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Assessment of pozzolanic activity of palm oil clinker powder

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HIGHLIGHTS

- A significant hump was observed in the angular 2θ range from 10° to 35°, representing an amorphous phase.
- Palm oil clinker is a pozzolanic material.
- Pozzolanic activity of palm oil clinker is higher than ground palm oil fuel ash.

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ABSTRACT

Palm oil clinker (POC) is a waste material produced as result of using palm oil shell and mesocarp fibres as fuel to run stream turbines in palm oil mills. The current practice is to dump the waste in open land or landfill sites, which leads to environmental problems. The suitability of using the palm oil clinker powder (POCP) in concrete as well as blended cement largely depends on its pozzolanic activity. In the present study, the pozzolanic activity of POCP has been investigated using X-ray diffraction (XRD), thermogravimetric analysis (TGA), Fourier transform infrared spectroscopy (FTIR) techniques, and compressive strength activity index measurement. The microstructure of the hydrated cement paste was observed using field emission scanning electron microscopy (FESEM). In order to evaluate the pozzolanic activity of the POCP, the pastes were prepared with ordinary Portland cement (OPC) at the level of substitution of 30%. The fluidity of the paste was maintained at 110 ± 5 mm. The strength activity index was evaluated according to ASTM standard. The microstructure properties investigation found that the portlandite ($Ca(OH)_2$) react with SiO_2 of POCP and formed C-S-H gel for strength development. This observation and strength activity index result confirmed that POCP is a pozzolanic material.

1. Introduction

A number of problems are associated with traditional supplementary materials such as fly ash, slag, and bottom ash due to their limited availability or unapproachable location, causing significant economic and environmental impact during their transportation. However, palm oil clinker (POC) is the most substantial waste material discarded from palm oil mills in Malaysia for use in concrete construction [1]. In contemporary practices, this waste is usually dumped onto open land which causes environmental pollution [1,2]. According to Malaysia Cement Industry Report 2015, the expansion of the construction activity in Malaysia has increased drastically in the last few years because the government has been spending a great deal of money on infrastructure development projects that have created extra pressure on the cement production industry. Therefore, research in assessing the pozzolanic activity of a newly introduced palm oil clinker powder (POCP) is very much encouraged for the main purpose of a cleaner environment, the reduction of carbon footprints in ordinary Portland cement (OPC) production, and for the preservation of natural resources such as limestone, clay and iron pyrites.

In recent years, the utilization of pozzolan in blended cement production has increased significantly. The cement industry is looking for new agricultural waste materials instead of natural pozzolan. Several researches have been reported on various agricultural waste such as rich hush ash [3], elephant grass ash [4], sugarcane baggase ash [5], fluid cracking catalyst residue [6], waste ceramic [7] and biomass ash [8] that have been used for the partial replacement of OPC in concrete as a pozzolanic material. There are also several researches that report increase in pozzolanic activity using mechanical [9], thermal [10] or the combination of both treatments. Recently, a few researches have been conducted on the utilization of POC as an aggregate in different types of concrete for various application purposes. It was found that the mechanical properties of lightweight concrete can be enhanced by using POC

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[11]. Other than that, it was shown that the economic and environmental effectiveness of POC in self-compacting concrete could also reduce the cost, energy, and carbon emission [12]. The application of POC as an aggregate in concrete has already been proven, but the pozzolanic activity of POCP has not been reported. It is also noted that another form of palm oil mill waste named palm oil fuel ash (POFA) shows pozzolanic activity and it also increases reactivity by size reduction [13,14]. The chemical, physical, and morphological characterizations of newly introduced pozzolanic materials are essential in ascertaining its pozzolanic reactivity [15,16]. The performance of the pozzolanic activity can be evaluated by calculating the strength activity index (SAI) according to the standard method [4]. This is a physical way to evaluate pozzolanic activity by comparing compressive strength with OPC at the curing age of 7 and 28 days. The pozzolanic reaction is basically an acid-based reaction between calcium hydroxide, also known as portlandite ($Ca(OH)_2$) and silicic acid (H_4SiO_4 or $Si(OH)_4$). This reaction can be presented as follows;

$$Ca(OH)_2 + H_4SiO_4 \rightarrow Ca^{2+} + H_2SiO_4^{2-} + 2H_2O \rightarrow CaH_2SiO_4 \cdot 2H_2O \quad (1)$$

As shown above, the product of chemical reaction is calcium hydroxide hydrate. The stoichiometry of the reaction may differ according to the pozzolanic materials that were involved in this reaction. There are a number of micro-analytical techniques, namely XRD [17], TGA [18], NMR [19], SEM [20], and FTIR [21] which can be used to investigate the pozzolanic reaction stated above. XRD technique was used to assess the pozzolanic activity by comparing the intensity of mineralogical phase, mainly portlandite present OPC and pozzolanic materials blended cement paste at different curing times which also helped to investigate the amorphisity of materials [16,22]. The dehydrolaxation of Ca $(OH)_2$ appeared at the range of 440–500 °C in thermogravimetric analysis. However, the relatively lower weight loss of an OPC paste than blended cement paste is a logical indication of pozzolanic activity [23] and the intensity of the vibration bands of Si—O, O—H, O—C—O and C—S—H of the cement paste conducted at different curing age showed the state of the pozzolanic reaction [21].

