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Materials

Effect of grinding on chemical and physical properties of rice husk ash

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Abstract: The effect of grinding on the chemical and physical properties of rice husk ash was studied. Four rice husk ashes with different finenesses, *i.e.* coarse original rice husk ash (RHA0), RHA1, RHA2, and RHA3 were used for the study. Ordinary Portland cement (OPC) was partially replaced with rice husk ash at 20% by weight of binder. The water to binder ratio (W/B) of the mortar was maintained at 110%±5% with flow table test. Specific gravity, fineness, chemical properties, compressive strength, and porosity test of mortars were determined. The differences in chemical composition of the rice husk ashes with different finenesses from the same batch are small. The use of RHA3 produces the mortars with good strength and low porosity. The strength of the mortar improves with partial replacement of RHA3 in comparison with normal coarse rice husk ash. The use of RHA3 results in a strong and dense mortar, which is due to the better dispersion and filling effect, as well as an increase in the pozzolanic reaction.

Key words: fineness; grinding; mortar; physical properties; rice husk ash

1. Introduction

The landfill of waste ash is a problem of environmental effects because these waste ashes are not used in any work. Therefore, a large number of researchers have been directed toward the utilization of waste materials. Nowadays, waste materials or pozzolans from industrial and agricultural by-products such as fly ash and rice husk ash are receiving more attention since their uses generally improve the properties of the blended cement concrete, the cost, and the reduction of negative environmental effects [1-2]. In Thailand and many parts of the world, a large amount of rice husk could be obtained as an agricultural by-product. By burning the rice husk under the controlled temperature and atmosphere, a highly reactive rice husk ash is obtained. The properly burnt and ground rice husk ash is also suitable for use as a pozzolanic material [2-3]. Rice husk ash is high in silica content in the form of noncrystalline or amorphous material silica.

Several researchers have studied the durability variation of the concrete with pozzolanic materials [1, 4-5]. According to Jaturapitakkul *et al*. [4], the use of ground coarse fly ash as a replacement of condensed silica fume in producing high-strength concrete results in high-strength concretes with a high fineness of fly ash. Rukzon and Chindaprasirt [1] studied the potential for using classified fly ash from Mae Moh Power Plant in Thailand as a pozzolanic material. They found that fly ash has a high potential to develop into a good pozzolanic material if it is improved to have high fineness.

Most of the previous works have been carried out on the effect of the fly ash fineness of cement paste, concrete, or mortar. But in this article, the results of the effects of grinding on the chemical and physical properties of four rice husk ash finenesses are presented. Ordinary Portland cement (OPC) and ground rice husk ash were used as the base materials for studying the blended cement. The knowledge in terms of chemical and physical properties, water requirement, strength activity index, and porosity would be beneficial for understanding the mechanisms, as well as for future applications of these materials.

2. Materials and methods

2.1. Materials

The OPC used in this work was a type I cement. The rice husk ash was obtained from open burning in a small heap of 20-kg rice husk at the maximum burn-

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ing temperature of 650°C. The burning was self-sustained with the total burning time of 24 h. The river sand with a density of 2.63 g/cm^3 and a fineness modulus of 2.82 was used in this study. The grading analysis, X-ray diffraction (XRD), and SEM photograph were performed on the rice husk ash. The fineness test in accordance with ASTM C204 [6] was tested of pozzolanic materials. The rice husk ash was ground into four lots.

(1) RHA0: the original rice husk ash with 75% retained on a 325# sieve;

(2) RHA1: the rice husk ash was obtained using ball mill grinding until the percentage retained on a 325# sieve was 30%;

(3) RHA2: the rice husk ash was obtained using ball mill grinding until the percentage retained on a 325# sieve was 15%;

(4) RHA3: the rice husk ash was obtained using ball mill grinding until the percentage retained on a 325# sieve was 3%.

2.2. Mix proportions and curing

The OPC was partially replaced with pozzolans at the dosage of 20% by weight of cementitious materials. For the mortar mix, the water content was adjusted to give a flow of 110%±5%, which was determined with the flow table test conformed to ASTM C230 [7]. The mass ratio of sand-to-binder of 2.75 was used. The cast specimens were covered with polyurethane sheets and damped cloth in the 23±2°C chamber. They were demoulded at the age of 1 d and moist cured at 23±2°C until the test aged. The mortar mix proportions and abbreviations are given in Table 1.

