

# Quality control of lightweight aggregate concrete based on initial and final water absorption tests

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**Abstract.** Water absorption test is used to evaluate overall performance of concrete in terms of durability. The water absorption of lightweight concrete might be considerably higher than the conventional concrete due to higher rate of pores in concrete and lightweight aggregate. Oil palm shell is a bio-solid waste in palm oil industry, which could be used as lightweight aggregate in the concrete mixture. The present study aims to measure the initial and final water absorption and compressive strength of oil palm shell lightweight concrete in order to evaluation of quality control and durability performance. Total normal coarse aggregates were substituted with coarse oil palm shell in a high strength concrete mixture. The quality of concrete was then evaluated based on the compressive strength and water absorption rates. The results showed that fully substitution of normal coarse aggregates with oil palm shell significantly reduced the compressive strength. However, this concrete with the 28-day compressive strength of 40 MPa still can be used as structural concrete. The initial and final water absorption test results also showed that this concrete is not considered as a good concrete in terms of durability. Therefore, it is recommended that both compressive strength and waster absorption tests must be performed for quality control of oil palm shell concretes.

## 1. Introduction

In construction industry, concrete is the most demandable material, which is obtained from combination of binding material, fine and coarse aggregate, chemical admixtures and water. It is considered a cheapest and most readily material with high resistance to water which can be formed easily when it is fresh [1]. Concrete is considered as a durable construction material. Durability in concrete is defined as the ability to last a long time against various environmental conditions without any significant deterioration[2]. Generally, the durability of concrete is controlled by specifying some certain requirements such as properties of concrete constituents, procedure of casting and concrete compaction, curing and compressive strength. The standard compressive strength of concrete is used as such a significant criterion in most of the specifications and technical codes, whilst only some potential of



durability can be determined by the compressive strength; and it cannot be only valid criterion for evaluation of concrete quality control [3].

It has been well established that the evaluation of the quality and performance of a concrete mixture is not limited to its mechanical properties since it is important to characterize the material in terms of the factors that rate its durability [4]. There are some tests that commonly specified for determination of the concrete durability such as water permeability, rapid chloride permeability, surface absorption and waster absorption. Water absorption test according to BS 1881-122: 2011 is a simple method of determining the water tightness by submersion of the concrete specimen. Low absorption of the water can be defined as a positive result for the test.

Oil palm shell (OPS) as a bio-solid waste obtained in the processing of palm oil in the tropical regimes. The use of OPS as a natural lightweight aggregate has been investigated by several researchers. The results of recent studies showed that high strength up to 53 MPa could be achieved for lightweight oil palm shell concrete with dry density of 1830-1920 kg/m<sup>3</sup> [5]. Although OPS lightweight concrete has sufficient compressive strength as a principal criterion of acceptance of concrete, it does not necessarily have a good water absorption and durability. It has been reported that 24 hr water absorption of the OPS is in the range of 21- 33%. However, the normal aggregate water absorption value is less than 2% [6]. In regard to higher absorption capacity of OPS, durability of lightweight concrete using OPS must be investigated. In this regard, initial and final water absorption for high strength concrete as control mix (C1) and lightweight concrete by fully substitution of normal coarse aggregates with OPS (C2) were investigated.

## 2. Materials

Ordinary Portland cement complying MS EN 197-1:2007 with specific gravity 3.14 and blain specific surface area 3410 cm<sup>2</sup>/gr was used as binder. The fine aggregate with maximum size 4.75 mm from local mine with a fineness modulus 2.72 and specific gravity 2.66 was applied. Crushed oil palm shell (OPS) and granite obtained from local mine with maximum nominal size 12 mm were used. The physical properties of crushed OPS and crushed granite are represented in table 1. In addition, Sika ViscoCrete as a chloride free superplasticizer with maximum dosage 1% of total cement mass was used.

**Table 1.** Physical properties of OPS and Granite stone

Physical property	OPS	Crushed granite
Specific gravity	1.17	2.62
Fineness modulus	5.78	6.60
Bulk density (compacted) (kg/m <sup>3</sup> )	618	1421
Water absorption (10 and 30 min) (%)	7.4 and 8.9	< 1
Water absorption (1 and 24 h) (%)	10.1 and 19.7	< 1

### 2.1. Mix proportions

Mix proportion of normal weight high strength concrete (C1) as control mix and lightweight concrete with using of OPS (C2) are shown in table 2. In OPS lightweight concrete, total normal coarse aggregates were replaced 100% with coarse oil palm shell by volume. The cement content, water and superplasticizer for both mix designs were the same.

