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CONCRETE PAVING BLOCKS INCORPORATING PALM OIL BOILER ASH AND PALM OIL CLINKER AS SUBSTITUTE CONCRETE MATERIALS

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Abstract

Concrete Paving Block (CPB) is known for its durability and strength, making it ideal for heavy-duty applications like roadways. However, the production of CPB however requires cement and natural aggregate, both of which have negative impact to environment. This study examines the potential of using by-products, specifically palm oil boiler ash (POBA) and palm oil clinker (POC), as substitute for cement and aggregate in the production of CPB. A total of 36 CPBs were prepared with 0%, 10%, 20%, and 30% of POBA and POC replacement. The materials properties and the compressive strength of CPB were measured. The results show CPBs of 10POBA+10POC has a potential to be used as CPBs in streets, sidewalks, and parking/garage. This alternative material could help reduce the environmental impact of CPBs production while still providing a durable and strong product.

Keywords: Compressive strength, Concrete paving block, Palm oil boiler ash, Palm oil clinker.

1. Introduction

Concrete block pavement also known as semi-rigid pavement is having unique features that includes durability, easy laying and immediate use, and aesthetics value. In general, this type of pavement typically used from ultra-heavy-duty areas such as industrial units, airport pavements, container stacking areas to lightly trafficked area intersections and driveway, car park/garage, and lastly, footpath. Concrete paving block (CPB) is the single unit or component of the semi-rigid pavement. The production of the CPB mainly using Ordinary Portland cement (OPC) as the binder material, and natural aggregates. These two main constituents, namely OPC and natural aggregate nowadays have been given a critical attention worldwide. Cement production is one of the main contributors to greenhouse gas emissions [1], and the high demand of natural aggregate worsens the damage to the environment. Besides, the production of traditional cement and natural aggregate can lead to the degradation of ecosystems and loss of biodiversity. The best options in reducing the massive usage of OPC and natural aggregate is by incorporating sustainable materials such as agricultural by-product, specifically from palm oil industry.

According to the Food and Agriculture Organization (FAOSTAT) [2] latest data, an average of 74.6 million tonnes of palm oil were produced globally, and 87.3% of the total output came from Asia. Indonesia recorded the highest palm oil production with 473 million tonnes and followed by Malaysia, as the second highest producer with 385.2 million tonnes in 2020. Malaysia and Indonesia being the global palm oil supplier has taken up a lot of this production including a negative impact on the environment. Different types of by-products are generated through oil extraction process, such as empty fruit bunches, palm oil fruit composite (kernel, mesocarp, fibre), clinker, boiler ash, and fuel ash [3]. Numerous research has been conducted to explore the feasibility of using palm oil by-products particularly clinker and boiler ash as concrete material [4-11]. Application of the by-products as cement and aggregate replacement is very promising towards the production of environmentally friendly concrete.

On the other hand, palm oil boiler ash (POBA) has been widely utilized as supplementary binder in concrete. According to Jusli et al. [12] and Roslan et al. [13], POBA comprised of high silica content which is essential component for developing hydrated products. The POBA is typically found in powder form, and suitable be utilized as cement replacement material or as a filler in concrete. Roslan et al. [13] reported that 5% and 10% cement replacement by POBA could attain compressive strength beyond 30 MPa at 28-day of curing age. Over the years, the palm oil clinker and boiler ash are mostly adopted for general concrete application or lightweight concrete yet not much application in concrete paving blocks (CPBs) production. Thus, this study is carried out to investigate the feasibility of using palm oil by-product as substitute material in CPBs production. In addition, the use of palm oil by-products as a substitute for cement and aggregate in the production of CPBs is related to several sustainable development goals (SDGs) components, namely SDG 9 - Industry, innovation and infrastructure, SDG 12 - Responsible consumption and production, SDG 13 - Climate action and SDG15 - Life on land.

2.Materials and Methodology

Palm oil by-products were used as partial substitute of cement and aggregate in the production of concrete paving block. Both palm oil clinker (POC) and palm oil boiler ash (POBA) were collected from the palm oil mill located in Mukah, Sarawak. The coarse and fine aggregate used are comprise of crush granite (with maximum size of 10 mm) and river sand locally available in Sibu, Sarawak. The POBA (Fig. 1(a)) is readily in powder form and black in colour whereas the POC as shown in Fig. 1(b), is a reddish grey porous stone. The properties of aggregates, POC, and POBA such as density, water absorption, and morphology were determined.

