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An investigation of bottom ash as a pozzolanic material

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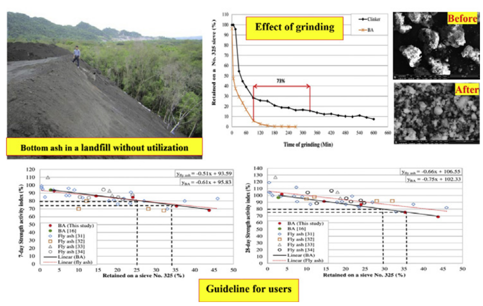
HIGHLIGHTS

- Unmodified bottom ash (BA) is not a good pozzolan.
- Ground BA can be used as a pozzolan in the same way as fly ash.
- Ground BA mortar had strength activity index higher than 100% after 28 days.
- This result can be used as a guideline to use ground BA as a pozzolan in concrete.

GRAPHICAL ABSTRACT



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ABSTRACT

Fly ash has been widely used as a pozzolan, but a huge quantity of bottom ash (BA) has been disposed in landfills every year. Therefore, this paper addresses the development and recommendation of using BA as a pozzolanic material. Mortar containing BA at a replacement rate of 20% by weight was used to study the pozzolanic properties. The results showed that the BA needed to have particles retained on a No. 325 (45-μm) sieve at least 25% by weight to achieve the requirements for pozzolan class C and F as specified by ASTM C618. The mortar containing BA from which the particles retained on a No. 325 sieve of 5% by weight produced better compressive strength than control mortar after 28 days. Additionally, BA from several sources had chemical properties favorable for acting as a pozzolanic material. This study's findings demonstrated that that BA with a proper fineness could be used as a pozzolanic material according to ASTM C618. The utilization of BA is a good solution for the added value, as well as the reduction of BA in landfills.

1. Introduction

Pozzolanic materials are commonly used for partially replacing ordinary Portland cement (OPC) to achieve properties of concrete or mortar depending on the demand of a user, and to reduce the cost due to the reduction in the use of OPC in the concrete mixture. Many pozzolanic materials, such as fly ash, bagasse ash, palm oil fuel ash, and rice husk ash were studied [1–6], while bottom ash (BA) was infrequently studied for use as a pozzolanic material.

BA, similar to fly ash, is a by-product of the coal power plants. At the Mae Moh power plant, Thailand, the amount of coal ash has been estimated as approximately 3.5×10^6 ton/year, of which 2.1×10^6 and 1.4×10^6 tons/year or approximately 60% and 40%, respectively, were fly ash and BA. In Thailand, fly ash has been widely utilized as a replacement for OPC in concrete construction. As a result, little or none of the fly ash has been sent to landfills. However, the large amount of BA has been disposed to landfills without utilization, and the amount tends to increase every year. If BA continues to be disposed, many problems such as the cost for BA disposal, loss of natural sites for BA disposal and environmental impact surrounding BA disposal will become increasingly acute.

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BA is formed from the melting of coal ash particles because the temperature in the kiln is higher than the melting point of coal ash. Therefore, BA has large particles with high porosity. For this reason, many studies focus on the utilization of BA as a fine aggregate in concrete or mortar [7–10]. However, the use of BA to replace fine aggregate had a bad effect on the workability and the mechanical properties of concrete or mortar. For example, the increase in BA content to replace fine aggregate in concrete caused a decrease in the workability and mechanical properties in terms of compressive strength, splitting tensile strength, and modulus of elasticity compared to the control concrete [11–13].

In Thailand, there is no or little utilization of BA as a pozzolanic material in concrete construction because the knowledge regarding the use of BA as a pozzolanic material has been limited. Before using BA as a pozzolanic material, several properties such as chemical composition, influence of fineness, and crystallinity of BA should be considered. Chindaprasirt et al. [14] found that the major chemical composition of BA was similar to fly ash when both materials were obtained from the same source of coal and power plants. The amounts of $SiO_2 + Al_2O_3 + Fe_2O_3$, CaO, and SO_3 in BA were 72.2, 16.5 and 2.4%, which was similar to 74.8, 16.6 and 2.6% of fly ash. However, the 2.9% loss on ignition (LOI) of BA was slightly higher than the 0.8% LOI of fly ash [14]. The chemical compositions of BA was in agreement with the specifications of ASTM C618 [15] for pozzolanic material class F which had the total amounts of $SiO_2 + Al_2O_3 + Fe_2O_3$ higher than 70%, while SO_3 and LOI must not exceed 5.0 and 6.0%, respectively. Generally, the major drawback of BA for using as a pozzolanic material is its large particles, which has more than 90% retained on a No. 325 (45-μm opening) sieve or the particle sizes are in ranges from 0.1 to 5 mm [16–18]. Therefore, the utilization of BA as a pozzolanic material, its fineness must be increased. Jaturapitakkul and Cheerarot [16] studied ground BA with 2.8% by weight of the particles retained on a No. 325 sieve replacing OPC in mortar and concrete. These researchers observed that the ground BA replacing OPC at rates of 10, 20 and 30% by weight of binder could obtain a compressive strength for the BA mortar higher than the control mortar. In addition, Cheriaf et al. [19] reported that the pozzolanic activity of BA mortar could be improved by up to 27% when BA was ground to increase fineness for 6 h. However, Hooi-Jun et al. [20] studied the BA obtained from un-burn coal with different particle size of 63, 75, and 150 μm as pozzolanic material. They found that use of BA with different particle sizes had slightly affected on compressive strength of mortar. The improvement of BA as a pozzolanic material was studied by Kim [21] who reported that the BA passing through No. 40 (425-μm) sieve and ground BA could produce the compressive strength of mortar similar to fly ash mortar with the same replacement rate. Moreover, Oruji et al. [22] found that the compressive strength of mortar containing BA with a median particle size of 4.5 μm at the cement replacement rates of 9.1, 23.1 and 33.3% by weight of binder gave the compressive strength at 28 days higher than the control mortar after 28 days while 41.2% replacement of Portland cement by 4.5 μm BA gave higher compressive strength than the control mortar at 90 days. Additionally, after normalization for particle size, age, and replacement rate, the strength activity index of BA mortar was less than fly ash mortar approximately 7%.

