Properties of Self-Curing Concrete Containing Palm Oil Clinker and Sawdust

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Abstract. Nowadays, concrete is widely used in construction due to its good compressive strength. A good concrete can be produced under a proper curing process. Desired concrete strength will only be achieved when it is cured properly. This study highlights the effect of Palm Oil Clinker (POC) and sawdust as internal reservoirs inside concrete for internal curing process of cement. A water/cement ratio of 0.53 was used in the concrete design. Three different curing conditions were used namely, water curing, air curing and 7 days water + outside curing conditions. The concrete samples were tested for compression test at the age of 3, 7 and 28 days while flexural and cylinder splitting tests were conducted at the age of 7 and 28 days. The broken sections of the prism were tested for modified compression test and compared with the cube compressive strength. As concrete samples were exposed to three different curing conditions, expansion and shrinkage test were also carried out. The experimental results indicated that the inclusion of POC and sawdust to some extent enhanced the hydration process and workability but reduced the concrete compressive strength due to the properties of POC aggregates.

Introduction

It is already known that concrete are made of cement, aggregates, water and admixtures. A good concrete is able to withstand the desired loadings and durable for its intended design life. A proper proportion of concrete materials during the mix design process will produce a good quality concrete.

Hydration process is a process of cement reacting with water producing C-S-H gel and calcium hydroxide ($Ca[OH]_2$). Somayaji [1] states that dry cement do not possess the cementing or binding properties. As to prepare good concrete, the concrete must be cured properly in order for the concrete to achieve its design strength and durability. Instead of using normal water cured, another alternative is to use self-curing method. For this method, the amount of water for curing will be reduced significantly compared with water cured. The concept is still the same, providing water for 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 commercials yet. There are many possible materials that can 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 may retain it for a longer period of time. Thus, it may provide additional water in the concrete acting as an internal curing. If continuously water evaporated from concrete surface and this condition will reduce the capability of 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 evaporation from the surfaces [2].

In practice, a lot of problems exist at construction site. Inappropriate tools and system of communication may affect construction progress. On site, the common curing methods used are fogging (water spray) and wet curing. A research by Michigan [3] indicates that fogging method is efficient in helping to reduce plastic cracking in concrete especially for low water/cement ratio. Fogging process will reduce the moisture loss before and after the finishing concrete. Unfortunately, the loss of water will make the concrete to shrink, that leads towards plastic shrinkage cracking [4]. This method needs a huge 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, wet covering curing is applied for 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 of Kenaf. Burg [5] 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 from evaporating for the hydration process. However, concrete is cast in many shapes and locations throughout the buildings. When it is involve with high or deep concrete place, this method is not practicable to be used. Thus, other method needs to be explored. In this study, Palm Oil Clinker (POC) and sawdust are being investigated as an internal water absorbent material. The problems that might be faced are the capability of water absorbent materials providing water for internal curing and the effect of the water absorbent to concrete properties. Thus, the main objectives of this study are as follows:

i. To determine the properties of concrete containing Palm Oil Clinker and sawdust as water absorbent material.
ii. To characterize the fresh and hardened properties of Palm Oil Clinker and sawdust concrete and compare it with control concrete.
iii. To investigate the expansion shrinkage of Palm Oil Clinker and sawdust concrete and compare with control concrete.

Previous Study

A study of self-curing concrete has been conducted by Naik and Fethullah [6] stated that water efficiency of internal curing of high strength concrete able to eliminate autogenous cracking. This study proved 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 traditional cracking or 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 wastes from this industries are Oil Palm Shell (OPS), empty fruit bunches, palm oil fibre and palm oil fuel ash. POC is a product of palm oil fibre and OPS that burnt at 850°C for electricity generation in palm oil industries. Generally, the proportion of palm oil fibre and OPS burnt was 70:30 and Shafigh [7] reported that POC is available in boulder sizes ranging from 100 to 300 mm. It can be crushed into the desired sizes for development of concrete. In addition, POC had a specific gravity of 2.08 and compacted bulk density of 782.1 kg/m3. Since POC has huge voids inside it, it can store water and act as internal reservoir in concrete for internal hydration of cement. Besides that, POC replacement as aggregates exhibits higher compressive strength than OPS replacement aggregates in the production of lightweight concrete. It is because POC had higher specific gravity value which is 2.08 compared to 1.22 for OPS. A study by Kanadasan [8] 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, chemicals variations were influenced by the burning temperature of POC in boiler. At low temperature of burning, pyrolysis process might be incomplete and leads towards variation in the POC chemical composition.

Tests of Fresh and Hardened Concrete

Material

The materials used in concrete were coarse aggregates, fine aggregates, water, Ordinary Portland Cement (OPC), POC and sawdust. The OPC used in this experiment was confirmed to BS EN 197-

1:2000. The sawdust was obtained from Structure and Materials Laboratory, UTM while the POC were obtained from Kulai, Johor. The estimated bulk density of POC was 782.1 kg/m^3 and crushed into 10mm nominal size. For sawdust, it was sieved through 300μm sieve to separate other unwanted material that might influenced the concrete properties. Figure 1 shows the sawdust and POC used in the study.