2.3. Compressive strength

The strength activity index test in accordance with ASTM C109 [8] was tested at the age of 7 and 28 d. Mortars were put in a mold to obtain the specimens of 50 mm×50 mm×50 mm, which were stored in a moisture room at 23°C for 24 h. The specimens were demoulded and stored in water at 23°C until the time of the test. The reported compressive strength was the average of the three samples. The mix proportions of the mortar were used in the current study as shown in Table 1.

Table 1. Mortar mix proportions for the strength activity index test (by weight)

Symbol	W/B	Cement	Rice husk ash	Flow / %
OPC	0.50	1.00	0.00	110.0
20RHA0	0.82	0.80	0.20	110.0
20RHA1	0.62	0.80	0.20	108.5
20RHA2	0.57	0.80	0.20	109.8
20RHA3	0.54	0.80	0.20	110.0

2.4. Porosity

For the porosity test, the cylinder samples of 50 mm×50 mm×50 mm were prepared in accordance with ASTM C109 [8]. They were tested at the age of 7 and 28 d. After being cured in water, they were dried at 100±5°C until constant weight was achieved and were then placed in desiccators under vacuum for 3 h. The set-up was finally filled with de-aired, distilled water to measure the porosity of the mortar. The porosity was calculated using the following equation:

$$P = \frac{W_a - W_d}{W_a - W_w} \times 100\% \quad (1)$$

where P is the vacuum saturated porosity, %; W_a the weight of the specimen in the air in saturated condition, g; W_d the dry weight of the specimen after 24 h in an oven at 100±5°C, g; and W_w the weight of the specimen in water, g. This method has been used to measure the porosity of the cement-based materials successfully [1, 3]. The reported results are the average of the two samples.

3. Results and discussions

3.1. Specific gravity

The effect of grinding on the density of rice husk ash is shown in Fig. 1. The density of the OPC is 3.14 g/cm^3. The densities of RHA0, RHA1, RHA2, and RHA3 are 1.98, 2.15, 2.21, and 2.23 g/cm^3, respectively. After 240 min, the density of the original rice husk ash increases from 1.98 to 2.23 g/cm^3. Similar finding was also reported by some investigations [9].

3.2. Fineness

The effect of grinding on the fineness of rice husk ash is presented in Fig. 2. The Blaine fineness of rice husk ash RHA1, RHA2, and RHA3 are 3200, 7800, and 12500 cm^2/g, respectively. The fineness of the rice husk ash increases with an increase in grinding time. As the finenesses of the rice husk ash increases, the specific gravity also increases (see Fig. 3). Fig. 2 indicates that grinding is most effective for the increase in the fineness of the original rice husk ash. Similar finding was also reported by some investigations [4]. The particle size distributions as shown in Fig. 4 reveal that RHA3 is the finest followed by RHA2, RHA1, and RHA0. The mean particle size of the material used from the finest to the coarsest is as follows: RHA3, 10 μm; RHA2, 17 μm; RHA1, 28 μm; and RHA0, 42 μm. The mean particle size of OPC is 15 μm. The particle size of rice husk ash decreases with an increase in grinding time [2-3].

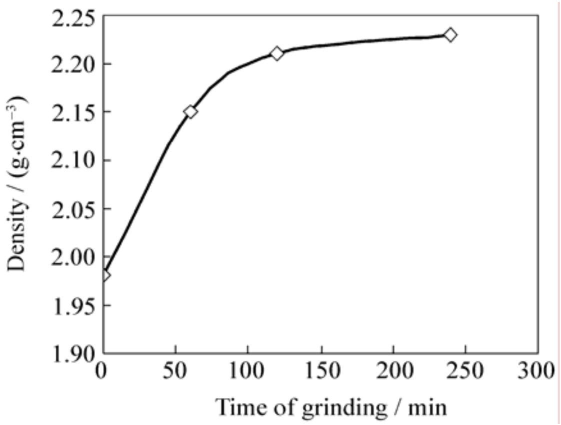

Fig. 1. Effect of grinding on the specific gravity of the rice husk ash.

