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Effect of palm oil clinker incorporation on properties of pervious concrete

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HIGHLIGHTS

- Palm oil clinker pervious concrete was produced.
- Incorporation of palm oil clinker reduced the compressive strength and density of the concrete.
- Permeability and porosity increased with addition of palm oil clinker.
- Optimum performance was at 25% replacement.

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ABSTRACT

Palm oil clinker (POC), a by-product of palm oil mill, can be found in large quantity in Malaysia and it is considered as waste. POC is suitable as aggregate replacement in lightweight concrete and other engineering applications due to its physical properties. This study presents the use of POC as coarse aggregate in the production of pervious concrete (PC). Materials used include OPC Type I, coarse aggregate 10 mm nominal size. Based on this, various mixes were developed with a fixed water-cement ratio of 0.3. The palm oil clinker pervious concrete (POCPC) were studied at various replacement levels of natural aggregate with POC aggregate ranging from 0% to 100%. Results indicated that substitution with POC reduced the compressive strength and density of the concrete. However, the coefficient of permeability and porosity rose. Compressive strength obtained was between 3.43 MPa and 9.52 MPa. Maximum loss in strength was about 65% at full replacement. However, replacement of POC at 25% exhibited a superior performance among others. As such, it has been identified as the best mix for optimum performance of the POCPC.

1. Introduction

Demand for construction materials has been on the rise in order to sustain the fast growing global population. As a result, there is continual depletion of naturally occurring construction materials leading to increase in their cost. To this effect, engineers are faced with the challenge of resolving this potential sustainability problem [1]. One of the current global trends is focused on recovery of usable materials from waste as well as utilization of waste as raw materials whenever feasible in construction. This can be done by exploring the means to put waste into beneficial alternative use [2]. Examples of waste materials that has been incorporated into construction include crumb rubber, palm oil clinker (POC), oil palm shell (OPS), palm oil fuel ash (POFA), wood chippings, seashell by-product etc.

In Malaysia, POC can be found in abundance and have little or no commercial value. As a result, it is one of the main contributors to the pollution problem of the nation [3–5]. However, various studies [3,6–9] have shown that this agro waste can serve as potential construction materials. POC is generally porous, irregularly shaped with good lightweight characteristics and is obtained in large chunks (Fig. 1a) during incineration process of oil palm shell and the fiber. It serves as an ideal alternative aggregate when crushed and sieved into suitable sizes as seen in Fig. 1b. In this study, POC was utilized for the production of pervious concrete (PC) for concrete construction.

PC is a concrete type comprising of cement, little or no sand and uniformly graded coarse aggregate with controlled amounts of water. However, omission of sand will usually decrease the fresh workability and strength of the PC compared to conventional concrete [10,11]. Typically, the permeability coefficient of PC varies from 0.25 to 6.1 mm/s, with void ratios ranging from 14% to 35% and the 28-day compressive strength is usually between 5.6 and

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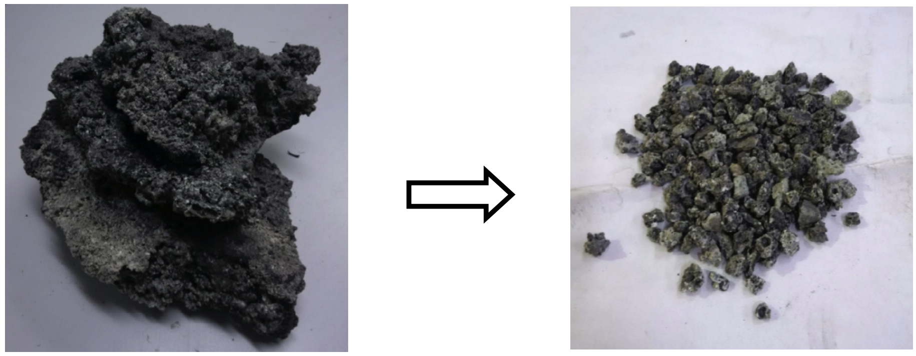

(a) (b)

Fig. 1. (a) Chunk of POC (b) POC coarse aggregate.

21.0 MPa [12]. The design compressive strength is dependent on its application. A design compressive strength in the range of 10–13 MPa is preferred for parking lots, stone protection, drainage pavement, and precast porous concrete products [13,14]. However, lower strength is acceptable for pedestrian trials and walkways since the PC will not be subjected to vehicular loads [14]. Also, compressive strength in the range of 0.69–6.89 MPa and 6.89–17.24 MPa are often employed for insulating concrete and fill concrete respectively [15]. As such, PC is not suitable for load bearing concrete application [16]. Some applications of PC includes permeable pavement, noise absorbing concrete, insulating concrete, sidewalks and pathways, pavement edge drains, and slope stabilization.