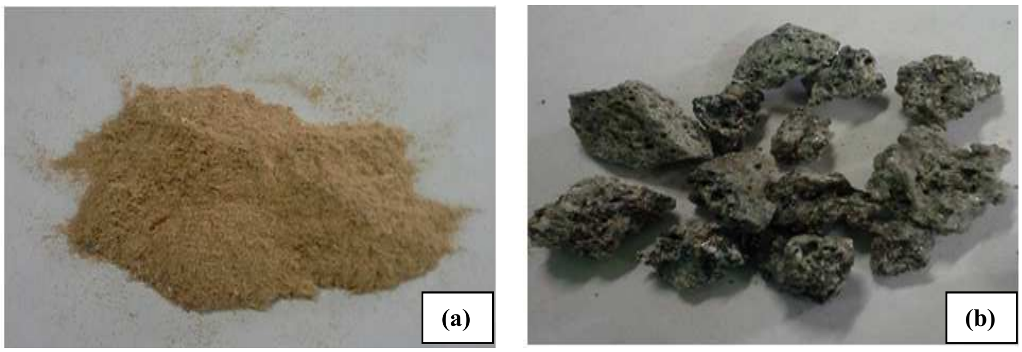

Figure 1: Sawdust (a) and POC (b) used in concrete mix

Water used for concrete mix was obtained from fresh tap water at the laboratory. The experimental works and preparation were conducted in the Structure and Materials Laboratory in the Faculty of Civil Engineering, Universiti Teknologi Malaysia.

Mix Proportions

The target compressive strength of concrete was 30 MPa with water-cement ratio of 0.53 and the design slump of 60-180mm with nominal aggregates sizes of 10mm. Table 1 shows the design mix proportion for concrete used in the study. In this experiment, the proportions of sawdust added into concrete was by 0.031% by weigh of cement while the POC replacement was 20 percent of coarse aggregates density.

Table 1: The design mix proportion

Materials	**Amount (kg/m^3)**		
	CPOC	**CSAW**	**CCON**
Cement	472	472	472
Water	250	250	250
Fine aggregate	720	720	720
Coarse aggregate	702	878	878
Water Absorbent Material	175.6	15.7	-

Specimen Preparation

The cube concrete samples were prepared, cured and tested at the ages of 3,7 and 28 days while for cylinder and prism specimens were tested at the ages of 7 and 28 days. The standard steel mould used in this experiments were cube 100x100x100 mm, prism 100x100x500 mm and cylinder with diameter of 100mm by 200mm height. Oil was used to coat the inside of steel mould before casting process. The fresh concrete mix was mixed by mechanical concrete mixer. Then, the fresh concrete was poured into the steel mould and compacted using vibrating table. After 24 hours, the samples were demoulded and cured inside the designated curing regimes.

The concrete mix was designed according to the Department of Environment (DoE) method. For the case, two types of concrete were produced which is a self-curing concrete which are sawdust and POC concrete and water-cured concrete as a control. Sawdust proportion was 3.1 percent of cement weight of concrete while the POC replacement into the concrete was 20 percent of weight of coarse aggregate. All the self-cured concrete properties such as concrete strength will be compared with control concrete.

Workability of Concrete
Slump test was carried out in accordance to BS1881: Part 102: 1983; using the mould with a smaller opening at top and the concrete is filled in three layers. Each layer was tamped 25 times by a tapping rod and then the mould is lifted upward slowly. The height of the slump was measured vertically the differences between concrete and the mould was recorded.

Compression Test
The compression test was carried out for both sawdust concrete, POC concrete and control concrete at the ages of 3, 7 and 28 days. The total number of self-cured concrete cube samples was 18 samples while 9 samples for control samples. The test was carried out in accordance to BS1881:116 (1983). Figure 2 shows the testing of cube sample.

Modified compression test was also performed using part of the broken prisms that has been used for flexural test. Since the prism dimensions are square in cross-section, modified compression was performed by applying the load through square plates of the same size across the prism section.

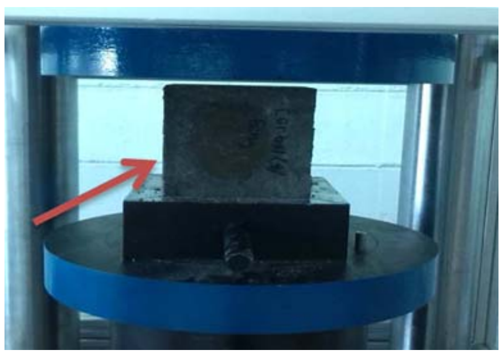

Figure 2: Compression test of concrete

Tensile Splitting Test
Tensile test was carried out on each type of concrete at the age of 7 and 28 days. The number of cylindrical samples tested for self-curing concrete were 24 while for the control was 12. Standard cylindrical sample with 100mm diameter x 200mm height was prepared and tested using compression testing machine. The compression load was applied until the sample fails and recorded the highest load. A piece of plywood was placed at the top and bottom of the cylindrical sample before it was tested. This test was carried out as specified in BS1881-117. Figure 3 shows the testing of the cylindrical sample.