**Table 2.** Mix proportions of concretes in one batch

Mix code	Cement (kg)	Water (kg)	Superplasticizer (kg)	Sand (kg)	Coarse aggregate (kg)	
					Crushed granite	OPS
C1	55	18.2	0.55	94	103	0
C2	55	18.2	0.55	94	0	46.6

### 3. Results and discussion

#### 3.1. Workability

Slump test is one of the common test for evaluation of the workability. According to ACI 116R 2000, slump test is the way to measure the consistency of concrete mixture [7]. In this regard, the workability of mix C1 and C2 was measured. The slump value for both mixtures is shown in table3. As can be seen in table 3, the incorporation of OPS in high strength concrete decreased significantly the slump value from 205 mm to 40 mm. The reason for this remarkable lower slump value of mix C2 is due to the higher water absorption of OPS comparing to the normal coarse aggregate. Another reason for higher water absorption of mix C2 could be due to high content of pores [6]. Okpala [8] reported that the porosity of the shell is 37% although the quality of OPS can be improved using pre-treatment methods such as apply 20% poly vinyl alcohol (as a PVA solution) which can decrease the water absorption of the shell from 23.3 to 4.2% [9].

**Table 3.** Slump value and densities of mixes

Mix code	Slump (mm)	Density (kg/m <sup>3</sup> )	
		Demoulded	Oven dried
C1	205	2400	2340
C2	40	1940	1900

#### 3.2. Density

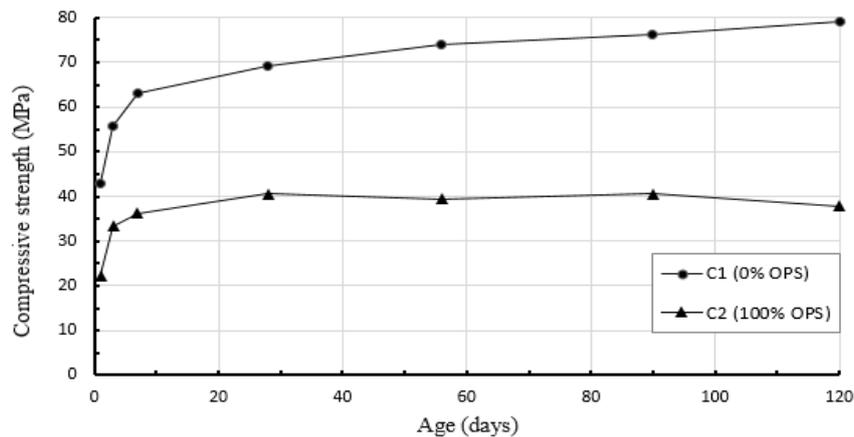
Density of the hardened lightweight concrete (LWC) for structural application is often more important than the compressive strength [10] and considered as an important variable for design of concrete structures. The range of density for LWC normally is defined between 1400 to 2000 kg/m<sup>3</sup> compared to the NWC with 2400 kg/m<sup>3</sup> [11]. Table 3 shows the density of 2 mixes. It could be concluded that fully substitution of normal coarse aggregates with oil palm shell in mix C2 reduced 17% of concrete density. This is due to low density of the oil palm shell aggregate in comparison to normal weight aggregate. The practise concrete with dry density less than 2160 kg/m<sup>3</sup> is considered as LWC [12]. Therefore, mix C2 with an oven density of 1900 categorised as LWC.

#### 3.3. Compressive strength

The compressive strength is a significant property of the structural concrete, which affects other mechanical properties such as splitting tensile strength, flexural strength and modules of elasticity. According to ASTM C330-89 the 28-day cylindrical compressive strength should not be less than 17 MPa. The results of compressive strength test on 100 mm cube are presented in figure 1. As shown in figure 1, it can be observed that the compressive strength achieved for HSC (C1) at the age of 28-day was 69 MPa, whereas for OPS light weight concrete (C2) at same W/C ratio the average of the compressive strength was 40 MPa which is approximately 41% lower than the control mix.