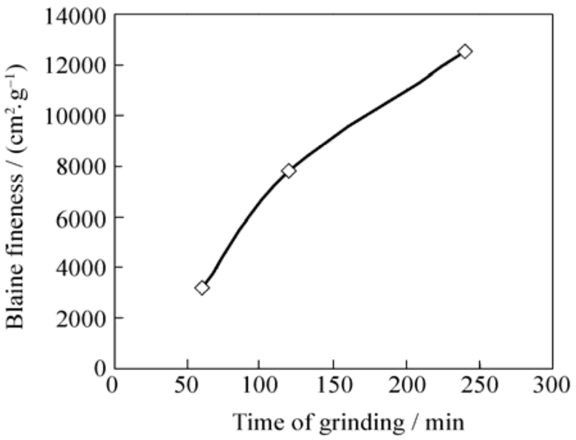

Fig. 2. Effect of grinding on the fineness of the rice husk ash.

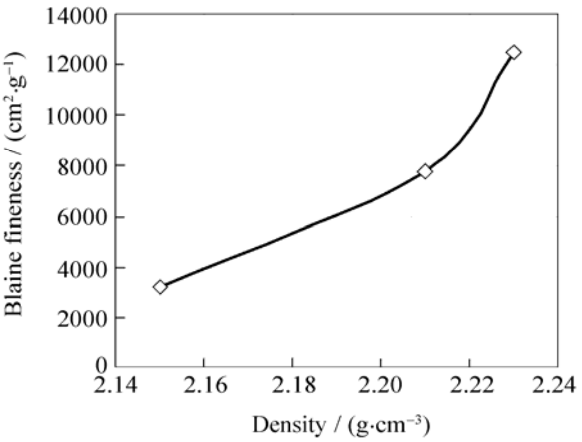

Fig. 3. Relationship between fineness and density of the rice husk ash.

3.3. SEM photo

SEM photos shown in Fig. 5 show that the rice husk ash consists of irregular-shaped particles with a sizable fraction showing a porous cellular structure. After grinding, the rice husk ash consists mainly of fine irregular-shaped particles. Similar finding was also reported by some investigations [2].

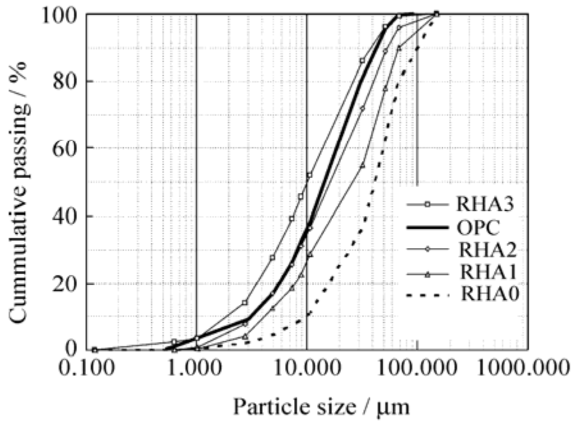

Fig. 4. Particle size distribution of the OPC and rice husk ash materials.

3.4. Chemical compositions of the materials

The chemical constituents of OPC and the rice husk ashes are given in Table 2. According to the chemical composition, the original rice husk ash (RHA0), RHA1 rice husk ash, RHA2 rice husk ash, and RHA3 rice husk ash are the pozzolanic materials of Class N as prescribed by ASTM C618 [10] since the sum of components SiO_3, Al_2O_3, and Fe_2O_3 is higher than 70wt%, and the loss on ignition (LOI) and SO_3 content are not higher than 5wt% and 6wt%, respectively. There are no significant differences in chemical composition of the rice husk ashes with different finenesses [9].

3.5. Water requirement

Fig. 6 presents the water requirement of the mortar made rice husk ashes with different finenesses, with the flow table test conformed to ASTM C230 [7]. The results indicate that the mortar containing rice husk ash as a cement replacement increases the water requirement in comparison with the control mortar (Fig. 6). This is due to the high fineness and porous surface of rice husk ash. The water requirement of the mix with RHA1, RHA2, and RHA3 is lower than that with RHA0. The increase in grinding time and the fineness of rice husk ash decreases the water demand of the mix. The W/B increases with an increase in the replacement level of rice husk ash. This observation is similar to that observed by other researches [9].