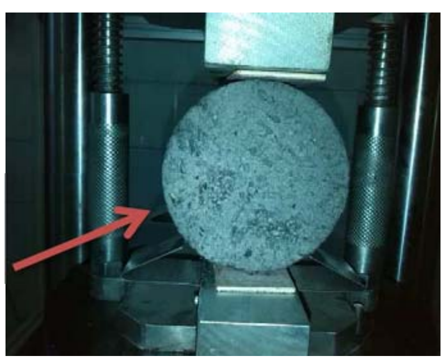

Figure 3: Cylinder split test of concrete

Flexural Test
Flexural test is 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. A concrete sample with

span length of equal to three times of its depth is tested to third-point load (ASTM C78). From the loading, concrete sample will experience compression at the top section and tensile at bottom section. It is known that concrete is weak in tension and it will crack and failed at section where the moment is maximum. From the failure load, it gives the tensile strength of concrete or modulus of rupture (MOR). Figure 4 shows the testing of prism sample.

Figure 4: Flexural test of concrete prism

Ultra-Pulse Velocity Test

Ultra-Pulse Velocity test is a non-destructive test that can be used to determine the homogeneity of concrete. This method used high frequency sound wave range between 25 to 60 kHz penetrating through concrete from source that transmit the pulse to receiver of portable test equipment. The wave speed varies depending on the density and elastic property of the concrete. This method was carried out according to BS (1881): Part 203, the time taken for pulse travel through concrete is recorded then velocity is calculated by dividing the length over time taken to travel from one point to the other.

Expansion and Shrinkage Test

For expansion and shrinkage test, a prism sample of 100mm x 100mm x 500 mm was prepared. Two samples were prepared for both expansion and shrinkage tests. Each sample was attached with Demec disc of 100mm gauge length. DEMEC gauge was used to measure the deformation of concrete with time. Before testing, two Demec discs were glued at 100mm apart on each side of the sample. After the glue dried, datum reading was taken from these Demec points. The reading was recorded at an interval to determine the expansion and shrinkage deformation until the end of testing. Direct strain reading can be obtained by multiplying the reading with gauge calibration of 1.09×10^{-5}. Figure 5 shows the Demec measurement test kit.

Figure 5: Demec measurement test kit

Results and Discussions

Workability of Concrete

From slump test results, POC concrete (CPOC) exhibited the highest workability compared with sawdust concrete (CSAW) and control concrete (CCON). The recorded slump for CPOC was about 27% and 21% higher than CCON and CSAW, respectively. In terms of moisture test, the POC materials absorbed 5.1% of water much more than sawdust (4.9%). The POC has voids inside, when it is soaked in water; the voids will be filled with water. The concept is the same with sawdust but the water filled inside wood cell is lesser than POC. Table 2 indicates the slump of all concrete tested.

Table 2: Slump Height of fresh concrete

Types of Water Absorbent	Slump Height, mm
CPOC	140
CSAW	116
CCON	110

UPV Test on Self-Cured Concrete and Control Concrete

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

Table 3: Concrete Types with its UPV values respectively

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
CSAW	7 days water+ Outside	3	4.08
		7	4.14
		28	4.16
CCON	Water	3	4.06
		7	4.16
		28	4.16

The experimental results indicates that the range of UPV recorded for POC 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. For sawdust concrete and control sample in 7 days water + outside curing and water curing, the UPV value was in the range between 4.08 and 4.16 km/s and 4.06 and 4.16 km/s, respectively. Control sample exhibited the highest average UPV value among other samples. It is because CCON has enough water for hydration process. For the CPOC sample, water curing shows the highest UPV than other curing conditions. This happened due to water losses during curing process in air curing and 7 days water+ outside curing due to evaporation upon drying.

Compressive Strength of Self-cured Concrete vs Control concrete

Compression test was conducted at the age of 3, 7 and 28 days. The compressive strength was compared between the self-cured concrete and control concrete. Table 4 shows the compressive strength of different types of concrete in different curing conditions.