Previously, most studies on PC have frequently adopted the use of natural aggregate (NA) such as crushed gravel, quartzite, limestone, dolomite and granite among others as coarse aggregate. The use of recycled aggregate (RA) or recycled waste materials (RW) in PC is rare which could be as a result of doubts concerning the resulting strength of the concrete. However, emphasis should be more on PC permeability rate and porosity rather than the strength for most of its application [17]. As such, researchers are beginning to identify alternative sustainable materials as aggregate replacement in PC. Materials such as waste tire rubbers [18], coal ash [19], seashell by-products and bottom ash [20], and electric arc-furnace slag [21] have been suggested as suitable PC material for constructions such as parking areas, road shoulders, walkways amongst others. Most of these studies indicate that the PC made with the various waste materials exhibit acceptable properties that compares to PC with natural aggregates, although, this is dependent on the ratio and level of replacement. Therefore, the utilization of wastes in the production of PC offers an alternative environment friendly material.

This study presents an experimental work on the use of POC as coarse aggregate in the production of palm oil clinker PC (POCPC) at different replacement levels. The investigated properties are compressive strength development with age, density, permeability and porosity. The results obtained are used to develop inter-relationships among these selected properties for the POCPC mixes.

2. Experimental program

2.1. Materials and properties

Type I ordinary Portland cement (OPC) complying with ASTM C150 [22] is used as a primary binder. Other constituents used in all the POCPC mixes studied are palm oil clinker powder (POCP) obtained by process of grinding POC with a ball mill equipment, granite, water and POC coarse aggregate obtained by crushing POC with a jaw crusher and sieved to desired size. All coarse aggregates used are single sized 10 mm nominal size. The physical properties of coarse aggregate are summarized in Table 1 and Fig. 2 depicts the sieve analysis grading curve. The aggregates satisfied the required parameters and can be seen to be within the range stipulated in BS882 [23] for nominal size of single-sized aggregate. The major properties of OPC and POCP can be seen in Table 2.

2.2. Mix proportion

POCPC mixes were chosen with cement to aggregate ratio of 4.79 at a constant water cement (w/c) ratio of 0.3. The percentage of POC replacement used in the POCPC are 0%, 25%, 50%, 75% and 100% by volume of natural aggregate. Due to the voids present in the POC coarse aggregate, a similar approach by Kanadsan [7] was adopted to determine the volume of the additional voids with reference to granite. Table 3 shows the percentage of void increment due to the voids of POC coarse at different replacement levels. The void volumes were incorporated into the mix design to obtain the final mix proportion for the POCPC. In order to maximize the use of palm oil waste, POCP was selected as a suitable filler material to pre-coat the voids present on the surface of the POC coarse aggregate. Fig. 3 depicts the steps adopted to determine the required volume of POCP for each replacement level for the mix proportion. The final mix proportion for POCPC is presented in Table 4.

The POCPC mixes were produced in a rotating drum type mixer. The batching sequence are as follows:

- Step 1: Dry mixing of POC coarse, (SSD), with POC powder for 30 s to pre-coat it.
- Step 2: Addition of cement (and granite when applicable) and mixing for 30 s.
- Step 3: Addition of water and mixing for 3 min.
- Step 4: Mixture allowed to rest for 3 min.
- Step 5: Mixing for 2 min.
- Step 6: Consistency test.

Once the consistency of the mixture is judged satisfactory, the concrete was then cast into 100 mm × 100 mm × 100 mm cubes. The specimens were demolded after 24 h in accordance with [25] and various samples were cured in water. The cubes were tested at the ages of 7 and 28 days to determine density and compressive strength of the concrete. Porosity and permeability tests were conducted after 28 days of curing the concrete samples. The properties were correlated to establish a relationship between them.

3. Sample preparation and testing

3.1. Hardened density

The hardened density of concrete was measured after 7 and 28 days of curing, before the compression tests. These were calculated as the ratios of densities of concrete cured under standard condition.

Table 1
Physical properties of coarse aggregate.

Aggregate type	Aggregate size (mm)	Specific gravity	Aggregate crushing value (%)	Bulk density (kg/m^3)	Water absorption (%)
POC	4.75–9.5	1.88	56.44	732	3 ± 2
Granite	4.75–9.5	2.72	18.22	1294	0.58