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Physical and Chemical Properties of Palm Oil Boiler Ash and Palm Oil Clinker Powder

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Abstract: Malaysia is known as one of the primary contributors to global oil palm production. The vast production of palm oil simultaneously intensifies the generation of biomass waste. This study characterized the physical properties of palm oil boiler ash (POBA) and palm oil clinker powder (POCP) such as density, specific gravity, particle size, morphology and chemical composition. The characterization was done using the density analyzer, field emission scanning electron microscopy (FESEM), and X-ray fluorescence (XRF). POBA and POCP had smaller particle sizes than Ordinary Portland Cement (OPC). Their structures were porous. The density and specific gravity of POBA and POCP were 52.7% and 28.6% lower than OPC. Containing 30.5% and 56.5% of silica dioxide (SiO_2), POBA and POCP can trigger pozzolanic action in concrete to increase the strength of concrete. Overall, the POBA and POCP possess huge potential as supplementary cementitious materials, especially for lightweight brick and concrete.

Keywords: Palm oil boiler ash, Palm oil clinker powder.

INTRODUCTION

Malaysia is one of the world's leading palm oil producers. The country is undergoing robust development of the oil palm industry since the 1960s. In 2019, the oil palm plantation area in Malaysia reached 5.9 million hectares and Sarawak covered the largest planted area of 26.9% (1.59 million hectares) [1]. This commodity plays an important role in Malaysian economic growth contributing to 4.5% of national gross domestic product (GDP) and foreign exchange earnings of RM 67.5 billion [2];[3]. According to the Malaysian Palm Oil Board [1], the production of crude palm oil reached 19.86 million tonnes in 2019.

The enormous production of palm oil simultaneously generates an abundance of biomass wastes that created a major disposal problem. This included empty fruit bunch (EFB), mesocarp fiber (MF), palm kernel shell (PKS), oil palm fronts (OPF) and oil palm trunk (OPT) [4]. Among those, mesocarp fibre and kernel shell can be used as biomass fuel for steam boilers in palm oil mills [5]. The mesocarp fiber is produced from the palm oil extraction process while the kernel shells are obtained after the process of nut separation from its kernel. Boiler ash and clinker are obtained from burning the mesocarp fiber and kernel shells in the boiler. According to Mohamed *et al.* [6], the annual production of boiler ash was estimated to exceed 4 million tonnes.

Concrete is an essential construction material worldwide and the main binder is cement. In general, Portland cement is made of 80% limestone and 20% clay. The production of cement requires these materials to be burnt at a high temperature thus release massive CO_2 due to the chemical decomposition of limestone. Benhelal *et al.* [7] reported that cement plants generate 5% to 7% of global CO_2 emissions. The production of one tonne of cement releases about 900 kg CO_2 into the atmosphere. This impacts the environment in terms of global warming and climate change. Flatt *et al.* [8] discovered that the biggest challenges faced by human society are to minimize the environmental impact of concrete without compromising people's need for housing and infrastructure. Thus, the Malaysian government aspires to reduce approximately 50% of carbon emission intensity by 2025 [9].

Over the years, studies have been conducted to examine the feasibility of using POBA and POCP as supplementary cementitious material [8];[10-13]. This can be achieved by characterizing POBA and POCP. Knowing the physical properties and chemical compositions allows researchers to further understand the functions of POBA and POCP as supplementary cementitious materials in concrete. Thus, this study is carried out to investigate the physical properties and chemical compositions of POBA and POCP.

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MATERIALS AND METHODS

The palm oil boiler ash (POBA) and palm oil clinker (POC) used in this study were obtained from the palm oil mill in Mukah, Sarawak. The samples were in powder form (Figure 1) and stored in airtight containers.

The physical properties of POBA and palm oil clinker powder (POCP) such as density, specific gravity, particle size, and morphology were examined. The chemical properties were determined using an X-ray fluorescence (XRF) analyzer.

The density and specific gravity of POBA and POCP were determined according to ASTM D5550 [14]. The microstructures of POBA and POCP were observed using Hitachi SU8020 FESEM. Magnifications of 5k and 10k were used to analyze the microstructures of the samples with an operating power of 2 kV. The particle sizes for both materials were examined using Mastersizer 2000. The samples were also tested using Rigaku CG (EDXRF) elemental analyzer. From the analysis, the chemical compositions of POBA and POCP were obtained.

(a) Palm Oil Boiler Ash

(b) Palm Oil Clinker Powder

Figure 1: Sample used in the laboratory

RESULTS AND DISCUSSION

Density and Specific Gravity

The density and specific gravity of POBA, POCP, and Ordinary Portland Cement (OPC) are presented in Table 1. Based on the result, the density and specific gravity of POBA and POCP were 52.7% and 28.6% lower than OPC respectively. Density and specific gravity are the physical properties, which depend on the chemical composition, internal microporosity, particle size and specific surface area. The porous structure of the particles caused POBA and POCP to have a lower density and specific gravity than OPC. Abutaha *et al.* [15] reported that POCP is light and suitable to produce lightweight and green concrete.