Table 4: Types of Absorbent Material with its compressive strength respectively

Types of Concrete	Curing	Age (days)	Compressive Strength (MPa)	Strength Ratio (%)	
				3/28 days	7/28 days
CPOC	Water	3	22.2	61.54	75.36
		7	27.2		
		28	36.0		
	Air	3	19.6	59.25	75.46
		7	24.9		
		28	33.0		
	7 days water+ Outside	3	19.2	63.21	79.74
		7	24.2		
		28	30.4		
CSAW	7 days water+ Outside	3	21.4	62.67	77.81
		7	26.6		
		28	34.2		
CCON	Water	3	21.8	56.84	73.36
		7	28.1		
		28	38.3		

It can be seen that the CPOC in 7 days water + outside curing recorded the highest strength ratio at day 3 and 7 with 63.21 and 79.74 percent, respectively. On the other hand, the CCON in water curing exhibited the lowest strength ratio at 3 and 7 days with 56.84 and 73.36 percent, respectively. The result shows that the hydration process of CPOC in 7 days water + outside curing is more rapid than other samples. It is due to extra water supplied for CPOC, internal curing and water curing process. The CPOC undergo both internal and external curing process that ensuring hydration process of CPOC is better than CCON.

For CSAW in 7 days water + outside curing, the strength ratio for both at 3 and 7 days was 62.67 and 77.81 percent, respectively. It clearly shows that the CSAW strength ratio is higher than CCON strength ratio for both ages. This can be explained through the effectiveness of hydration process between both concretes. From the analysis, the strength ratio of CSAW is higher because of two types of curing process occurred for CSAW compared to CCON that has only water curing process. The CSAW undergo same internal curing and external water curing as CPOC. Curing in both internal and external for CSAW encourage better hydration of cement for CSAW.

Flexural Test Result on Control, Sawdust and POC Concrete

Flexural test was carried out at age of 7 and 28 days. Same as compressive strength test, the MOR of CPOC and CSAW was obtained and compared with control concrete as shown in Table 5.

Table 5: MOR of Self-Cured Concrete and Control

Types of Concrete	Curing	Age (days)	MOR (MPa)	Strength Ratio (%) 7/28 days
CPOC	Air	7	1.57	75.48
		28	2.08	
	7 days+ Outside	7	1.9	77.55
		28	2.45	
CSAW	7 days+ Outside	7	2.21	71.52
		28	3.09	
CCON	Water	7	2.3	69.70
		28	3.30	

Table 5 shows the strength ratio of MOR at the age of 7 days of different concrete and different curing exposure. From the table, the CPOC in 7 days water + outside curing exhibited the highest strength ratio while CCON in water curing had the lowest strength ratio with 77.55 and 69.7 percent, respectively. The highest flexural strength at 7 days was recorded for CCON prism with water curing condition. The MOR of CCON was about 3.9% and 31.7% higher than CSAW and CPOC of water curing conditions, respectively. For concrete at the age of 28 days, CCON prism of water cured sample recorded the highest MOR and recorded about 6.4% and 36.9% higher than CSAW of 7 days water + outside curing and CPOC of water curing, respectively. This can be explained due to the existence of air voids inside the CPOC samples. Air voids creates more failure modes inside concrete that will significantly reduce concrete compressive strength.

On the other hand, the flexural strength at 28 days of CPOC of 7 days water + outside curing recorded about 15.1% higher than CPOC in water curing conditions. This result happened due to aggregate capacity factors inside CPOC. Replacement of coarse aggregate by POC was found to reduce the flexural strength and concrete loading capacity.

Modified Compression Test for CCON, CSAW and CPOC.

Modified compression test was carried out after flexural test. Both sections after failure were tested under compression and compared with cubes compressive strength. Table 6 shows the modified compression test results of CCON, CSAW and CPOC.

Table 6: Modified Compression Test Vs Cube Compressive Test Results

For CCON, CSAW and CPOC

Types of Concrete	Curing	Age (days)	Modified Compressive (MPa)	Cube Compressive (MPa)	Strength Ratio (%) 7/28 days	
					Modified	Cube
CPOC	Air	7	20.9	24.9	76.3	75.5
		28	27.4	33.0		
	7 days+ Outside	7	20.9	27.1	68.8	89.1
		28	30.4	30.4		
CSAW	7 days+ Outside	7	20.5	26.6	91.1	77.8
		28	22.5	34.16		
CCON	Water	7	21.1	28.1	91.7	73.4
		28	23.0	38.3		

From Table 6, it can be seen that for modified strength ratio, CCON of water curing conditions had the highest strength ratio while the CPOC of 7 days water + outside curing recorded the lowest strength ratio with 91.1% and 68.8%, respectively. For cube, the highest strength ratio was recorded on CPOC in 7 days water + outside curing while the lowest strength ratio was recorded on CCON with 89.1 and 73.4 percent, respectively.

The experimental results show that the modified compressive strength at the age of 28 says for CPOC in air curing conditions was recorded 17% lower than CPOC cube compressive strength in air curing conditions. On the other hands, modified compressive strength of CPOC in 7 days water + outside curing conditions exhibited same modified compressive strength with CPOC of same exposure curing conditions of cube compressive strength. Generally, it can be said that the modified compressive strength and cube strength of CPOC in 7 days water + outside curing conditions has no significant different at the age of 28 days.

Tensile Split Test Result on Sawdust, POC and Control Concrete.