3.6. Compressive strength and strength activity index

ASTM C618 [10] specifies that fly ash mortar should have a strength activity index of at least 75%

of the control mortar (OPC) at the age of 7 or 28 d when the fly ash is used to replace Portland cement at the rate of 20% by weight of binder [11]. The rice husk ash specimens of 50 mm×50 mm×50 mm were conditioned and tested at the ages of 7 and 28 d with the strength index in a similar manner to those for the method applied in ASTM C109 [8] and ASTM C618 [10].

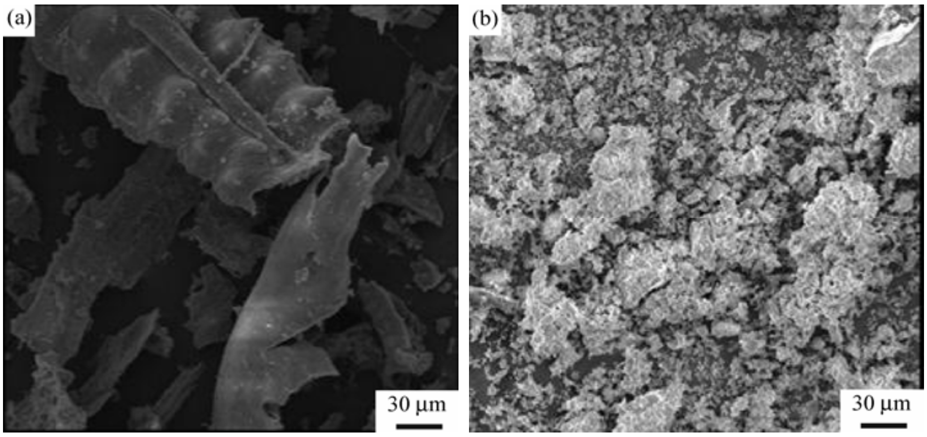

Fig. 5. SEM images of the OPC and rice husk ash materials: (a) unground (RHA0); (b) ground (RHA3).

Table 2. Chemical analysis of Portland cement and rice husk ash **wt%**

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	LOI
OPC	20.90	4.76	3.41	65.41	1.25	0.24	0.35	2.71	0.96
RHA0	92.00	0.29	0.1	1.28	0.37	0.05	2.19	0.94	3.43
RHA1	92.50	0.28	0.1	1.40	0.20	0.06	2.35	0.93	3.65
RHA2	90.10	0.25	0.1	1.45	0.01	0.08	2.42	0.92	3.56
RHA3	93.24	0.44	0.1	1.10	0.01	0.03	1.27	0.96	3.72

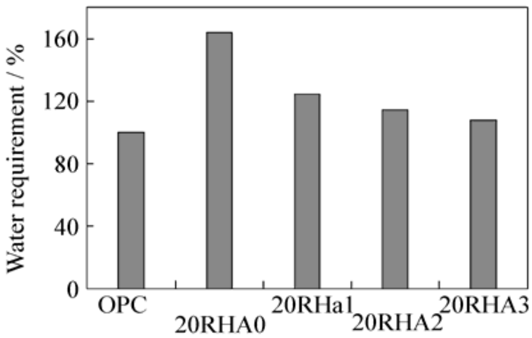

Fig. 6. Water requirement of the OPC and rice husk ash mortar.

