Rapid Chloride Permeability Test on Lightweight Concrete Made with Oil Palm Clinker

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Abstract

This paper presents an experimental program on rapid chloride permeability test on lightweight concrete produced from oil palm clinker aggregates. Oil palm clinker is obtained from by-product of palm oil milling. Utilising oil palm clinker in concrete production not only solves the problem of disposing this solid waste but also help to converse natural resources. The parameter of investigation included rapid chloride permeability test for a period of 7 days, 28 days and 90 days. 3 oil palm clinker concrete specimens of 100×50 mm cylinders were cast and tested. The chloride permeability values of oil palm clinker concrete were compared to ASTM C1202 criteria.

Keywords- Oil palm clinker, Chloride permeability, Lightweight concrete

1. Introduction

Increase of population has made large demand on construction material and it leads to a chronic shortage of building materials and thereby increasing the construction cost due to the shortage. To solve this problem, engineers are not only challenged for the future homebuilding in term of construction cost control but also need to convert the industrial wastes to useful construction and building materials. Once of the way was introduced industrial waste material in concrete to reduce the use of aggregate. Such wastes material like fly ash, wood chipping, paper mill, crumb rubber, silica fume and palm oil clinker etc [1-7].

Extensive research work has been carried out by Mohammed and Mohammed et al. to produce lightweight concrete utilizing oil palm clinker as full replacement to fine and coarse aggregate [8,9]. The physical and mechanical properties of the oil palm clinker concrete have been established. The developed oil palm clinker concrete easily attains strength of more than 17 MPa, which is a requirement for structural lightweight concrete as per ASTM C330 [10]. Lightweight concrete using oil palm clinker as replacement aggregate is still a relatively new

Construction material and the structural performance of the concrete has not yet been investigated. Therefore, the ability of chloride ions to penetrate the concrete must then be known for design as well as quality control purposes.

Reinforced concrete structures are exposed to harsh environments yet is often expected to last with little or no repair or maintenance for long periods of time (often 100 years or more). To do this, a durable structure needs to be produced. For reinforced concrete bridges, one of the major forms of environmental attack is chloride ingress, which leads to corrosion of the reinforcing steel and a subsequent reduction in the strength, serviceability, and aesthetics of the structure. This may lead to early repair or premature replacement of the structure. A common method of preventing such deterioration is to prevent chlorides from penetrating the structure to the level of the reinforcing steel bar by using relatively impenetrable concrete. The ability of chloride ions to penetrate the concrete must then be known for design as well as quality control purposes. The resistance of concrete to penetration by chlorides is an important factor in protecting reinforced concrete structures from premature deterioration.

The penetration of the concrete by chloride ions, however, is a slow process. It cannot be determined directly in a time frame that would be useful as a quality control measure. Therefore, in order to assess chloride penetration, a test method that accelerates the process is needed, to allow the determination of diffusion values in a reasonable time. The Rapid Chloride Permeability Test (RCPT), as it is commonly called, has been in existence for over 20 years and was standardized by ASTM over 16 years ago. The test is used extensively in the concrete industry for assessing concrete quality.

2. Oil Palm Clinker Aggregate Properties

The oil palm clinker was sieved to 2 categories which is fine aggregate (< 5mm) and coarse aggregate (5mm-14mm). Table 1 below shows the aggregate properties for both fine and coarse aggregate.

Table 1: Properties of oil palm clinker

Properties	Fine	Coarse
Aggregate size (mm)	< 5	5-14
Bulk Density (kg/m^3)	1118.86	781.08
Specific gravity (SSD)	2.01	1.82
Moisture content	0.11	0.07
Water absorption (24 hours)	26.45	4.35
Fineness modulus	3.31	6.75
Los Angeles abrasion value, %	-	27.09
Aggregate impact value (AIV), %	-	25.36
Aggregate crushing value (ACV),%	-	18.08

Aggregates having dry unit weights (of less than) 1200 kg/m^3 are classified as lightweight [11]. Due to the porous nature of oil palm clinker aggregate, low bulk density and high water absorption were expected. Oil palm clinker fine and coarse aggregate has a unit weight of 1119 kg/m^3 and 781 kg/m^3. This is approximately 25% lighter compared to the conventional river fine sand [12] and 48% lighter compared to the crashed granite stone [13]. Consequently, the resulting concrete will be lightweight. This reduces the overall dead load in a structure, which comes with a significant amount of saving in the total construction cost.