Tensile splitting test was carried out at the age of 7 and 28 days. Cylindrical sample for each concrete type was prepared for this test. Table 7 shows the tensile splitting test results of all types of concretes.

Table 7: Tensile Split Test results of CPOC, CSAW and CCON

Types of Concrete	Curing	Age, (days)	Tensile Strength, (MPa)	Strength Ratio (%) 7/28 days
CPOC	Water	7	2.5	78.9
		28	3.2	
	Air	7	2.1	84.0
		28	2.5	

	7 days+ Outside	7 28	2.2 3.0	73.3
CSAW	7 days+ Outside	7 28	2.0 2.4	83.3
CCON	Water	7 28	2.7 3.4	79.4

Table 7 indicates the CPOC in air curing having the highest strength ratio at the age of 7 days while CPOC in 7 days water + outside curing conditions exhibited the lowest strength ratio with 84 percent and 73.3 percent, respectively. For CCON sample, strength ratio was recorded about 6 percent lower compared with CPOC in 7 days water + outside curing conditions. This can be explained through present of internal and external curing occurred for CPOC sample. Curing in both internal and external for CPOC encourage better hydration of cement.

From the table, CCON sample recorded the highest tensile strength at the age of 7 and 28 days with 2.7 MPa and 3.4 MPa, respectively. For CPOC sample in water curing conditions, it 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 srength in water curing condition was affected by present of air voids within the concrete as air voids created the point of failure within concrete as loading was applied.

As for the CSAW sample in 7 days water + outside curing conditions, the tensile strength recorded was 10% slightly lower than CPOC in 7 days water + outside curing conditions. At the age of 28 days, the tensile strength was observed 20% lower than CPOC in 7 days water + outside curing conditions. In additions, for the CPOC in air curing exposure, the tensile strength recorded was 16% and 35% less than CPOC in water curing exposure at ages of 7 and 28 days, respectively. This happened due to the evaporation of water from concrete surface upon drying. As water escaped from concrete, the sawdust was found incapable to provide enough internal curing for CSAW sample that leads toward the reduction of concrete tensile strength.

Expansion and Shrinkage Results

The expansion and shrinkage results and discussion of all samples tested are shown in the following sections.

POC Expansion and Shrinkage Analysis. Figure 6 illustrates behaviour of CPOC when it is exposed to three different curing conditions. Different curing conditions provide CPOC different expansion and shrinkage strains due to several factors that influenced the expansion and shrinkage of the CPOC.

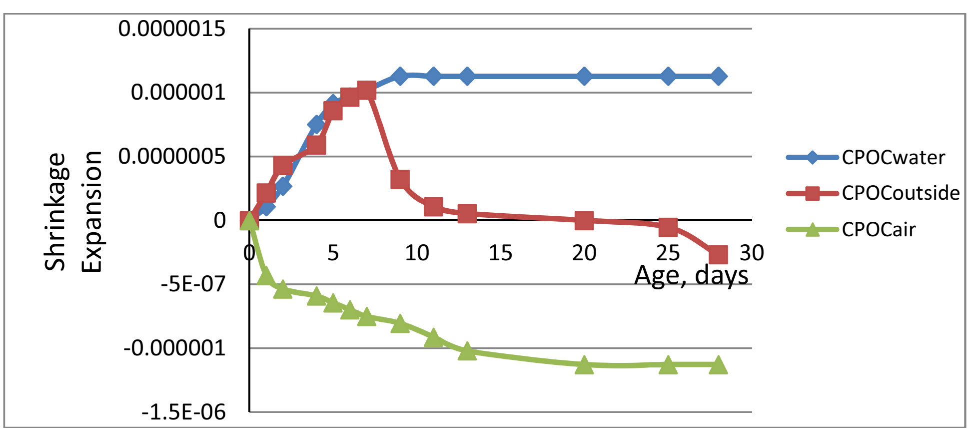

Figure 6: Expansion and shrinkage of CPOC

At the age of 4 days, the expansion strain of CPOC in 7 days water + outside curing conditions recorded was about 22% lower than expansion strain of CPOC in water curing conditions. Then, the expansion strains for both CPOC concrete at the age of 7 days was observed equal with strain value of 1.06x10^{-6}. After 7 days of water curing, the CPOC sample was exposed to outside exposure condition. Shrinkage strain recorded at the age of 9 days for CPOC in outside curing was in the range of 1.06x10^{-6} to 0.322x10^{-6}. Shrinkage strain continues to increase until the age of 28 days where the strain recorded was -0.268x10^{-6}. This shrinkage happened due to evaporation of water from concrete surface upon drying. As water is slowly escaped out from the pores, concrete will shrink as the results of water losses.

For the CPOC in air curing condition, the specimen was experiencing shrinkage strain from early age until 28 days. After the concrete hardened, it was placed inside laboratory for air curing. During 7 days, the strain recorded was -0.751x10^{-6} and continued to decrease until 28 days. From this result of strain, it shows that the concrete had experienced the loss of water.

