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EFFECTS OF PALM OIL CLINKER AS COARSE AGGREGATES REPLACEMENT IN SELF CURING CONCRETE

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Abstract: Concrete, if properly design, can be one of the most durable material and widely used in construction due to its availability and good compressive strength. A good quality concrete can be produced not only through good design of concrete mix proportions but also good and proper curing process that ensure a complete hydration process of the cement. However, sometimes proper curing process was not provided during concreting on site due to various reasons. This study investigates the effects of 10 mm crushed Palm Oil Clinker (POC) as partial aggregates replacement to act as internal reservoirs in concrete to provide internal curing process of cement. This process or technique is also popularly known as self-curing process for concrete. The POC which has the density of 780 kg/m^3 was used to replace 20% of the coarse aggregates. A water/cement ratio of 0.53 was used in the concrete mix design. Three different curing conditions were employed, namely, normal water curing, air curing and 7 days in water plus outside curing conditions. The workability of the POC and control concretes was determined through slump test. The concrete samples were tested for compression at the age of 3, 7 and 28 days while concrete prisms and cylindrical samples were tested at the age of 7 and 28 days. The experimental results show that the inclusion of POC was found to increase the workability of concrete by 27% but reduced the concrete compressive strength by about 6% compared with the control concrete. In addition, the flexural and tensile strengths of POC concrete were found to be less than the control concrete due to the properties of the POC which was lightweight and porous. The experimental results show that the porous structure of the POC aggregates can be utilised as water reservoir for the process of internal curing for the self-curing concrete.

Keywords: *concrete, palm oil clinker, self-curing concrete, compressive strength, hydration*

1.0 Introduction

A properly design and good manufacturing enable concrete which is made of cement, aggregates, water and admixtures to withstand the desired loadings and durable for its intended design life. Cement hydration is a process of cement reacting with water producing C-S-H gel and calcium hydroxide that will determine the quality of concrete. Somayaji (1995) states that dry cement do not possess the cementing or binding properties. One of the factors to produce good quality concrete is that the concrete must be cured properly in order for the concrete to achieve its design strength and durability. Instead of using normal external water curing, another alternative or technique that can be considered is to use internal self-curing method. For this method, the amount of water for curing will be reduced significantly compared with normal curing. The concept is still the same, providing water for the hydration process; only differ by the way to supply water for hydration. This method was introduced around two decades ago but still it is not being widely used in practice.

At present there are a few materials that can possibly be used as internal curing agent such as Super Absorbent Polymer (SAP), Palm Oil Clinker (POC) and sawdust. It was found that these type of materials can absorb water and retain water for a longer period of time. Thus, it may provide additional water in the concrete and acting as an internal curing. Continuous water evaporation from concrete surface due to improper curing will reduce the capability of cement hydration process to be completed. So, the function of this absorbent material is to provide water in the mix and mainly form hydrogen bond with water molecules, reduces chemical potential of the molecules which in turn reduces the vapour pressure thus, decreasing the evaporation from the surfaces (Tarun *et. al.*, 2006). In practice, many problems exist at construction site including curing process. Normally on site, the common curing methods used are fogging (water spray) and wet curing. A research by Michigan (1997) indicates that fogging method is efficient in helping to reduce plastic cracking in concrete especially for low water/cement ratio concrete. Fogging process will reduce the moisture loss before and after the finishing concrete. Unfortunately, the loss of water will make the concrete shrink that leads towards plastic shrinkage cracking (Bushra *et. al.*, 2011). This method, however, needs a large amount of water for the purpose of curing process. Since the water is sprayed on concrete surface, the water will dry out depending on the humidity and surrounding temperature. After the concrete hardened, curing using wet covering is applied to the concrete surface. Fabric covering such as burlap is used for curing purpose. Burlap requirement is described in AASHTO M182 in the Specification for Burlap Cloths Made from Jute or Kenaf. Burg (1996) states that moisture retaining covering should be applied to hardened concrete as soon as possible whenever the concrete is already hardened. This is to ensure moisture inside concrete is kept and prevented from evaporating to be used for the hydration process. However, in-situ concrete is cast in many shapes, forms and locations throughout the buildings. When it is involve with difficult locations or complicated shape, this method of curing is not practical to be used.

2.0 Previous Work

A study on self-curing concrete conducted by Naik and Fethullah (2006) stated that water efficiency in internal curing of high strength concrete able to eliminate autogenous cracking. This study shows that high performance concrete with low water cement ratio will have high resistance to internal cracking. It is because autogenous cracking cannot be eliminated by water curing method. Therefore, it is seen that internal curing is one of the options that can be used in reducing autogenous cracking.