In general, most lightweight aggregate have higher water absorption values compared to conventional aggregate. Although oil palm clinker has high water absorption, even higher water absorption were reported for pumice aggregate which have a value of about 37% [14]. However the high water absorption of oil palm clinker aggregate can be beneficial to the resulting hardened concrete. It has been reported that lightweight concretes with porous aggregate (high water absorption) are less sensitive to poor curing as compared to normal weight concrete especially in the early ages due to the internal water supply stored in the porous lightweight aggregate. [15]

From Table 1, it can be observed that the aggregate impact value (AIV) and aggregate crushing value (ACV) of oil palm clinker aggregates were higher compared to the conventional crushed stone aggregates [12]. More specifically the AIV and ACV were approximately 34% and 30% higher respectively compared to the granite aggregate. The higher ACV value for the oil palm clinker aggregate might be caused by the particle shape of oil palm clinker used in this study which is porous and angular. The aggregate with such shape and condition have the possibility to be crushed when load is applied on them.

3. Experimental Program

3.1. Material

The materials used in this work are water, Ordinary Portland Cement and oil palm clinker aggregate. The water used is a potable drinking water from tap which suitable for concrete work [16]. Commercial cement meeting the ASTM C150 [17] for Type I Portland cement was employed in this study. The aggregate used is oil palm clinker obtained from locally palm oil manufacturer in Malaysia. The clinkers are crushed and were separated into desired size; fine aggregate (particles less than5mm) and coarse aggregate (particle between 5-14mm).

3.2. Mix Proportions

The mix proportioning was done in according to the requirements of ACI Committee 211.2-98 [18]. A central composite design (CCD) was employed for the factor setting after an extensive trail mixes were done in the laboratory. The factors used in this work are water-cement ration (x_1) and cement content (x_2). Each factor has fixed the limit in accordance to the requirements of ACI Committee 211.2-98 [18] which water-cement ratio and cement content have range 0.40-0.46 and 480-520 kg/m^3 respectively. The factors value is shown in Table 2.

Table 2: Factor setting using central composite design

Factor	Axial point	minimum	centre	Maximum	Axial point
x_1	0.38	0.40	0.44	0.46	0.50
x_2	460.00	480.00	500.00	520.00	540.00

Figure 1 has shown the water-cement ratio verses cement content in the range water-cement ratio (0.4-0.46) and cement content (480-520 kg/m^3). 5 mixes proportions design were chosen to obtain the concrete properties and the five mixes proportion were denoted as A1, A2, A3, A4 and A5 respectively.