The compressive strength of the mortar containing RHA0 is lower than that of the control mortar (OPC) at all ages as shown in Fig. 7. For mortar RHA0, the 7-d strength is 48% of that of the OPC mortar at the same age. At the age of 28 d, the strength of the RHA0 mortar is 55% of that of the OPC mortar at the same age (Fig. 8). The use of RHA1 results in an increase in strength compared with RHA0 at all ages as shown in Fig. 7. The high strength development is the common feature of pozzolanic materials [2-3]. At the ages of 7 and 28 d, strengths of the RHA2 and RHA3 mortars are 103%-112% of that of the OPC mortar at the same age (Fig. 8). The increase in compressive strength could be attributed to the reduced water content, the filler effect, and the higher pozzolanic reaction of fine rice husk ash. The results of water requirement and the strength of the mortar conform to other investigations [12-13]. The fine fineness of pozzolans had a greater pozzolanic reaction and the small particles could also fill in the voids of the mortar mixture, thus increasing the compressive strength of the mortar [14]. The effect of grinding on the strength activity index is presented in Fig. 9. High strength activity indexes are obtained using the rice husk ash that was subjected to 60 min-grinding, and these indexes are 28% and 32% higher than those of unground rice husk ash at 7 and 28 d, respectively. Therefore, RHA1 can be used as pozzolan to replace part of Portland cement in making the mortar with a relatively high strength. This is because RHA1 has the strength activity index at least 75% of the control mortar (OPC) at the age of 7 or 28 d when pozzolan is used to replace Portland cement at the rate of 20% by weight of binder [10].

3.7. Results of porosity

The results of porosity of the mortar at 7 and 28 d are shown in Fig. 10. At the age of 7 d, the porosities of the mortars containing 20% of RHA0, RHA1, and RHA2 are higher than those of the OPC mortars at all ages. The mortar containing RHA3 gives a slightly less porosity than those of RHA0, RHA1, and RHA2. In other words, RHA3 is slightly more effective in modifying pores and reduces the porosity of the mortar. The porosity at 7 d of the 20% RHA3 mortar is 14% in comparison with 14.5%, 22.5%, 19%, and 15.5% of the OPC, RHA0, RHA1, and RHA2 mortars.

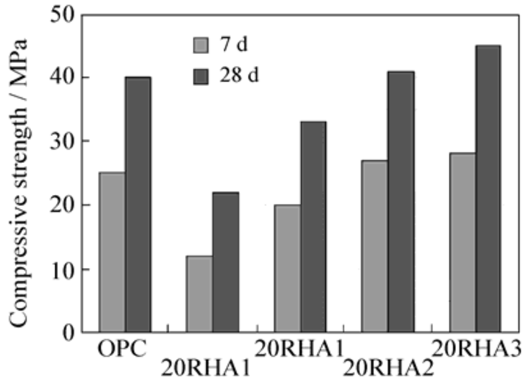

Fig. 7. Compressive strength of the OPC and rice husk ash mortars.

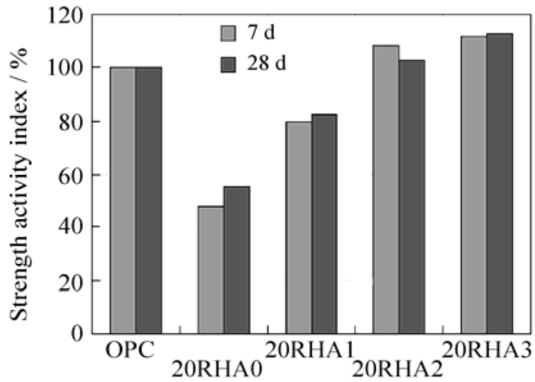

Fig. 8. Strength activity index of the OPC and rice husk ash mortars.

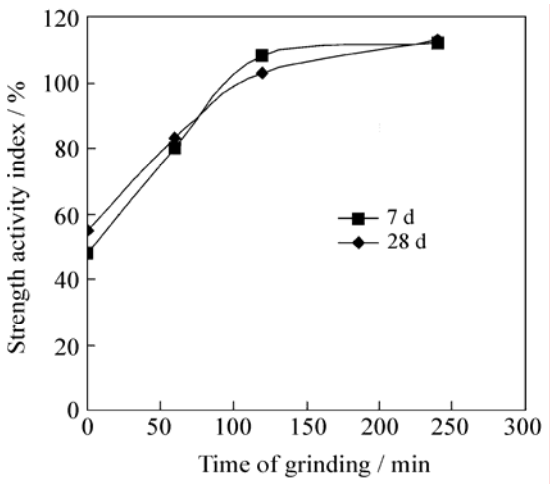

Fig. 9. Effect of grinding on the strength activity index.