Malaysia is one of the largest palm oil producing countries in the world and as a result many waste products are produced. Some of the wastes from this industries are Oil Palm Shell (OPS), empty fruit bunches, palm oil fibre and palm oil fuel ash. Palm Oil Clinker (POC) is a product of palm oil fibre and OPS burnt at 850^{o}C for electricity generation in palm oil industries. Generally, the proportion of palm oil fibre and OPS burnt was 70:30 and Shafigh (2014) reported that POC is available in boulder sizes ranging from 100 to 300 mm. It can be crushed into smaller and desired sizes for the production of concrete. In addition, the POC had a specific gravity of 2.08 and compacted bulk density of 780 kg/m^3. Since POC has many voids, it is expected that it can absorb and store water and act as internal reservoir in concrete for the hydration of cement. A study by Kanadasan (2015) showed that different states have different chemical composition of POC due to different soil composition in Malaysia that contributed to the POC chemical composition. Furthermore, chemical variations in POC were influenced by the burning temperature of POC in the boiler. At low temperature of burning, the pyrolysis process might be incomplete and lead towards variation in the POC chemical composition.

Due to the importance of curing process in ensuring the quality of concrete and sometimes the difficulties to do the curing, other new methods need to be investigated and explored. In this study, Palm Oil Clinker (POC) obtained from palm oil industries was investigated for its possibility to be used as water absorbent material for the internal curing process of concrete.

3.0 Experimental Programme

3.1 Materials

The materials used in concrete mix were coarse aggregates, fine aggregates, water, Ordinary Portland Cement (OPC), and Palm Oil Clinker (POC). The OPC used in this experiment was obtained from Tasek Cement conforming to BS EN 197-1:2000. The POC were obtained from palm oil industry in Kulai, Johor. The estimated bulk density of POC was 780 kg/m^3 and was crushed into 10 mm nominal size as coarse aggregates. Figure 1 shows the POC used in the study showing its rough texture and irregular shape. Normal tap water was used in the concrete mixing process.

Figure 1: POC used in concrete mix

3.2 Mix Proportions

The design compressive strength of concrete used in the study was 30 MPa with water-cement ratio of 0.53. The concrete mix proportion was designed according to the Department of Environment (DoE) method. The design slump for workability measurement was in the range of 60-180 mm using nominal crushed aggregates with the size of 10 mm. Table 1 shows the design mix proportions for concrete used in the study. In this experiment, the POC was used to replace part of the coarse aggregates by 20 percent.

Table 1: Proportions of concrete constituents

Material (kg/m^3)	*CPOC*	*CCON*
Cement	472	472
Water	250	250
Fine Aggregate	720	720
Coarse aggregate	702	702
Water Absorbant Material (POC)	176	-

3.3 Samples Preparation

Concrete cubes, 100x100x100 mm, were prepared and cast, cured and tested at the ages of 3,7 and 28 days while for the cylindrical specimen with the diameter of 100 mm by 200 mm height and prism of 100x100x500 mm were cast and tested at the ages of 7 and 28 days. The standard steel mould was used in the preparation of the samples. The concrete ingredients were mixed using mechanical concrete mixer and were poured into the mould and compacted using vibrating table. After 24 hours, the concrete samples were demoulded and cured in the designated curing regimes either water curing, air curing or 7 days in water then air curing. All the self-curing concrete properties such as concrete compressive strength, tensile splitting strength and flexural strength were determined and compared with the control concrete.

3.4 Fresh Concrete Test

The workability of the POC concrete (CPOC) and control concrete (CCON) was determined through slump test. The slump test was carried out in accordance to BS1881: Part 102: 1983.

3.5 Hardened Concrete Test

The type of tests conducted in determining the properties of CPOC and CCON concretes include compression test, modified compression test, tensile splitting test, flexural test and ultrasonic pulse velocity test. The compression test was carried out in accordance to BS1881:116 (1983). On the other hand, the modified compression test was performed using part of the broken prisms that has been used for flexural test. The tensile splitting strength test was carried out in accordance to BS1881-117. Flexural test is a common test used in determining the indirect tensile strength of concrete. The testing procedures used in the study are stated in BS EN 1015-11: 1999. The Ultrasonic Pulse Velocity (UPV) test is a non-destructive test that can be used to assess the homogeneity of concrete. This method used high frequency sound wave in the range of 25 to 60 kHz penetrating through concrete from a source that transmits the pulse to receiver of the portable test equipment. The UPV test was carried out according to BS 1881: Part 203.

