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A new method of producing high strength oil palm shell lightweight concrete

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ABSTRACT

This paper presents a new method to produce high strength lightweight aggregate concrete (HSLWAC) using an agricultural solid waste, namely oil palm shell (OPS). This method is based on crushing large old OPS. Crushed OPS are hard and have a strong physical bond with hydrated cement paste. The 28 and 56 days compressive strength achieved in this study were about 53 and 56 MPa, respectively. Furthermore, it was observed that it was possible to produce grade 30 OPS concrete without the addition of any cementitious materials. Compared to previous studies, significantly lower cement content was used to produce this grade of concrete. Unlike OPS concrete incorporating uncrushed OPS aggregate, this study found that there is a strong correlation between the short term and 28-day compressive strength.

1. Introduction

Typically, through the incorporation of various pozzolans and water reducers, high strength lightweight aggregate concrete (HSLWAC) has a compressive strength range of between 34 and 69 MPa. This concrete has a water to cement ratio of less than 0.45 and its air-dry density is less than 2000 kg/m^3 [1]. The use of high strength concrete (HSC) has many advantages such as a reduction in beam and column sizes, increased building height, greater span-depth ratio for beams in pre-stressed concrete construction and improved durability of marine concrete structures [2]. It can be said that HSLWACs have a significant advantage over normal weight HSC because of the reduction of dead load and construction cost. For instance, it has been reported that the length of high strength/high performance lightweight concrete prestressed bridge girders can be extended by 15–20% [3]. Furthermore, in some environments the use of HSLWC is mandatory. Haque et al. [4] investigated the strength development and durability of 35 and 50 MPa total lightweight concretes made with Lytag lightweight aggregate using 1, 3 and 7 days initial moist curing and then exposure to hot marine conditions for a period of 7 years. They suggested that it would not be wise to use LWC with a compressive strength of less than 50 MPa. In another example, it was reported that because of the limited bearing capacity of the soil, an all-LWC (a concrete mixture of 1840 kg/m^3 density and 41.2 MPa compressive strength) structure of 52 storeys was made as compared to a 35-storey structure using NWC [5].

There are different types of lightweight aggregate (LWA) with a wide range of properties. However, not all types of LWA are suitable for the production of HSC [6]. Oil palm shell (OPS) or palm kernel shell (PKS) are waste materials from the agricultural sector; products obtained in the processing of palm oil and are available in large quantities in tropical regions. It has been found that OPS can be used as a coarse aggregate for the manufacture of structural lightweight concrete and most researches have shown that producing OPS concrete with 28-day cube compressive strength of grade 35 or less is possible [7–13]. Okafor [7] reported that the maximum compressive strength of concrete produced using palm kernel shell aggregate is approximately 25–30 MPa. Basri et al. [8] used freshly discarded OPS in their study. They found that the compressive strength of OPS concrete is about 50% less than ordinary concrete. They produced grade 20 OPS lightweight concrete with low slump value. Mannan and Ganapathy [9] showed that by using 480 kg/m^3 ordinary Portland cement and free w/c ratio of 0.41, the 28-day compressive strength of OPS concrete is between 20 and 24 MPa, depending on the curing conditions. Furthermore, they reported [10] that the use of an accelerator such as calcium chloride ($CaCl_2$) results in higher strength of up to 29 MPa. The slump values for their study were lower than 10 mm. Mannan et al. [11] have used six types of preservatives, similar to preservative treatment to wood, to improve OPS and used it as coarse aggregate. The highest 28-day compressive strength of about 33 MPa with slump value of 95 mm was reported in this study. Alengaram et al. [12] reported that the 28-day compressive strengths of the mixes containing cementitious materials were in the range of 26–36 MPa and slump value was in the range of 0–160 mm. They used cement content in the range of 440–530 kg/m^3 with 5% fly ash (FA) as cement replacement and 10% silica fume (SF) as additional cementitious material. A recent study conducted by Shafigh et al. [13] revealed that OPS

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can be used as a lightweight aggregate for producing HSLWAC. The 28-day compressive strength of about 43–48 MPa was reported in the study. From the literature, it is obvious that there is very little information available concerning the properties of HSLWAC containing OPS as LWA. Because of the importance of achieving high strength LWC, this investigation concentrates on developing and producing HSLWAC by using OPS. The aim of the research is to produce grade 30 OPS lightweight concrete with much reduced cement content than previously published studies.

2. Experimental programme

2.1. Materials

2.1.1. Cement

The cement used was ordinary Portland cement (OPC) with a specific gravity of 3.14 g/cm^3. The 7 and 28-day compressive strength of the cement was 34.2 and 45.9 MPa, respectively. Its Blaine's specific surface area was 3510 cm^2/g.

2.1.2. Superplasticizer (SP) and water

The SP used in this study was Sika viscocrete, supplied by Sika in conformity with EN 934-2, and was used in the range of 0.8–1.8% of cement weight. Potable water was used in all the mixes.