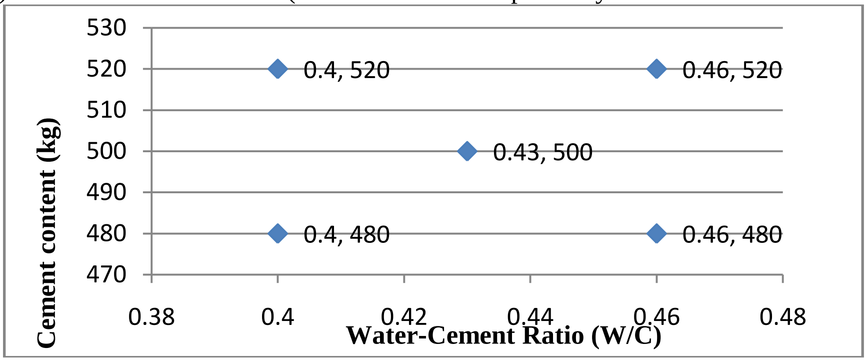

Figure 1: Mix proportion water-cement ration over cement content

The aggregate is considered in dry condition since oil palm clinker is easily loses its water. The natural moisture content of oil palm clinker is almost zero when the aggregate is kept for some day. Since material results have shown that oil palm clinker have high value of water absorption so pre-soaking oil palm clinker for 24 hours with water was employed before mixing. This is expected to prevent further absorption during mixing. The saturated surface dry (SSD) state oil palm clinker was obtained. Two stage mixing approach was employed to allow the cement paste to coat the aggregate permitting the absorbed water to be retained and preventing any water absorption or penetration of cement paste into the aggregate. For each of the mix proportions the air dry density was measured in accordance to the requirement of [19]. Nine cylindrical and three 100mm x 100mm x 500mm concrete specimens were cast and cured under water according to the requirement of [20] for each mixes and the specimens tested for compressive strength, splitting tensile strength, flexural strength and modulus of elasticity at 28 days in accordance to the requirement of [21-24].

3.3 Compressive Strength Test

Compressive strength test usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. The compression test is an important concrete test to determine the strength development of the concrete specimens. Compressive strength tests were performed on the cube specimens at the ages of 28 days.

3.4 Splitting Tensile Strength

The indirect method of applying tension in the form of splitting was conducted to evaluate tensile properties of POC concrete. The split tensile strength is a more reliable technique to evaluate tensile strength of concrete (lower coefficient of variation) compared to other methods. The split tensile strength of 150 mm diameter and 300 mm high concrete cylindrical specimens was determined to assess the tensile properties of the POC concrete.

3.5. Air Dry Density

The measured or calculated equilibrium density of structural lightweight concrete determines whether specified density requirements have been met. Test Method ASTM C567 - 05a will be use to determine the density of 100 mm x100mm POC concrete cube specimens at the ages of 28 days.

3.6 Modulus of Rupture

Modulus of Rupture (MOR) for concrete is the tensile strength of the concrete determined using a flexural specimen. ASTM C78 Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) will be used to determine the MOR of 100mm x 100mm x 500mm Moist-cured POC concrete beams at the ages of 28 days.

3.7 Elastic modulus

Modulus of elasticity is the ratio of the stress applied to a body to the strain that results in the body in response to it. The modulus of elasticity of a material is a measure of its stiffness and for most materials remains constant over a range of stress. The modulus of elasticity of 150 mm diameter and

300 mm high concrete cylindrical specimens was determined to assess the mechanical properties of the POC concrete at age of 28 days.

3.8 Rapid Chloride Permeability Test

The Rapid Chloride Permeability Test method (RCPT) was carried out in accordance to ASTM C 1202 [25]. The concrete specimen used for this test was 100 mm diameter x 50 mm thick slices cut from middle portion of the 100 mm diameter x 200 mm height cylindrical specimen. Figure 2 shows the top view of RCPT set up. A direct current voltage of 60.0 ± 0.1 V was applied across the two faces and the current passing through the concrete specimen was monitored at 30 min intervals over a period of 6 h. The total charge passed in Coulombs was determined and the rating of the concrete was determined according to Table 3. The tests were performed at the age of 7, 28 and 90 days and the results obtained at each age were reported as an average of three tested specimens. The following formula, based on the trapezoidal rule can be used to calculate the average current flowing through one cell.

$$Q = 900(I_0+2I_{30}+2I_{60}+2I_{90}+2I_{120}+\ldots+2I_{300}+2I_{330}+I_{360})$$

Where,
Q = current flowing through one cell (coulombs)
I_0 = Current reading in amperes immediately after voltage is applied, and
I_t = Current reading in amperes at t minutes after voltage is applied

Table 3: RCPT ratings as per ASTM C 1202

Charge passing in Coulombs	Chloride permeability rating
Greater than 4000	High
2001 to 4000 Moderate	Moderate
1001 to 2000	low
100 to 1000	Very low
Less than 100 Negligible	Negligible