Although the previous studies proved that the ground BA could be used as a pozzolanic material, the appropriate fineness should be addressed. Therefore, this study proposes to demonstrate the use of BA with different levels of fineness partially to replace the as an alternative pozzolanic material and enhancement of the new knowledge about the utilization of BA. If the BA could be used in the concrete construction industry, it would not only reduce the environmental problems due to sending the BA to landfills but would also reduce OPC usage, as well as increasing the economic value of the construction material.

2. Experimental program

2.1. Materials

The materials used in this study were bottom ash (BA), ordinary Portland cement (OPC) which is type I in accordance with TIS 15 [23], and river sand graded to pass a No. 30 sieve and to be retained on a No. 100 sieve.

The wetted BA obtained from Mae Moh power plant, Thailand, was oven-dried at 110 ± 5 °C (approximately 24 h) to reduce the moisture content such that the BA could be ground easily. Next, the BA was sieved using a No. 4 sieve to eliminate several large fractions (designated as OBA material) which was 17 ± 2% retaining on No. 4 sieve. The BA was then ground until the weight retained on a No. 325 (45-μm opening) sieve of 5 ± 2, 15 ± 2, 25 ± 2, 35 ± 2, 45 ± 2% by weight were obtained, designated as 5BA, 15BA, 25BA, 35BA and 45BA, respectively.

2.2. Physical properties of materials

The particles retained on a No. 325 (45-μm opening) sieve, specific gravity, and median particle size (d_{50}) of OPC and those of BA with different particle sizes were presented in Table 1. The particles retained on a No. 325 sieve of 5BA, 15BA, 25BA, 35BA and 45BA were 3.7, 14.5, 24.0, 35.3 and 43.7% by weight corresponding with the median particle size (d_{50}) of 4.3, 15.4, 24.2, 39.8 and 72.3 μm, respectively, while OBA had particles retained on a No. 325 sieve at 96.3% by weight. The fineness modulus of the OBA was 2.09, which was less than the fineness modulus of river sand (3.07). Fig. 1 shows the particle size distributions of OBA and river sand compared with the requirement of ASTM C33 [24]. OBA had a cumulative particle size larger than 1 mm of 75% while the cumulative particle size larger than 1 mm for the river sand was 55%. Moreover, the particle size lower than 0.7 mm of the OBA had cumulative

Table 1
Physical properties of materials.

Materials	Retained on a No. 325 Sieve (% by weight)	Specific Gravity	Median Particle Size, d_{50} (μm)
OPC	16.8	3.14	14.7
5BA	3.7	2.88	4.3
15BA	14.5	2.85	15.4
25BA	24.0	2.83	24.2
35BA	35.3	2.76	39.8
45BA	43.7	2.72	72.3
OBA	96.3	2.33	400

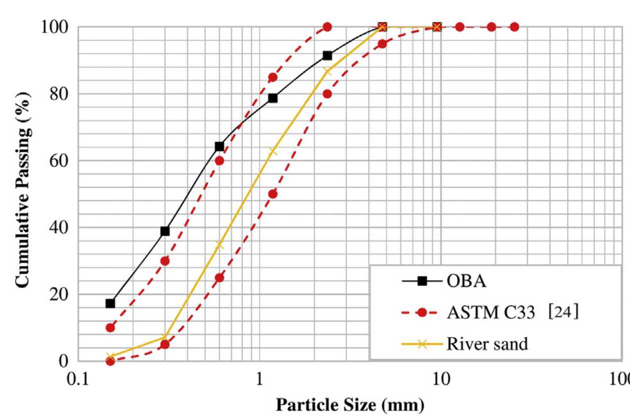

Fig. 1. Relationship between cumulative passing and particle size distribution of OBA and river sand compared to ASTM C33 [18].