The porosities of the mortars reduce with an increase in age as expected. This is due to the increase in the hydration of cementitious materials. At a later age of 28 d, the porosities of the mortars containing rice husk ash reduce to slightly higher values than that of the OPC mortar owing to the pozzolanic reaction of rice husk ash. The porosities of 20% RHA0, 20% RHA1, 20% RHA2, and 20% RHA3 mix at 28 d are 18.5%, 17%, 13.5%, and 11% compared with 12% of the OPC mortar at the same age. When all ages are considered, this range stretches from 11% to 22.5%. It is important to note that this range of porosity values corresponds to the compressive strength over the range of 12 to 45 MPa (Fig. 11). Rice husk ash has a high potential to develop into a good strength if it is improved to have low porosity.

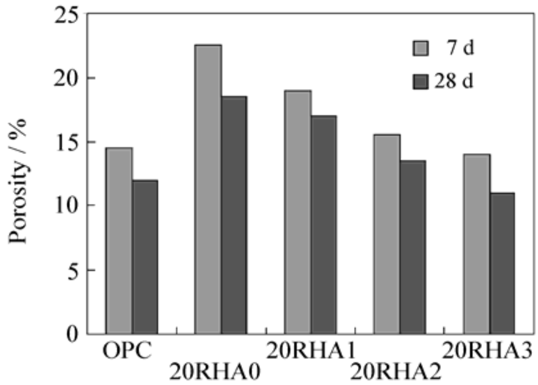

Fig. 10. Porosity of the OPC and rice husk ash mortars.

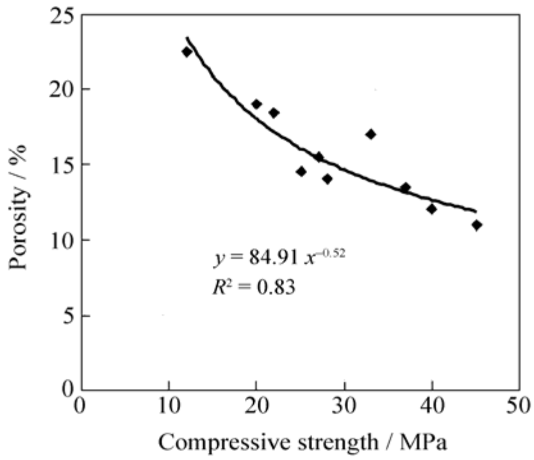

Fig. 11. Relationship between compressive strength and porosity of mortars.

The addition of RHA3 rice husk ash whose particles are finer than those of Portland cement causes the segmentation of large pores (Fig. 4) and increases nucleation sites for the precipitation of pozzolanic reaction products in cement paste. This increases the pozzolanic reaction and refines the pore structure of the paste. The increase in hydration leads to a reduction of calcium hydroxide in the paste. With regard to permeability, the incorporation of pozzolan such as fly ash reduces the average pore size and results in a less permeable paste [15]. It has also been shown that reactive RHA3 can be used to produce good quality concrete with reduced porosity. Therefore, the incorporation of RHA3 increases nucleation sites for the precipitation of hydration products, reduces $Ca(OH)_2$, and improves the permeability of the mortar. These factors contribute to the improvement in the durability of the mortar with RHA3 rice husk ash being the most effective, followed by RHA2, RHA1 rice husk ash, and coarse original rice husk ash.

4. Conclusion

It can be concluded that the differences in chemical composition of the rice husk ashes with different finenesses from the same batch are small. Fine rice husk ash reduces the water to binder ratio (W/B) and improves the strength of the mortar compared with the coarse original rice husk ash. The use of RHA3 results in a good strength in comparison with that of other rice husk ashes owing to the better dispersion and filler effect despite an increase in the pozzolanic reaction. RHA3 can be used as a good pozzolan to replace part of Portland cement in making the mortar with relatively high strength and low porosity. The hydration reaction, pozzolanic reaction, and nucleation effect were enhanced by the incorporation of fine rice husk ash. Therefore, rice husk ash has a high potential to develop into a good pozzolanic material if it is improved to have high fineness. However, RHA1 have the strength activity index of at least 75% of the control mortar (OPC) at the age of 7 or 28 d when pozzolan is used to replace Portland cement at the rate of 20% by weight of binder. Therefore, RHA1 can be used as a pozzolan to replace part of Portland cement in making the mortar with relatively high strength.

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