POC and Control Expansion Shrinkage Comparison. Figure 7 shows the expansion and shrinkage curve of CPOC and CCON samples. From the figure, CCON in water curing exhibited the highest expansion strains compared with other concrete samples. At the age of 7 days, the expansion of CPOC in water curing conditions was about 64% lower than CCON in water curing conditions while strains for CCON in 7 days water + outside curing conditions exhibited strain about 61% higher than CPOC in the same curing conditions. This happens due to lower water entrances into CPOC samples than CCON. The voids inside CPOC already filled with water while CCON had empty air voids within concrete. Hence, water entrance for CCON was higher than CPOC which leads to higher expansion for the CCON sample.

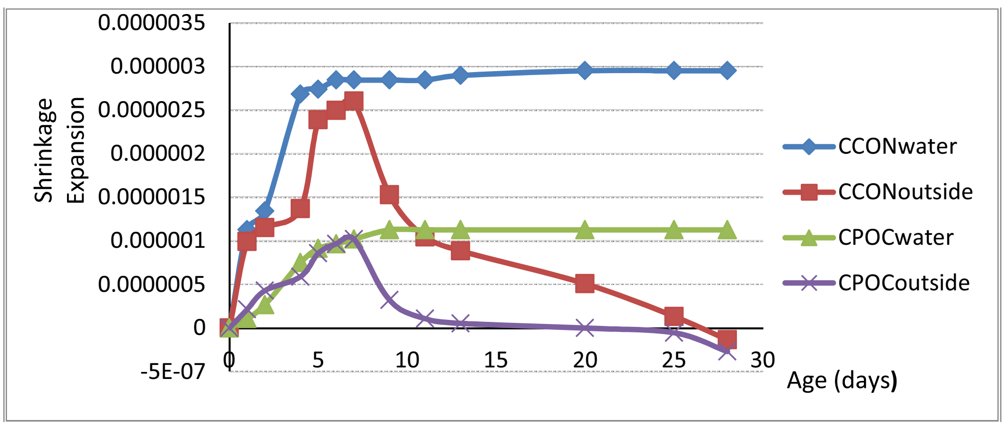

Figure 7: POC and control expansion shrinkage graph

At 28 days, the shrinkage of CPOC in 7 days water + outside curing conditions was about 50% higher than CCON in 7 days water + outside curing conditions. This happened due to higher evaporation rates in CPOC than CCON upon drying. As both concretes were placed in weathered outside condition, it was exposed to extreme weather and windy condition. Water inside concrete was slowly escaped from concrete into the air due to the differences in pore pressure between surface concrete and air humidity. Hence, water is pulled out from inside concrete into the air.

POC and Sawdust Expansion Shrinkage Comparison. Figure 8 shows the expansion and shrinkage curve of CSAW and CPOC samples. From the figure, the expansion strain of CPOC in water curing conditions recorded was about 20% higher than expansion strain of CSAW in water curing conditions. An increment of expansion strain for CPOC in water curing conditions from 7 to 9 days was about 3% higher than increment of expansion strain for CSAW in water curing conditions. At the age of 28 days, expansion strain for CSAW in water curing conditions was about 20% lower than CPOC in water curing condition. Expansion strain of CSAW in 7 days water + outside curing condition was recorded of about 10% higher than the expansion strain of CPOC in 7 days water + outside curing conditions. At the age of 28 days, the shrinkage strain for CSAW and CPOC in 7 days water + outside curing condition was observed approximately equal but CSAW sample exhibited shrinkage strain earlier than CPOC samples. At the age of 20 days, strain for CSAW sample was already achieved shrinkage strains compared with CPOC strain. This result shows that sawdust was found to be less capable to conserve moisture than POC for internal curing for concrete.