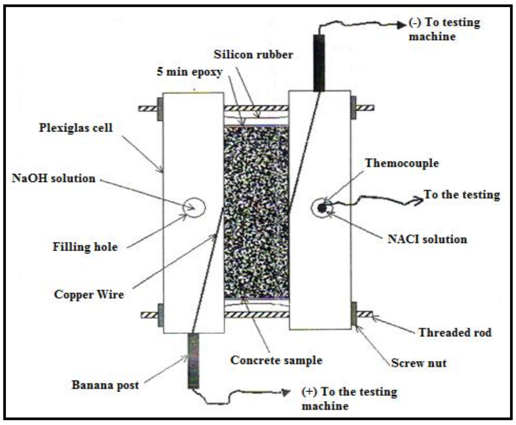

Figure 2: Schematic diagram of RCPT (ASTM C 1202-94)

4. Results and Discussions

4.1 Properties of POC Concrete

The properties of the hardened oil palm clinker concrete for the 5 mix proportions tested at an age of 28 days are presented in Table 4.

Table 4: Properties of oil palm clinker concrete for 5 chosen mix proportion

Mixture	Air dry density (kg/m^3)	Compressive strength, MPa	Splitting tensile strength, MPa	Modulus of rupture, MPa	Elastic modulus, Gpa
A1	1845.62	42.56	2.72	4.64	26.94
A2	1835.79	32.08	2.51	4.38	19.35
A3	1832.95	27.15	2.26	4.01	16.87
A4	1820.53	26.52	1.90	3.64	12.61
A5	1818.24	25.50	1.85	3.46	9.73

Figure 3 show the test result for compressive strength ranges between 25.5 to 42.56 N/mm^2. It is approximately 60% higher than the minimum required strength of 17 N/mm^2 for structural lightweight concrete recommended by ASTM C330 [10].

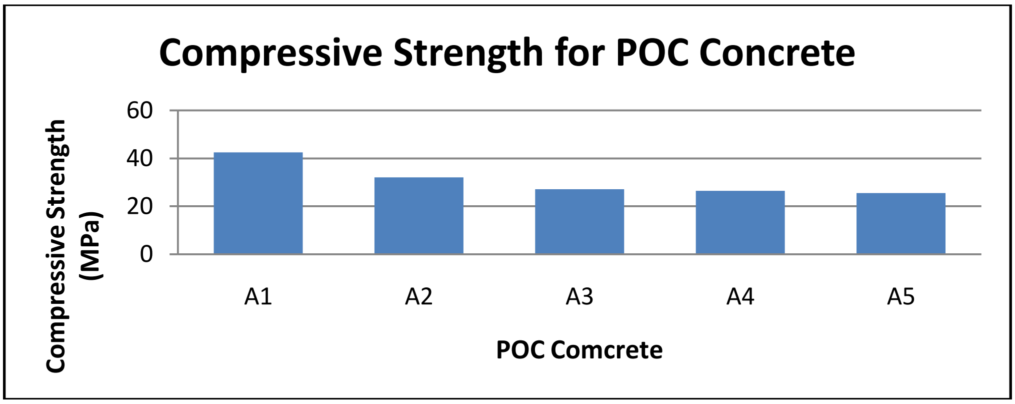

Figure 3: The Compressive strength of POC concrete

Lightweight concrete normally have density of less than 2000 kg/m^3 and the air dry density for oil palm clinker concrete ranges between 1818.24 to 1845.62 kg/m^3 are fall within this limit and it is approximately 16% lighter than normal concrete (2200 kg/m^3). The result was show in Figure 4. [13].

