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Filler effect and pozzolanic reaction of ground palm oil fuel ash

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ABSTRACT

This research examines the compressive strength of mortar and how the filler effect and pozzolanic reaction of ground palm oil fuel ash (POFA) contribute to this strength. POFA and river sand were ground to three different particle sizes and used to replace Type I Portland cement at 10–40% by weight of binder to cast the mortar. The compressive strengths of ground POFA and ground river sand mortars were determined at various ages between 7 and 90 days. The results showed that the compressive strength of mortar due to the filler effect of ground river sand was nearly constant during the 7–90 day period for a specified replacement rate of cement. However, the compressive strength of mortar due to the filler effect tended to increase slightly with increased cement replacement. The pozzolanic reaction of ground POFA increased with increasing particle fineness of ground POFA, replacement rate of cement, and age of the mortar. The compressive strength contribution from the pozzolanic reaction of ground POFA was much more pronounced than the contribution from the filler effect when the smallest sizes of both materials were considered.

1. Introduction

Presently, many types of pozzolans are used worldwide, mainly as a partial replacement for Portland cement in concrete. It is well-known that pozzolan, when present in mortar or concrete, contributes to the compressive strength of mortar or concrete in two ways: by the filler effect and by the pozzolanic reaction. Determining how much of the compressive strength is due to the filler effect or the pozzolanic reaction is complicated. ASTM C618 [1] stipulates that the amount of pozzolan particles retained on a 45-μm sieve should not be greater than 34% by weight. In addition, it also specifies that the strength activity index at 7 or 28 days should not be less than 75% compared to the strength of the control mortar. However, ASTM C618 does not distinguish how much the filler effect or the pozzolanic reaction contributes to the compressive strength of mortar.

The filler effect or particle size effect is defined as the proper arrangement of small particles that fill the voids and contribute to the increment of compressive strength without any chemical reaction [2–4]. Smaller pozzolan particles tend to produce a higher compressive strength than coarser particles [5–7]. One of the problems in analyzing the filler effect for a material is that it cannot be determined from the compressive strength alone. Tangpagasit et al. [8] studied the pozzolanic reaction of fly ash on the compressive strength of mortar. When 20% of the Portland cement was replaced by fly ash, they reported that the pozzolanic reaction of the fly ash was small, approximately 3% at 3 days, and increased to 20% and 27% of the control mortar strength at ages of 28 and 90 days, respectively. However, no report on the pozzolanic reaction of palm oil fuel ash was presented.

In Thailand, more than 100,000 tons of palm oil fuel ash (POFA) from a biomass power plant have been produced annually, and this by-product is still disposed of as waste in landfills. Due to the increasing disposal costs, difficulty in locating new landfill sites, and the environmental problems related to landfills, the utilization of POFA is an important issue for the industry and the public. Although many researchers have concluded that POFA can be used as a pozzolan to replace Portland cement in concrete [9,10], its utilization has been very limited.

This paper describes a method to determine the compressive strength due to the filler effect and the pozzolanic reaction of ground POFA. The contribution from the pozzolanic reaction to the compressive strength of mortar can be determined by using a pozzolan and a non-reactive material, both having approximately the same particle size and same replacement rate of Portland cement. Thus, the difference in compressive strength between the pozzolan mortar and the non-reactive material mortar can be considered as the compressive strength due to the pozzolanic reaction [8]. To determine the contribution from the filler effect for mortars containing non-reactive materials, the difference in compressive strength between small-sized particles and large-sized particles must be calculated; the mortars must have the same replacement rate of Portland cement, same workability, and same curing age.

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From this concept, the compressive strengths due to the filler effect and the pozzolanic reaction for mortars containing ground POFA with different particle sizes are reported.

2. Experimental program

2.1. Materials

In this study, Type I Portland cement was used as a cementitious material. POFA from Thailand was used as a pozzolan while river sand was used as the fine aggregate.

To fabricate the fine aggregate, the river sand was cleaned by water and sun-dried for 2–3 days to reduce its moisture content to less than 0.1%. It was then sieved through a 1.18-mm sieve; only river sand retained on a 150-μm sieve was used as the fine aggregate.

POFA received directly from the power plant was not suitable as a pozzolan due to its large particle size and high porosity. To improve the reactivity, it was ground by a ball mill into three different particle sizes as follows.

2.1.1. Large particles

About 34 ± 2% by weight of the materials were retained on a 45-μm sieve. This fineness value (not more than 34% by weight) is specified by ASTM C618 for a suitable pozzolan to be used in concrete. This size was designated as large (LPA).

2.1.2. Medium particles

About 13.5 ± 2% by weight of the materials were retained on a 45-μm sieve. We found that the particles of Type I Portland cement were retained on a 45-μm sieve at 13.5% by weight. This size was designated as medium (MPA).

2.1.3. Small particles

About 5 ± 2% by weight of the materials were retained on a 45-μm sieve. This size is designed as small (SPA).

To obtain a non-reactive material, the river sand was also ground by a ball mill until its fineness value was in the same specified limits as those for the ground POFA (small (SGS), medium (MGS), and large (LGS)).