The objective of this study, consequently, is to investigate properties such as the chemical, amorphisity, micro-pores, and particle size of the POCP. The pozzolanic activity of POCP was observed based on the strength activity index and comparing the pozzolanic activity assessing index of OPC and POCPC paste at different curing age based on the micro analytical studies.

2. Materials and methods

2.1. Materials

The POC was obtained from a palm oil mill in the vicinity of Kuala Lumpur, Malaysia. The POC and POFA are obtained as a result of burning of the palm oil shell and fibre at the bottom of the boiler. The picture of a bulk quantity of the POC and big chunk, a blackish-gray colour solid material, used in this experiment is shown in Fig. 1. On the other hand, the particles of POFA are smaller and lighter like fly ash which is separated using vacuum pump from the burning zone at the bottom of a boiler. The free water of bulk POC was removed by heating it in the furnace at 100 °C for 3 h. The moisture free POC was ground in the control ball mill at 150 RPM for 8 h. Then, it was turned into a powder form which becomes POCP, the research material for this experiment. On the other hand, the OPC (CEM I 42.5 N) was obtained from a local cement works in Malaysia.

2.2. Properties investigation

The elemental composition (major oxides) of the POCP was observed using PANalytical (AXios^{maX}) spectrophotometer and the phase composition was determined by XRD (PANalytical-Empyream). The Malvern particle size analyzer was used for the particle size investigation. The morphology of POCP was performed using the Phenom table top of SEM while the specific surface area was explored using Blaine apparatus.

2.3. Paste preparation

The OPC (70%) and POCP (30%) were put into the tube mills which are cylindrical rotating drums; containing steel balls at RPM 150 for 30 min to ensure homogeneity. This palm oil clinker powder blended cement (POCPC) was placed into the bowl of the mixer. After two minutes of mixing, water was added and mixed up for 2 min. The required amount of water was added to maintain

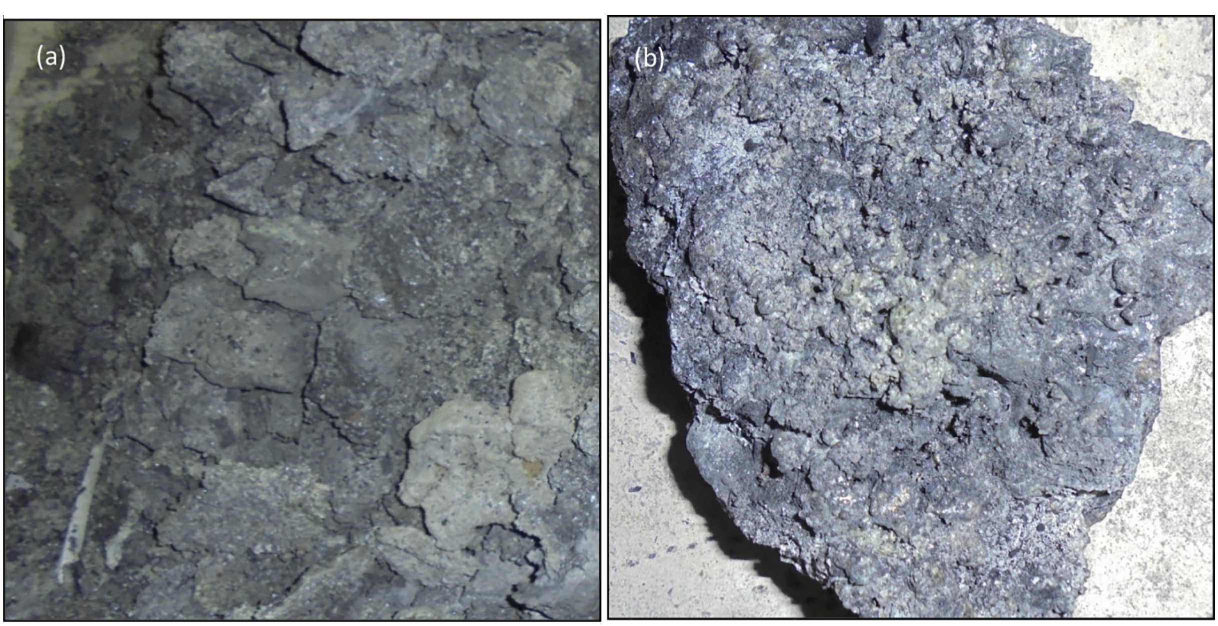

Fig. 1. Photographs of (a) bulk quantity of POC and (b) large chunk of POC.