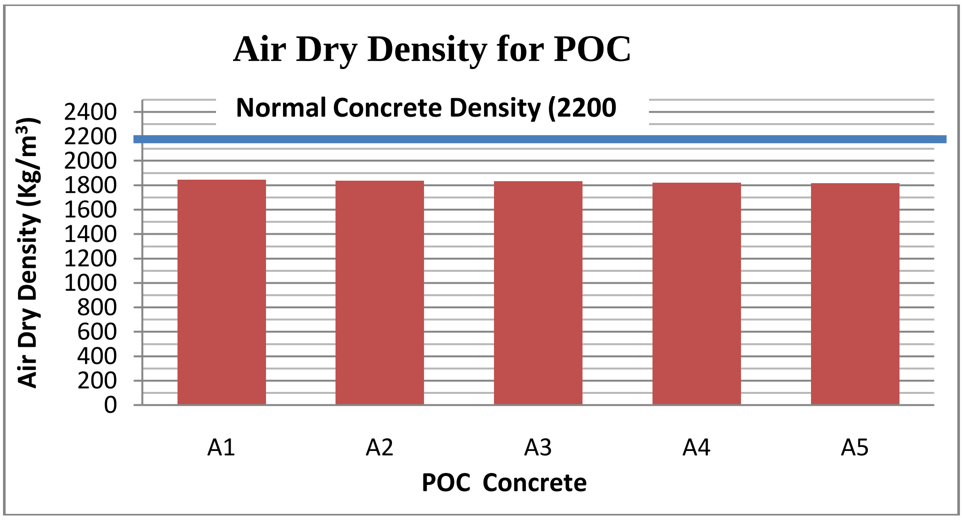

Figure 4: The Density of POC concrete

The test results shown that the oil palm clinker concrete modulus of elasticity ranges 9.73 to 26.94 GPa. The splitting tensile strength and modulus of rupture result ranges 1.85 to 2.72 N/mm^2 and 3.46 to 4.64 N/mm^2 respectively. The results show that splitting tensile strength and modulus of rupture have an increasing value by increase the cement content and a decreasing value by increase the water-cement ratio.

4.2 Rapid Chloride Permeability Test

The centralize mix proportion (A3) which compressive strength ranged within 25-30 N/mm^2 was chosen to be use in the further study of RCPT with oil palm clinker concrete. The acceptable mix comprised 500 kg/m^3 cement, 473 kg/m^3 fine oil palm clinker aggregate, 155 kg/m^3 coarse oil palm clinker aggregate and with a free water/cement ratio of 0.44. The concrete properties are presented in Table 5.

Table 5: Properties of oil palm clinker concrete

Concrete Properties	Average of 3 sample
Air dry density (kg/m^3)	1832.95
Compressive strength, 28days (MPa)	27.15
Splitting tensile strength (MPa)	2.26
Modulus of rupture (MPa)	4.01
Elastic modulus (GPa)	16.87

The object of the test was to evaluate the performance of POC concrete and compared the chloride permeability value with ASTM rating as Table 3. Chloride ion penetrability test were conducted on cylinder specimens for each concrete mixture at 7, 28 and 90 days for POC concrete. The results of chloride permeability in coulombs for different age are given in Table 6.

Table 6: Chloride permeability for POC concrete with age

Sample	7 days Chloride Permeability		28 days Chloride Permeability		90 days Chloride Permeability	
	Coulombs	Remark	Coulombs	Remark	Coulombs	Remark
C1	5126	H	4387	H	3945	M
C2	5389	H	4294	H	3972	M
C3	5174	H	4573	H	3871	M
Average	5230	H	4418	H	3929	M

The seven-day total charged passed for POC concrete are ranged from 5126 to 5389 coulombs and the average charge passed was 5230 coulombs. The twenty-eight day total charged passed for POC concrete are ranged from 4294 to 4573 coulombs and the average charge passed was 4418 coulombs. The ninety day total charged passed for POC concrete are ranged from 3871 to 3972 coulombs and the average charge passed was 3929 coulombs.