The density and water absorption of coarse aggregates were determined in accordance with ASTM C127 [14] whilst ASTM C128 [15] is used for fine aggregates. Coarse aggregate impact value (AIV), aggregate crushing value (ACV), and Los Angeles abrasion value (LAAV) were measured to identify the toughness of aggregates to sustain loading and abrasion. The aggregates sample was examined according to BS EN 1097 Part 2 [16]. Compression test was conducted according to BS EN 1338 [17] to determine the compressive strength of the CPBs. The CPBs were soft capped with two pieces of plywood (4 mm ± 1), then placed under a compression machine (with a maximum capacity of 3000 kN) and compressed with a loading rate of 2.5 kN/s. Each compressive strength value represents an average of three samples for each curing age.

Fig. 1. (a) Palm oil boiler ash and (b) palm oil clinker.

The mix and replacement details are presented in Table 1. A total of four mixes were designed. The control mix (CM) composed of ordinary Portland cement (OPC), coarse and fine aggregates with mixing ratio of 1:1.7:1.5 (C:A:S). In addition, water/cement ratio of 0.5 and 0.1% superplasticizer (SP) were used. The modified CPBs consist of OPC, POBA, POC, aggregates, water, and SP. The replacement percentage of OPC and coarse aggregate varies from 10%, 20%, and 30%, respectively. The CPB with dimensions of 100 mm x 100 mm x 80 mm was fabricated.

Table 1. Mix proportion for specimens.

Mix Design	OPC (kg/m^3)	POBA (kg/m^3)	Coarse Aggregate (kg/m^3)	POC (10 - 4.75 mm) (kg/m^3)	Fine Aggregate (kg/m^3)
CM	489	-	831.3	-	733.5
10POBA-POC	440.1	23.1	748.17	67.8	733.5
20POBA-POC	391.2	46.3	665.04	135.5	733.5
30POBA-POC	342.3	69.4	581.91	203.3	733.5

3. Results and Discussion

3.1. Materials properties

The density and water absorption of materials is presented in Table 2. The density of POBA was found to be 52.7% lower than that of OPC, whereas POC having approximately 18% lower density compared to crush granite. The average water absorption of POC is twice higher than that of crush granite. The density and water absorption are the physical properties, which corelated to the internal microporosity. The porous structure of the POBA and POC particles initiate lower density than OPC and coarse aggregate, respectively.

Table 2. Density and water absorption of materials.

Materials	Density (g/cm^3)	Water absorption (%)
POBA	1.49	N/A
POC	2.16	4.56
OPC	3.15	N/A
Coarse Aggregate	2.65	1.85
Fine Aggregate	2.54	2.32

The porous structures of POBA and POC are clearly observed in Figs. 2(a) and (b). It is noted that the microporosity directly affecting the materials' density, and water absorption. It is also spotted that the morphology structures of POC was less porous than POBA and thus its density was higher. The morphology structure of POC is less porous than POBA due to differences in their production processes. POBA is produced through combustion, which results in a more porous structure, while POC is produced through calcination, which lead to a denser structure. The higher density of POC makes it suitable for aggregate replacement.

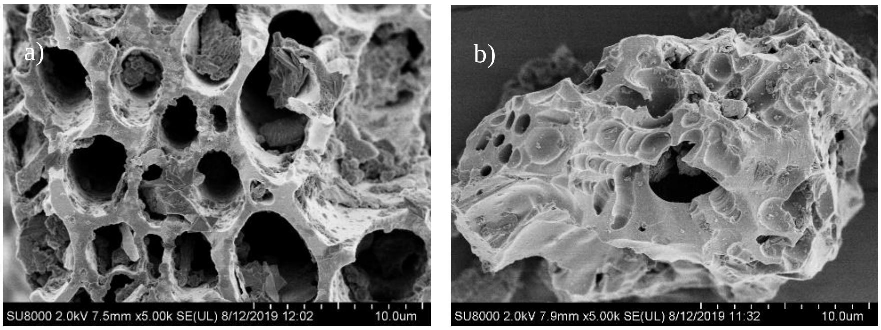

Fig. 2. Morphology of (a) POBA and (b) POC [12].