2.1.3. Aggregates

Local mining sand with a specific gravity, fineness modulus, water absorption and maximum grain size of 2.68, 2.65, 0.94% and 4.75 mm, respectively, was used as the fine aggregate.

As in previous studies [8–13] OPS in different shapes were used as the coarse aggregate. Initially, the old OPS were collected from a local crude palm oil producing mill. The advantages of using this type of aggregate in OPS concrete were reported by Shafigh et al. [13]. The OPS were washed and sieved with a 9.5 mm-sieve. OPS aggregates retained in this sieve were collected and then crushed with a stone crushing machine in the laboratory.

The thickness of shells is in the range of 0.15–8 mm [14]. Larger sizes of OPS aggregates have greater thickness (Fig. 1). Its flakiness index is high, about 65% of that obtained by Mannan and Ganapathy [15]. By crushing the larger sizes of OPS aggregate, its flakiness significantly decreases, which results in a better performance of coarse aggregate and consequently better compressive strength. After crushing, the crushed OPS aggregate was sieved using a 2.36 mm-sieve to remove the OPS aggregate of less than 2.36 mm in size. They were weighed in dry room conditions, and then immersed in water for 24 h. Subsequently, they were air dried in the laboratory to obtain an approximately saturated surface dry condition. For comparison, concrete containing original OPS aggregate (uncrushed OPS) was also cast. The physical properties and grading of OPS are shown in Table 1.

2.2. Mix proportions

The CP1 mix has similar mix proportions of high strength OPS concrete used in previous research [13]. Mix CP2 has a lower water/cement ratio than the CP1 mix. The total weight of normal weight aggregates of this mix is similar to that of CP1 mix. However according to Aitcin's recommendation [5], 20% of the fine aggregate of mix CP1 was replaced with crushed granite with a maximum size of 12.5 mm to achieve a coarser fine aggregate. According to Aitcin's [5], for HSC, it is better to use fine aggregate with higher fineness modulus because coarser fine aggregate requires less water to obtain the same workability. Mix CP3 was designed with the highest recommended cement content for high strength sanded-LWC as proposed by ACI 213R-87 [16]. This mixture was designed with a higher crushed OPS content with an acceptable workability (50–75 mm) for structural lightweight concrete. Similar to the CP3 mix, mix CTR has original OPS (uncrushed OPS) with a maximum size of 12.5 mm. The CP4 mix has a cement content of 360 kg/m^3, which is lower than the previous studies. For making grade 25 and 30 OPS lightweight concrete, the cement content from previous mixes varied in the range of 420–550 kg/m^3 [10,15,17–25]. Details of the concrete mix proportions are presented in Table 2.

2.3. Test methods

During the mixing procedure, the cement, sand and OPS were blended in a pan mixer for 1 min. Then, the mixture of SP and about 70% of the mixing water was added to the mixture. After 3 min of mixing the remaining water was added and mixing was continued for 10 min, before the slump test was performed. The concrete specimens were cast in 100-mm cube steel moulds and compacted using a vibration table. The specimens were demoulded after approximately 24 h and were cured in water at 25 ± 2 °C until test days. The compressive strength of specimens was determined on the 1st, 3rd, 7th, 28th and 56th day in accordance to BS 1881: Part 116 [26] by compression testing machine of 3000 KN capacity with a rate of loading controller. Three concrete cubes were cast for obtaining the average value at any age.

3. Results and discussion

3.1. Workability and density

The results for workability and densities of LWAC are presented in Table 3. All mixes, except for mix CP4, showed high or accept-

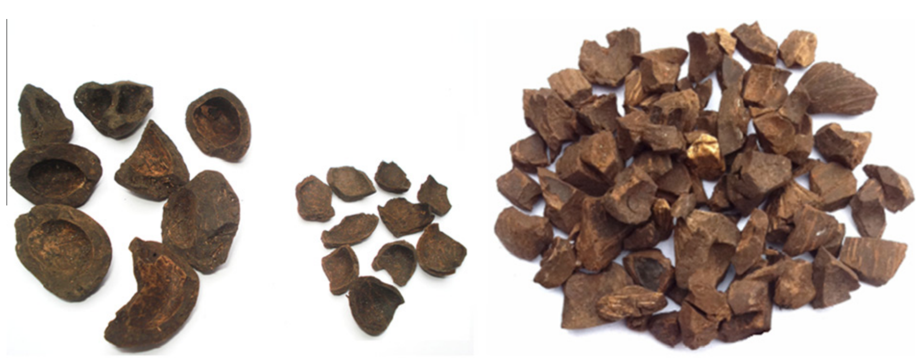

Fig. 1. OPS aggregates: (a) original large size, (b) original small size, and (c) crushed from original large size.