According to ASTM rating standard, POC concrete show high chloride-ion penetrability at age 7 days and 28 days. This high value of chloride-ion penetrability of POC concrete was expected because of the porous nature of POC. The chloride resistance of concrete is thus highly dependent on the porosity of concrete in terms of pore size, pore distribution and interconnectivity of the pore system [26]. At age 90 days, POC concrete show moderate chloride-ion penetrability. From previous researches [27-30], concrete will exhibit a general downward trend in the amount of electrical charge passed with an increase in time. The result is show in Figure 5. With the age increasing, the cement paste hydrates the pores become less well connected and therefore more resistant to the passage of electrical current are recorded.

In preview research [28], moderate chloride-ion penetrability value was recorded for ordinary concrete which form by river sand. The RCPT result for POC concrete at age 90 days are comparable to ordinary concrete.

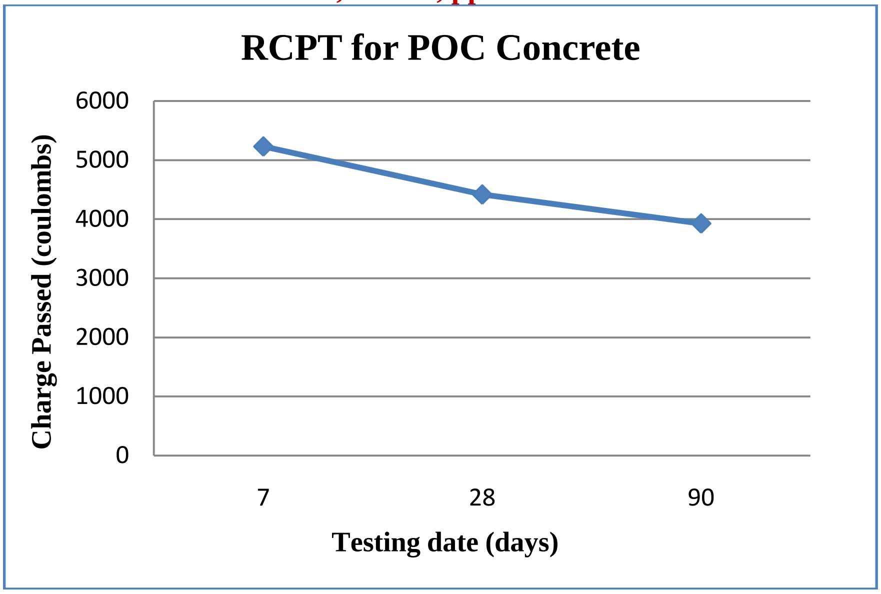

Figure 5: RCPT value for different testing date

5. Conclusions

The result from this study shown that the chloride permeability value of oil palm clinker concrete is comparable to ordinary concrete and give encouragement for oil palm clinker to be used as aggregate in production of durable structural lightweight concrete. The following conclusions can be made on the basis of the current experimental results.

1. The compressive strength of POC concrete at age of 28 days ranges between 25.5 $N/mm^2$to 42.56 N/mm^2. It is approximately 60% higher than the minimum required strength of 17 N/mm^2 for structural lightweight concrete recommended by ASTM C330.
2. The density of POC concrete ranges between 1818.24 kg/m^3 to 1845.62 kg/m^3 are fall within the limit of lightweight and it is approximately 16% lighter than normal concrete (2200 kg/m^3)
3. The oil palm clinker concrete modulus of elasticity ranges 9.73 GPa to 26.94 GPa. The splitting tensile strength and modulus of rupture result ranges 1.85 N/mm^2 to 2.72 N/mm^2 and 3.46 N/mm^2 to 4.64 N/mm^2 respectively. The splitting tensile strength and modulus of rupture have an increasing value by increase the cement content and a decreasing value by increase the water-cement ratio.
4. POC concrete show high value of chloride-ion penetrability at age of 7 days and 28 days due to the porous nature of POC.
5. Moderate value of chloride-ion penetrability was recorded for POC concrete in age 90 days resulted by the cement paste hydrates the pores become less well connected.
6. The results show that POC concrete are comparable to ordinary concrete. Therefore POC concrete are suitable to be use as durable structural lightweight concrete.

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