Table 1: Density and specific gravity of POBA, POCP, and OPC

Material	Density (g/cm^3)	Specific Gravity
Palm Oil Boiler Ash (POBA)	1.4909	1.4938
Palm Oil Clinker Powder (POCP)	2.2485	2.2528
Ordinary Portland Cement (OPC)	3.1500[a]	3.1561

[a]Karim *et al.* [16]

Particle size

The particle size distribution of POBA, POCP, and OPC are tabulated in Table 2. POBA recorded median particle size $D(v, 0.5)$ of 24.5 µm and 364.3 m^2/kg specific surface area. On the other hand, the $D(v, 0.5)$ of POCP was 11.3 µm with a specific surface area of 807.4 m^2/kg. Generally, the fineness of POBA was close to cement. From the result, the particle of POCP was finer than POBA and OPC. The surface area per unit volume (or mass) increases as particle size decreases. Thus, larger surface area promotes rapid reaction especially during hydration process. This would further enhance the interfacial bonding between particles and the cement matrix [11].

Table 2: Particle size of POBA, POCP, and OPC

Average Size (µm)[a]	POBA	POCP	OPC[b]
$D(v, 0.1)$	6.36	2.76	-
$D(v, 0.5)$	24.5	11.3	27.98
$D(v, 0.9)$	105	788	-
Specific surface area (m^2/kg)	364.3	807.4	331.0

[a]D = diameter, v = volume, 0.1, 0.5, 0.9 = percentage (10%, 50% and 90% respectively) of the particles are smaller than this diameter.
[b]Kanadasan and Razak [17]

Morphology of POBA and POCP

The morphology of POBA shown in Figure 2(a) was a porous structure filled with numerous oval and spherical poles of irregular sizes. From Figure 3(b), the particle of POCP was also irregular in shape but the pores were less visible (i.e. smaller and shallower) compared with POBA. According to Kow *et al.* [18], the pores may be due to the decomposition of the organic compounds in the fibres during the combustion process. The close-up of POBA and POCP in Figures 2(b) and 3(b) indicate that both materials had rough and flaky surfaces. Similar observations were obtained by Yahya *et al.* [19] and Kanadasan and Razak [17].

The generation of porosity, especially when due to small pores, can produce surface area far more than that produced only by reducing the particle size. This further increases the reaction rate to produce more hydration products.

On the other hand, a different particle shape of OPC was observed in Figure 4. The particle was irregular in shape with no visible pores. It showed that OPC particle was solid compared with POBA and POCP. The morphology of the materials correlated well with the results listed in Table 1. The porous structures of POBA and POCP affected their densities and specific gravities. POCP was less porous than POBA and thus its density and specific gravity were higher.