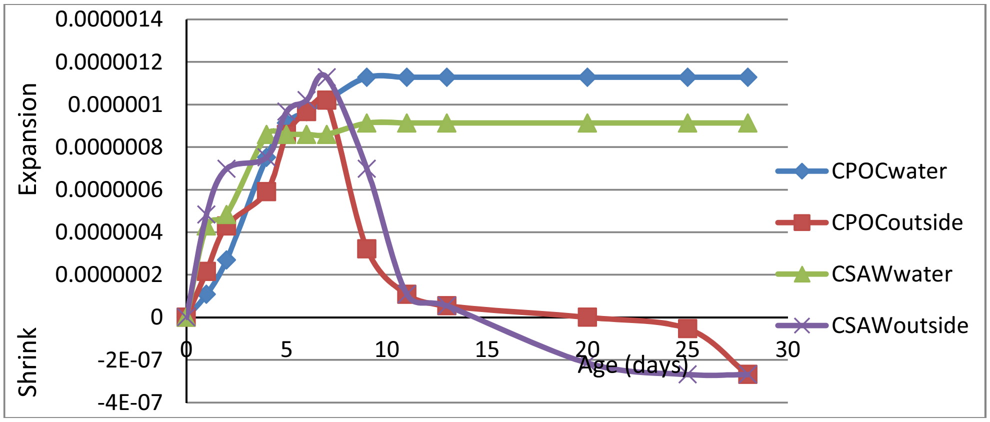

Figure 8: Expansion and shrinkage curve of CSAW and CPOC

Mode of Failure

Figures 9 to 11 show the cube and splitted prism cross-section of CPOC, CSAW and CCON samples. From the figures, it can be seen that failure inside CPOC sample occurred through POC aggregates while sawdust and control concrete failed through cement bonding between aggregates. The present of voids inside POC aggregates weakening the CPOC sample structure against loading and failures occurred by passing through the weakest point inside the concrete.

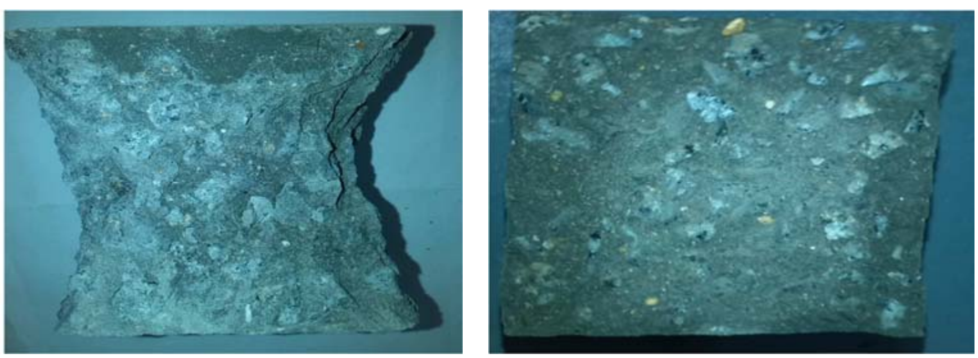

Figure 9: Cube Compression cube (left) and split prism sample (right) of CCON

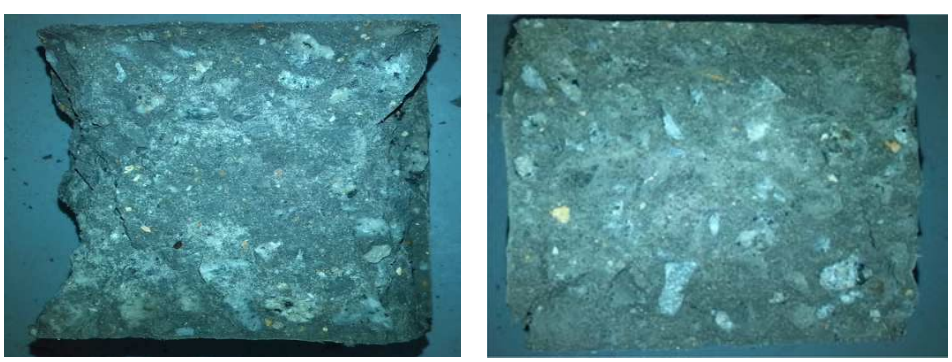

Figure 10: Cube Compression cube (left) and split prism sample (right) of CSAW

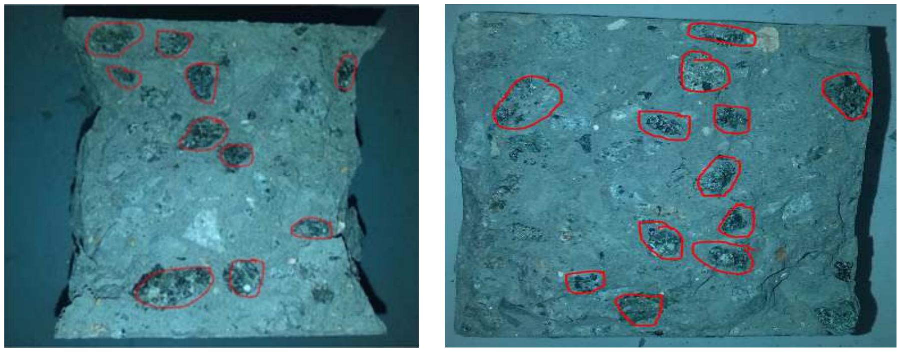

Figure 11: Cube Compression cube (left) and split prism sample (right) of CPOC

Figures 12 to 14 show the failure mode of cylinder and cross-section of the cylinder for CPOC, CCON and CSAW samples, respectively. It can be seen from the figures that the failure inside CPOC sample occurred through porous POC aggregates while for the sawdust and control concrete samples the failure was through cement bonding between aggregates. Porous POC aggregates that present inside the CPOC sample structure was weakening the concrete loading capacity as the present of voids increasing the possibilities of failure modes inside concrete.

