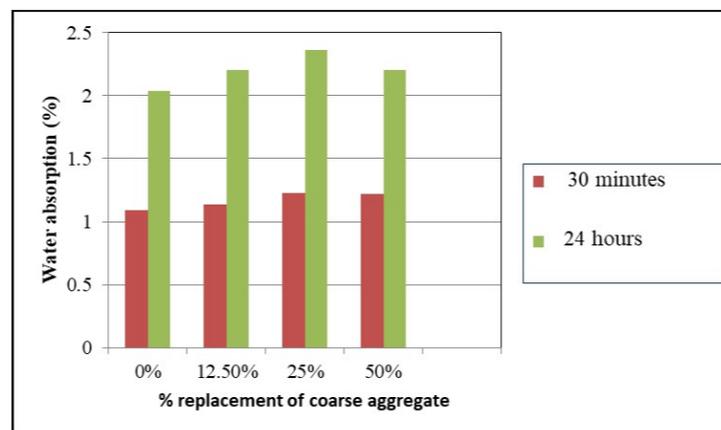


Figure 2. Relationship between OPBC volume and water absorption.

4. Conclusions

From the results obtained in this study, the following conclusion can be drawn:

1. High strength semi-lightweight aggregate concrete with good workability could be manufactured by inclusion of 37.5 to 50% lightweight OPBC as coarse into normal weight concrete.
2. Concrete containing 12.5% OPBC has the highest compressive strength among the different curing conditions compared to the other concrete mixes. Therefore, it is recommended that at least 12.5% of conventional coarse aggregate to be replaced with OPBC in concretes.
3. Two days wet curing is sufficient for OPBC concretes to obtain the equivalent compressive strength of the concrete under full water curing. However, increasing the wet curing time to 4 and 6 days results in a higher compressive strength than the standard curing. Therefore, it is expected that OPBC coarse aggregate has great potential for internal curing.
4. Inclusion of OPBC in conventional concrete decreases the flexural strength.
5. With increasing the replacement of normal coarse aggregates with OPBC, the water absorption of mixture increases. A concrete containing OPBC up to 50% of the total volume of coarse aggregate can still be categorized as good concrete.

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