The AIV, ACV, and LAAV of POC and crush granite are presented in Table 3. In general, the results for crush granite are acceptable and meet the requirement stated in the BS EN specification. The crushing and abrasion value of POC however recorded values more than 30 %. It is known that lower aggregate impact, crushing, and abrasion value indicates the aggregate is stronger. Thus, this may affect the strength of the hardened concrete.

Table 3. Impact, crushing, and abrasion values for materials.

Materials	AIV (%)	ACV (%)	LAAV (%)
POC	23.6	37.82	32.3
Coarse aggregate	26.5	18.5	21.7

3.2. Compressive strength

Based on the results in Fig. 3, the compressive strength of the modified CPB ranged from 20.88 to 40.71 MPa at 28-day of curing age. The increase in replacement level significantly affected the strength of blocks, indicating that the strength is influenced by the properties of materials used. According to Roslan et al. [13], the interfacial bonding between particles is affected by the contact surface area. The large surface area of POBA enhanced the chemical reactivity of siliceous and aluminous components with calcium hydroxide to form compounds that possess cementitious properties [18]. In addition, Roslan et al. [13] also highlighted that mixtures with POBA have higher pozzolanic activity compared to that of OPC only. It is also confirmed by Jusli et al. [12] that the silica content in POBA is 35% higher than OPC, thus led to an increase of the compressive strength. As presented in Table 3, shows that the POC is not strong enough to cater high loading. Reduction of compressive strength also due to weak bonding between the POC and cement matrix [19].

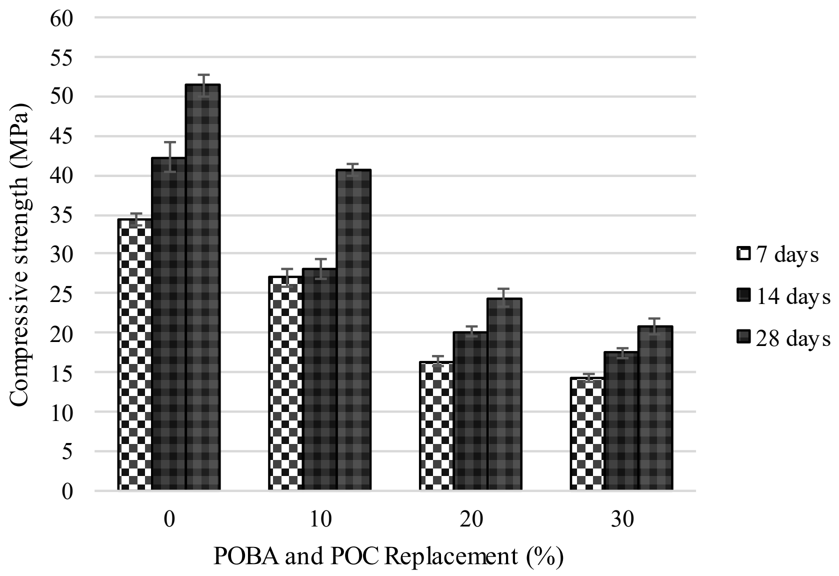

Fig. 3. Compressive strength of modified CPBs.

4. Conclusion and Recommendation

This study investigated the application of palm oil by-product as replacement materials of cement and coarse aggregate in CPBs production. It showed that the compressive strength of CPBs significantly affected by the physical properties of POC. Based on the overall results, the modified CPBs of 10POBA-POC had the potential to be used as paving blocks in streets, sidewalks, and parking/garage for meeting the minimum compressive strength of 30MPa set by BS EN 1338. It is recommended that POC replacement should be limited to fine aggregate replacement instead of coarse aggregate to minimize the impact of concrete strength reduction. Further research is needed to investigate the long-term durability and performance of these modified CPBs in real life applications. Overall, the utilization of palm oil by-products as replacement materials in the production of CPBs not only reduces waste in the palm oil industry by also contribute to the sustainable development of the construction industry.

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Abbreviations

AIV	Aggregate Impact Value
ACV	Aggregate Crushing Value
CM	Control Mix
CPBs	Concrete paving blocks
LAAV	Los Angeles Abrasion value
OPC	Ordinary Portland Cement
POBA	Palm oil boiler ash
POC	Palm oil clinker

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