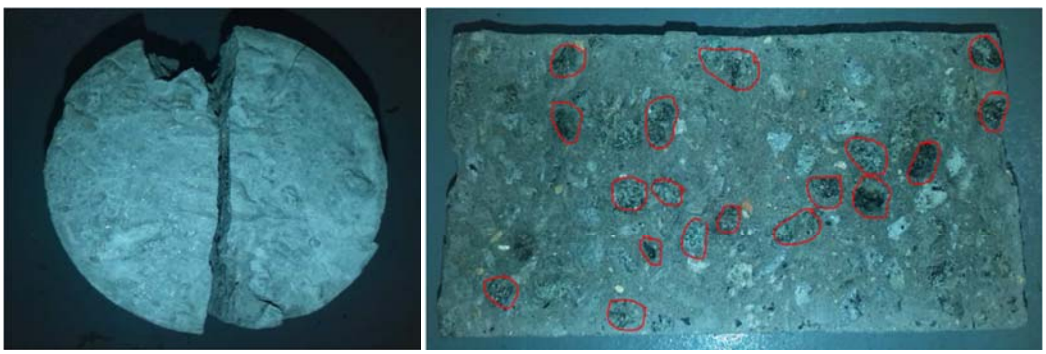

Figure 12: Cylinder failure mode and cross- section of CPOC

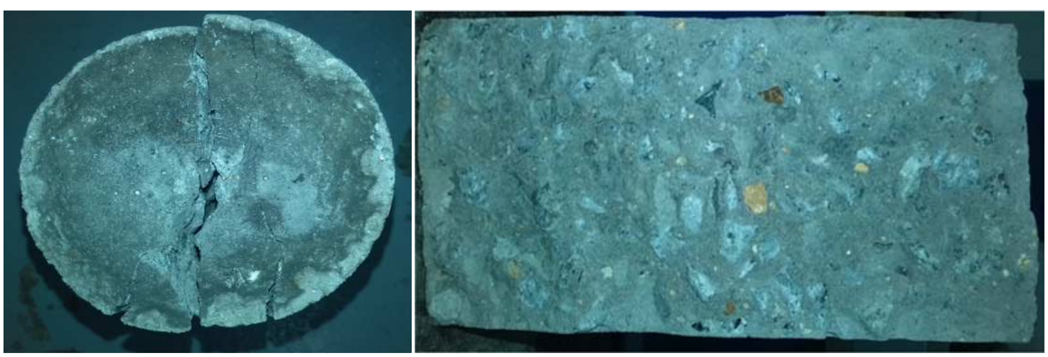

Figure 13: Cylinder failure mode and cross- section of CCON

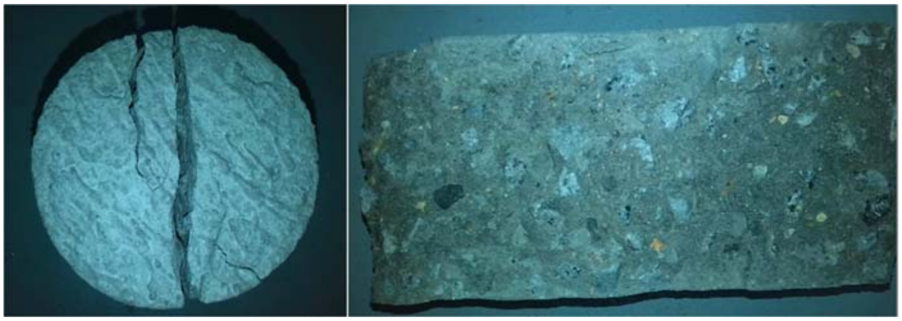

Figure 14: Cylinder failure mode and cross- section of CSAW

Conclusions

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

1. The workability of concrete containing POC was higher compared to control concrete and sawdust concrete.
2. The compressive strength of CPOC in water curing was the highest among compressive strength of CPOC in air curing and 7 days water + outside curing conditions due to evaporation of moisture from concrete.
3. The compressive strength for CSAW in 7 days water + outside curing exhibited higher than compressive strength of CPOC in 7 days water + outside curing at the age of 3, 7 and 28 days.
4. The modulus of rupture (MOR) of CPOC was the lowest compared to CSAW and CCON due the present of air voids inside POC materials within CPOC.
5. The strength ratio of the modified compressive strength for CPOC in water curing conditions was higher than CPOC cube compressive strength in water curing conditions.
6. The tensile strength of splitting cylinder of CPOC in water curing condition was the highest compared to CPOC tensile strength in air curing and 7 days water + outside curing conditions due to different hydration process of concrete.
7. The expansion curve strain of CPOC in water curing was less compared to the expansion strain of CCON in water curing condition because of the lower water penetration into the concrete.
8. The shrinkage curve strain after 7 days water curing of CPOC in 7 days water + outside curing conditions was less steep compared to the expansion strain of CCON in 7 days water + outside curing because of the capability of POC as internal reservoirs than sawdust.

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