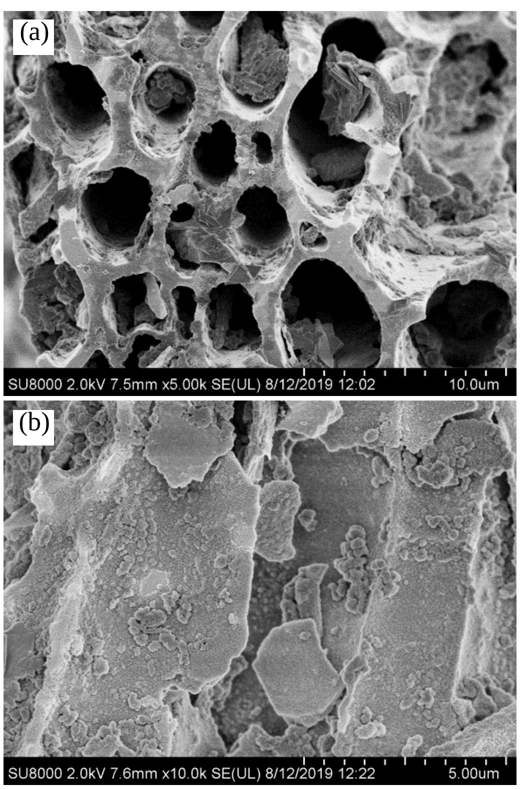


Figure 2: Morphology of palm oil boiler ash

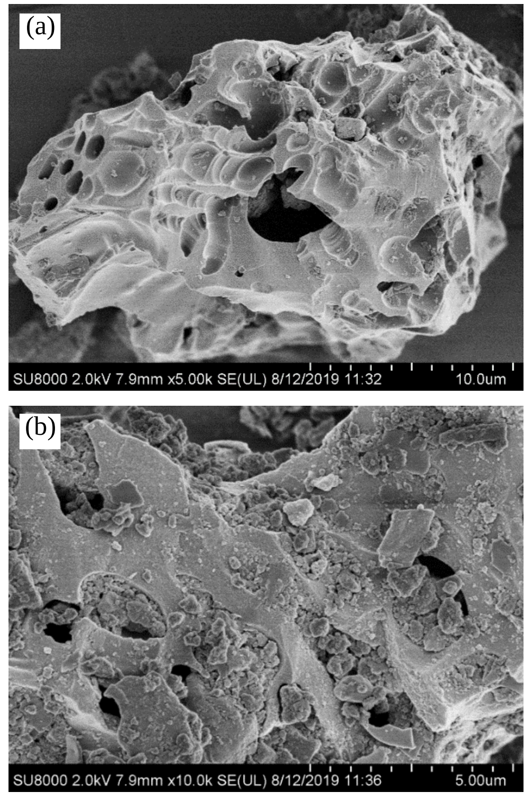


Figure 3: Morphology of palm oil clinker powder

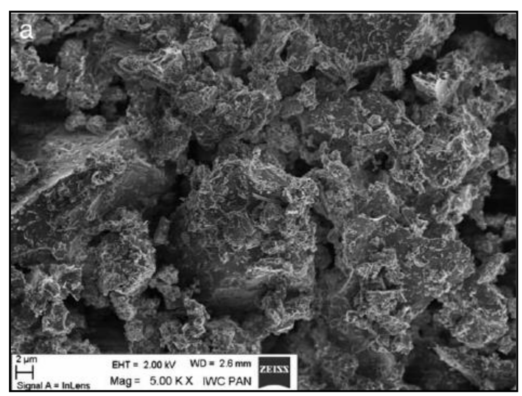


Figure 4: Morphology of cement type I [20]

Chemical compositions

The results of XRF analysis in Figure 5 exhibited that the main chemical composition of POBA was iron (Fe_2O_3), followed by silica dioxide (SiO_2), potassium oxide (K_2O), calcium oxide (CaO). Meanwhile, SiO_2 was the main component in POCP, followed by CaO. Both components can influence the properties of fresh and hardened concrete.

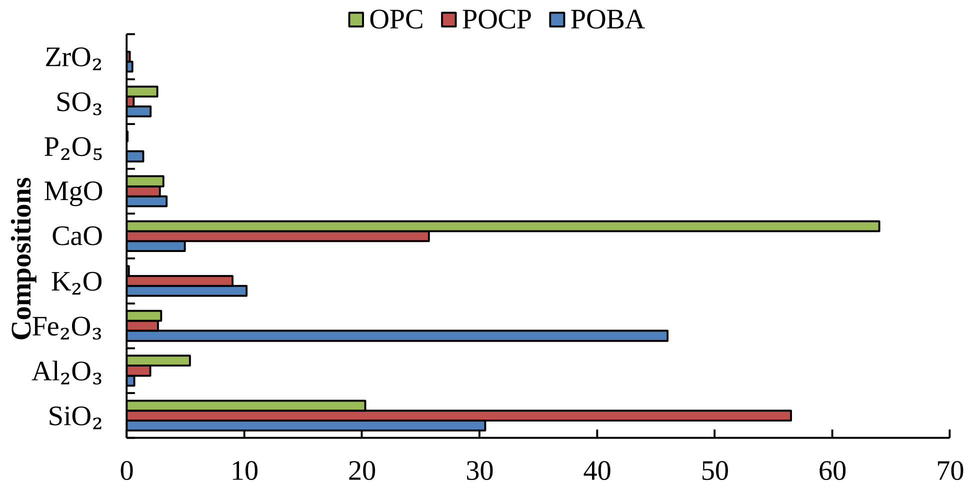
POCP comprised 56.5% SiO_2, which was the highest content compared with POBA and OPC of only 30.5% and 20.29% respectively. According to ACI Committee 234 [21], the concrete strength increased with the presence of SiO_2 due to the pozzolanic action. Karim *et al.* [22] also observed the reaction between portlandite ($Ca(OH)_2$) and SiO_2 of POCP that formed C-S-H gel for the strength development of concrete. Ahmmad *et al.* [13] and Subramaniam *et al.* [23] suggested the application of POBA and POCP as both pozzolan and filler materials to produce sustainable concrete and reduce the negative impact on the environment.

CONCLUSION

This study characterized the physical and mechanical properties of palm oil boiler ash (POBA) and palm oil clinker powder (POCP).

In terms of the physical properties, POBA appeared as a porous structure with oval and spherical poles of irregular sizes, whereas POCP was irregular in shape with smaller and shallower pores. For these pores, their densities and specific gravities were lower than OPC. The POCP particle was finer than POBA and OPC.

As for the chemical composition, POBA comprised mainly Fe_2O_3, which was followed by SiO_2, K_2O and CaO. The main composition of POCP was SiO_2 and CaO. SiO_2 may be used to improve the strength of concrete through the pozzolanic action. For that, POBA and POCP can be used as the pozzolan and filler material for concrete.



	SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	P_2O_5	SO_3	ZrO_2
OPC	20.29	5.37	2.94	0.17	64.00	3.13	0.07	2.61	0.00
POCP	56.50	2.01	2.66	9.01	25.70	2.83	0.00	0.58	0.27
POBA	30.50	0.66	46.00	10.20	4.93	3.40	1.40	2.03	0.47

Percentage (%)

Figure 5: Chemical composition of POBA, POCP, and OPC

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