2.2. Chemical composition of the materials

The chemical compositions of Type I Portland cement, ground palm oil fuel ash MPA, and ground river sand MGS are shown in Table 1. For MPA, $SiO_2 + Al_2O_3 + Fe_2O_3$ had a total concentration of 69.84%. Moreover, SO_3 and the loss on ignition (LOI) were 0.47% (<4%) and 10.05% (≈10%), respectively. Although ground POFA is not a natural pozzolan, its chemical composition satisfied the ASTM C618 class N standard [1]. This result is in line with previously published data [9]. For MGS, SiO_2 was the major constituent with a concentration of 92.86%, and the Al_2O_3 concentration was 3.17%. Other constituents, such as CaO, MgO, SO_3, were less than 1%. From Kiattikomol et al. [10], ground river sand can be treated as a non-reactive material because it consists of more than 92% of insoluble or non-reactive materials, of which 91.27% is SiO_2 (quartz).

Chandara et al. [11] determined the crystalline phase and glassy phase of palm oil fuel ash using semi-quantitative XRD analysis internal standard method and showed that palm oil fuel ash contained 67.22% of glassy phase which could be used as a pozzolanic material.

2.3. Physical properties of the materials

Table 2 shows the physical properties of Type I Portland cement, ground POFA, and ground river sand. Type I Portland cement had 13.5% of its particles retained on a 45-μm sieve. The weight retained on a 45-μm sieve for SPA, MPA, and LPA were 4.3%, 13.7%, and 34.8%, respectively. For SGS, MGS, and LGS, the weight retained on the same-sized sieve were 5.8%, 12.6%, and 33.8%, respectively. Thus, Type I Portland cement, MPA, and MGS had approximately the same weight percent of materials retained on a 45-μm sieve. The Blaine fineness between MPA and MGS were slightly different (7190 and 6605 cm^2/g, respectively). Moreover, the mean particle sizes (d_{50}) of the materials were approximately the same (12.1, 13.0, and 11.5 μm, respectively for Type I Portland cement, MPA, and MGS). The particle size distributions of materials are shown in Fig. 1. It is noted that each pair of the materials has slightly different in particle size distribution.

Table 1
Chemical composition of materials.

Chemical composition (%)	Portland cement	POFA (MPA)	Ground river sand (MGS)
SiO_2	20.80	65.30	92.86
Al_2O_3	5.50	2.56	3.17
Fe_2O_3	3.16	1.98	0.27
CaO	64.97	6.42	0.55
MgO	1.06	3.08	0.49
Na_2O	0.08	0.36	0.42
K_2O	0.55	5.72	0.32
SO_3	2.96	0.47	0.55
LOI	2.89	10.05	0.67

Table 2
Physical properties of materials.

Sample		Specific gravity	Retained on a 45-μm sieve (%)	Mean particle size, d_{50} (μm)	Blaine Fineness (cm^2/g)
Portland cement		3.15	13.5	12.1	3580
Ground	SPA	2.39	4.3	12.3	12,285
palm oil	MPA	2.22	13.7	13.0	7190
fuel ash	LPA	2.05	34.8	30.8	6605
Ground	SGS	2.64	5.8	8.1	9750
river	MGS	2.63	12.6	11.5	6605
sand	LGS	2.64	33.8	21.4	4285

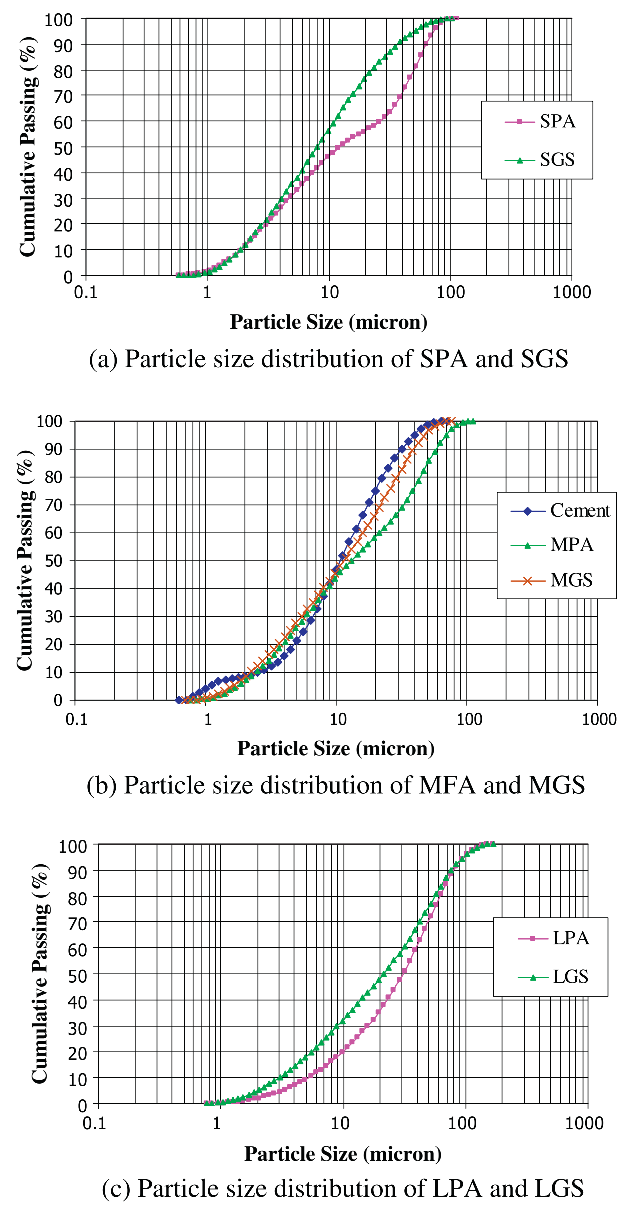

Fig. 1. Particle size distribution of materials.