4.0 Results and Discussions

The experimental results gathered from the tests and the analysis of the data is presented in the following sections.

4.1 Workability of Concrete

Based on the slump test results, the CPOC concrete was found to exhibit higher workability compared with control concrete (CCON). The recorded slump for the CPOC concrete was about 27% higher than CCON concrete. This may be due to the influence of water absorbed in the POC that was used as coarse aggregates. In terms of water absorption test, the POC aggregate absorbed about 5.1% of water because the POC aggregates has many voids that enable water to be absorbed and stored. Table 2 shows the slump of CCON and CPOC concretes tested in this study.

Table 2: Workability of CCON and CPOC concretes

Types of concrete	*Slump (mm)*
CCON	110
CPOC	140

4.2 Compressive Strength

The compression test of cube samples was conducted at the age of 3, 7 and 28 days and the results are shown in Table 3. The compressive strength with different curing regimes was compared between the self-cured concrete (CPOC) and control concrete. It can be seen that the CPOC concrete in 7 days water + outside curing recorded the highest 3 to 28 day and 7 to 28 day strength ratios with 0.632 and 0.797, respectively. On the other hand, the CCON concrete in water curing exhibited the lowest strength ratio of 0.568 and 0.734, respectively. The results indicate that the hydration process rate of CPOC concrete in 7 days water + outside curing was more rapid than the other samples. It is probably due to the extra water supplied by the POC aggregates for the CPOC concrete internal curing and water curing process. The CPOC concrete most likely to have undergone both internal and external curing processes that ensuring the cement hydration process of CPOC concrete is better than CCON concrete.

Table 3: Compressive strength of CPOC and control concretes

Types of Concrete	*Curing*	*Age (days)*	*Compressive Strength (MPa)*	*Strength Ratio*	
				3/28 days	*7/28 days*
CPOC	Water	3	22.2	0.615	0.754
		7	27.2		
		28	36.0		
	Air	3	19.2	0.593	0.755
		7	24.9		
		28	33.0		
	7 days water+ Outside	3	19.2	0.632	0.797
		7	24.2		
		28	30.4		
CCON	Water	3	21.8	0.568	0.734
		7	28.1		
		28	38.3		

4.3 Flexural Strength

Flexural strength test of the samples was carried out at age of 7 and 28 days. Similar to compressive strength test, the flexural strength results for the CPOC concrete was obtained and compared with the control concrete as shown in Table 4.

Table 4: Flexural strength of CPOC and control concretes

Types of Concrete	*Curing*	*Age (days)*	*Flexural Strength (MPa)*	*Strength Ratio 7/28 days*
CPOC	Air	7	1.57	0.755
		28	2.08	
	7 days water+ Outside	7	1.90	0.776
		28	2.45	
CCON	Water	7	2.30	0.697
		28	3.30	

Table 4 shows the strength ratio of the flexural strength at the age of 7 to 28 days of different concretes and different curing conditions. From the table, the CPOC concrete in 7 days water + outside curing exhibited higher strength ratio, while the CCON concrete in water curing had lower strength ratio with 0.697. The highest flexural strength at 7 days was recorded for CCON concrete sample in water curing condition. The flexural strength of CCON concrete was about 31.7% higher than CPOC concrete in water curing condition. For concrete at the age of 28 days, the CCON concrete sample in water curing recorded flexural strength of about 36.9% higher than CPOC sample in water curing. This can be explained due to the existence of many voids inside the CPOC samples. The voids create more failure modes inside concrete that will significantly reduce the concrete strength. On the other hand, the flexural strength at 28 days for CPOC concrete in 7 days water + outside curing was about 15.1% higher than the CPOC concrete in water curing condition. This result happened due to properties of the aggregate inside CPOC concrete in which replacement of coarse aggregate by POC was found to reduce the flexural strength and concrete loading capacity.

4.4 Modified Compressive Strength

The modified compression test was carried out after the flexural test has been conducted. Both sections of the sample after failure, as shown in Figure 2, were tested under compression and compared with the results of cubes compressive strength. The test was conducted to determine the actual compressive strength of the concrete using the broken prism sample. The results show the actual compressive strength of the prism sample and the relationship between flexural strength and compressive strength can be made. Table 5 shows the modified compression test results of CCON and CPOC concretes. The results of the flexural strength to modified compressive strength ratio at 28 days for CPOC and CCON concrete were 7.9% and 11.0%, respectively. The difference in the values most likely due to the different curing conditions between CPOC and CCON concretes.