With increasing of the OPS content in the mixture along replacement of normal weight coarse aggregate, the specific area of aggregates was increased due to lower density of the OPS, thus requiring more cement paste for better and effective bonding with the shells. Since the binder (cement) remain the same,

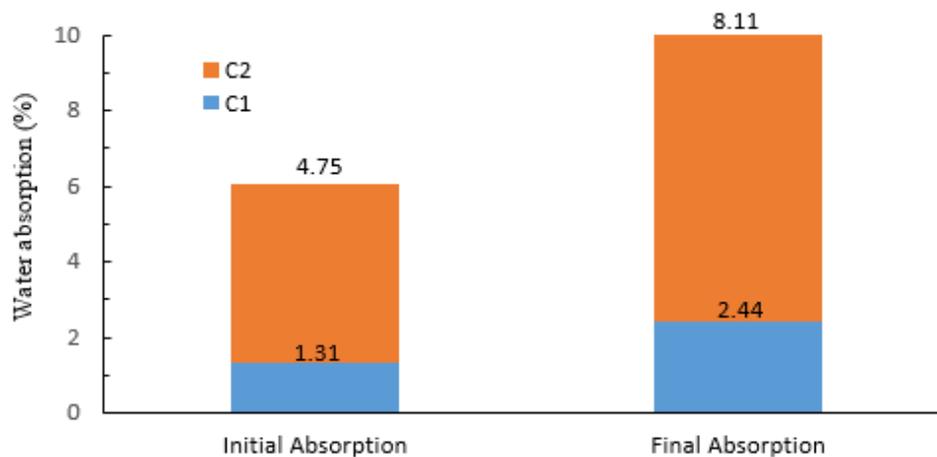
the bonding to achieve proper mechanical properties is inadequate. The failure mechanism of OPS concrete was investigated. It was reported that failure is depending on breakdown of interfacial transition zone (ITZ). Due to the smooth surface of the shell on both concave and convex there is a weakness in the bond between cement matrix and OPS aggregate to sustain against high loads. Hence, the failure of OPS concrete is mainly caused by easy debonding between the shells and cement paste that less than contribution of the aggregates strength [7, 8, 13, 14].



**Figure 1.** Compressive strength versus time

### 3.4. Water absorption

Water absorption is water flow into the unsaturated pores of concrete due to the differences of pressure caused by gravitational and capillary forces [13]. Water absorption of both mix C1 and C2 was measured at the age of 28-day for 30 min and 72 h. as shown in Figure 2, it could be seen that both initial and final water absorption of OPS lightweight concrete is significantly higher than the control HSC. Due to high rate of water absorption of OPS, fully substitution of normal coarse aggregates with this pores aggregate increased its water absorption capacity. Therefore, with reducing volume of OPS in concrete mixture, it can be expected that the initial and final water absorption reduce.



**Figure 2.** Water absorption of concrete mixes

Teo et al. [14] reported that water absorption rates for structural lightweight concrete using OPS in air and water curing conditions were 10.64 and 11.23 % respectively. Water absorption ranges for

other types of lightweight concrete such as pumice aggregate concrete and expanded polystyrene aggregate were 14-22% and 3-6%, respectively [15, 16]. Based on 30 min water absorption value of 0-3%, 3-5% and 5% above, the quality of concrete was categorised as good, average and poor respectively by CEB-FIP [17].

Accordingly, mix C2 had initial absorption of 4.75% that could be classified as “average” quality. Furthermore, final absorption was 8.1%, which is relatively higher than the control mix by 2.4%. It has been reported that water absorption of high quality concrete usually is lower than 5% [17]. Therefore lightweight concrete using OPS as fully replacement of aggregate cannot be considered as a high durable concrete due to the high rate of water absorption although compressive strength was 40 MPa at the age of 28-day.

#### 4. Conclusion

In this study, normal coarse aggregate was fully replaced (by volume) with oil palm shell (OPS) lightweight aggregate in a high strength concrete. Water absorption test as indicator of the quality of concrete was used to assess durability properties of the new concrete containing OPS.

Experimental test results showed that fully substitution of normal coarse aggregate with OPS in a high-strength normal-weight concrete significantly reduced the slump value of the concrete due to high water absorption of the OPS aggregates. Although, grade 40 could be achieved for OPS lightweight concrete, however, it cannot be used for constructing structural elements. This is due to the OPS concrete with high initial and final water absorptions is not classified as good and durable concrete. It can be concluded that just compressive strength test is not a good indicator to assess the quality of OPS concrete, and, therefore, durability test should be considered in the assessment. Water absorption test has a simple procedure and can be used as a first durability test for OPS concrete.

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