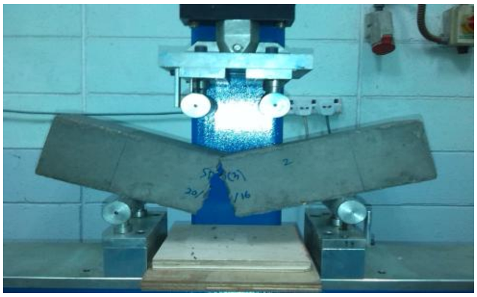

Figure 2: Broken prism sample after flexural test

Table 5: Modified compressive strength of CCON and CPOC concretes

Types of Concrete	*Curing*	*Age (days)*	*Modified Compressive Strength (MPa)*	*Cube Compressive Strength (MPa)*	*Strength Ratio 7/28 days*	
					Modified	*Cube*
CPOC	Air	7 28	20.9 27.4	24.9 33.0	0.763	0.755
	7 days water+ Outside	7 28	20.9 30.4	27.1 30.4	0.688	0.891
CCON	Water	7 28	21.1 23.0	28.1 38.3	0.917	0.734

From Table 5, it can be seen that for the modified strength ratio, the CCON concrete in water curing condition had higher strength ratio, 0.763, while the CPOC concrete in 7 days water+ outside curing recorded lower strength ratio of 0.688. For cube sample, the highest strength ratio was recorded on CPOC concrete in 7 days water + outside curing while the lowest strength ratio was recorded on CCON concrete with 0.734. The experimental results show that the modified compressive strength at the age of 28 says for CPOC concrete in air curing condition was 17% lower than the CPOC concrete cube compressive strength in air curing condition. On the other hand, the modified compressive strength of CPOC concrete in 7 days water + outside curing condition exhibited similar cube compressive strength of CPOC concrete with the same exposure curing condition. Generally, it can be said that the difference of the modified compressive strength and cube strength of the CPOC concrete in 7 days water + outside curing conditions was not significant.

4.5 Tensile Splitting Strength

The tensile splitting test of the samples was carried out at the age of 7 and 28 days. Cylindrical sample for each concrete type was prepared and tested to failure. Table 6 shows the tensile splitting strength results of all types of concretes.

Table 6: Tensile splitting strength of CPOC and CCON concretes

Types of Concrete	*Curing*	*Age (days)*	*Tensile Strength (MPa)*	*Strength Ratio 7/28 days*
CPOC	Water	7	2.5	0.789
		28	3.2	
	Air	7	2.1	0.840
		28	2.5	
	7 days water+ Outside	7	2.2	0.733
		28	3.0	
CCON	Water	7	2.7	0.794
		28	3.4	

Table 6 shows the CPOC concrete in air curing had higher strength ratio of 7 to 28 days while CPOC concrete in 7 days water + outside curing conditions exhibited lower strength ratio with 0.733. For the CCON sample, the strength ratio was recorded about 6% lower compared with CPOC concrete in 7 days water + outside curing condition. This can be explained through the possible activities of internal and external curing occurred for the CPOC sample. Both internal and external curing processes for CPOC concrete resulted in better hydration of cement. From the table, the CCON sample recorded higher tensile strength at the age of 7 and 28 days with 3.4 MPa. For the CPOC sample in water curing condition, the strength was lower of about 9% and 6% at the age of 7 and 28 days, respectively, compared with CCON sample. The reduction of CPOC tensile strength in water curing condition was likely affected by the presence of voids within the concrete as voids in the POC aggregates created the point of failure within the concrete as loading was applied.

4.6 UPV Test Results

Before the cube samples were tested for compression, the UPV test was carried out on the cube samples. The UPV test was conducted at the age of 3, 7 and 28 days. Grease was used as platform between the receiver and concrete surface for uniform surface contact between the two mediums. Table 7 shows the UPV value of all samples tested.

Table 7: UPV results for CPOC and CCON concretes

Types of Concrete	*Curing*	*Age (days)*	*UPV values (km/s)*
CPOC	Water	3	3.92
		7	4.06
		28	4.08
	Air	3	3.81
		7	3.96
		28	4.02
	7 days water+ Outside	3	3.79
		7	3.87
		28	3.98
CCON	Water	3	4.06
		7	4.16
		28	4.16

The experimental results indicated that the range of UPV recorded for CPOC sample in water curing, air curing and 7 days water + outside curing were between 3.92 and 4.08 km/s, 3.81 and 4.02 km/s and 3.79 and 3.98 km/s, respectively. Generally the water curing samples recorded the higherst values at all ages. This indicates the hydration process was better than samples in other curing conditions. The control concrete sample exhibited higher average UPV value among other samples. Again it is probably due to the fact that the CCON concrete has enough water for the hydration process to occur. For the CPOC sample, water curing shows higher UPV than other curing conditions. This happened due to water loss during the curing process in air curing and 7 days water + outside curing because of the evaporation of water upon drying.

4.7 Mode of Failure

Figures 3 and 4 show the mode of failure of cube and prism cross-section of the CCON and CPOC concrete samples, respectively. From the figures, it can be seen that the failure inside the CPOC sample occurred through the POC aggregates while for the control concrete cube and prism failed through bonding between cement and aggregates. This is an indication that the presence of voids inside the POC aggregates has weakened the CPOC sample structure against loading and failures occurred by passing through the weakest point of the POC aggregates inside the concrete.

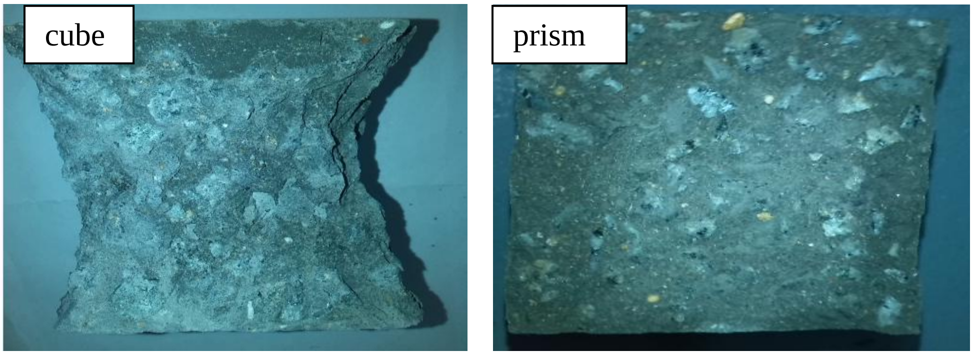

Figure 3: Failure mode of cube and prism samples for CCON

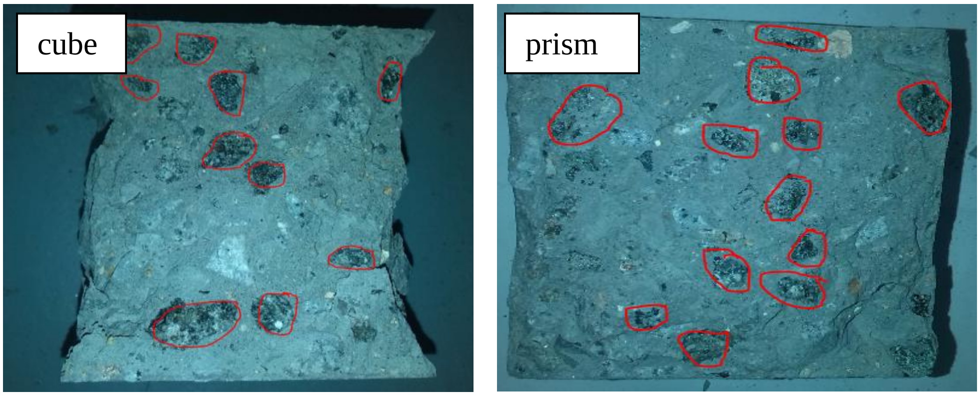

Figure 4: Failure mode of cube and prism samples for CPOC

5.0 Conclusions

The following conclusions can be drawn from the test results obtained from the experimental study:

i. The workability of concrete containing POC was found to be higher compared to control concrete possibly due to the additional absorbed water by the POC aggregates.

ii. The compressive strength of CPOC concrete in water curing was the highest compared to the compressive strength of CPOC in air curing and 7 days water + outside curing conditions due to less evaporation of moisture from concrete.

iii. The flexural strength of CPOC concrete was lower compared to CCON concrete due the present of voids inside the POC aggregates that eventually generate weaker points within the CPOC concrete.

iv. The strength ratio of the modified compressive strength for CPOC concrete in water curing condition was higher than the ratio of CPOC concrete cube compressive strength in water curing condition.

v. The splitting tensile strength of the cylindrical sample for CPOC concrete in water curing condition was higher compared to CPOC concrete in air curing and 7 days water + outside curing conditions due to different level of hydration process of concrete.

vi. The experimental results indicate that Palm Oil Clinker (POC) has the ability to absorb water and has potential to be used as water absorbant material for self-curing concrete.

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