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Original Article

Use of waste ash from various by-product materials in increasing the durability of mortar

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Abstract

This paper presents a study on the strength and corrosion resistance of mortars made with binary blends of ordinary Portland cement (OPC) and ground rice husk ash (RHA) or ground palm oil fuel ash (POA). The mortar mixtures were made with Portland cement Type I containing 0-40% RHA and POA. RHA and POA with 1-3% by weight retained on a sieve No.325 were used. The water to binder ratio was kept constant at 0.5 and the flow of mortar was maintained at 110±5% with the aid of superplasticizer (SP). Scanning electron microscopy (SEM) was used for analysis. The compressive strength, chloride penetration and corrosion resistance of the mortar were determined. The results show that strength as well as the resistance of mortar to chloride and corrosion can be improved by blending with RHA and POA. Thus, RHA and POA have a high potential to be used as a good pozzolanic material.

Keywords: rice husk ash, palm oil fuel ash, corrosion, chloride penetration, mortar

1. Introduction

Rice husk is one of the major agricultural wastes. When rice husk is burnt at temperatures lower than 700°C, rice husk ash with a cellular microstructure is produced. Rice husk ash has a high silica content, in the form of non-crystalline or amorphous silica. Therefore, rice husk ash is a pozzolanic material and can be used as a supplementary cementitious materials (Metha, 1979).

Palm oil fuel ash is one promising pozzolan and is available in many parts of the world. It is a by-product obtained from a small power plant, which uses the palm fiber, shells and empty fruit bunches as a fuel and burnt at 800-1000°C. Palm oil fuel ash continues to garner more attention because it is shown to generally improve the properties of blended cement concrete and its use poses a comparably milder environmental hazard. The main chemical composition of palm oil fuel ash is silica which is a main ingredient of pozzolan (Chindaprasirt *et al.*, 2008).

One of the main causes of corrosion of reinforcement structures in concrete is chloride. When the chloride concentration of mortar or concrete exceeds a certain threshold value, depassivation of steel occurs and reinforced steel starts to corrode (Thomas, 1996; Alonso *et al.*, 2000). The objective of this research is to study the strength, chloride penetration and corrosion resistance of blended cement mortar containing ground rice husk ash and ground palm oil fuel ash. The results of the study will be beneficial for future applications of the material in increasing the durability of mortar and concrete.

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2. Experimental details

2.1 Materials

Ordinary Portland cement (OPC), local rice husk, palm oil fuel ash from a thermal power plant in southern of Thailand, river sand with specific gravity of 2.63 and fineness modulus of 2.82, and type-F superplasticizer (SP) were the materials used in this study. Rice husk ash was obtained from open burning in small heaps of 20 kg rice husk with maximum temperature of burning of 650°C. Ground palm oil fuel ash (POA) and ground rice husk ash (RHA) were obtained using ball mill grinding until the percentage retained on a sieve No. 325 (opening 45 mm) was 1-3%. Scanning electron microscopy (SEM) and grading analysis were used to study.

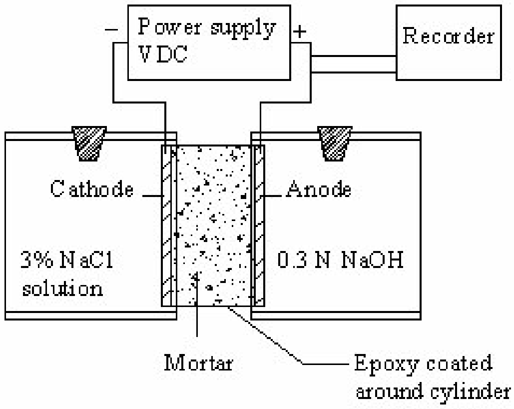

Figure 1. The rapid chloride penetration test (RCPT).

2.2 Mix proportions and curing

OPC is partially replaced with pozzolans at the dosage of 0-40% by weight of cementitious materials. A sand-to-binder ratio of 2.75 by weight and a water to binder ratio (W/B) of 0.5 were used. SP was incorporated in order to obtain mortar mixes with a similar flow of 110±5%. The cast specimens were covered with a polyurethane sheet and dampened cloth in a 23±2°C chamber. They were demoulded at the age of 1 day and moist cured at 23±2°C until the test ages.

2.3 Compressive strength

50 × 50 × 50 mm cube samples were used for the compressive strength test of mortar. They were tested at the age of 7, 28 and 90 days. The test was done in accordance with the ASTM C109 (2001). The reported result is the average of two samples. The mix proportions of mortar are given in Table 1.

2.4 Rapid chloride penetration test (RCPT)

Cylindrical samples of 100 mm diameter and 200 mm height were prepared in accordance with ASTM C39 (2001). They were demoulded at the age of 24 hours. After being cured in water until the age of 27 days, the cylindrical samples were cut into 50 mm thick slices with the 50 mm ends discarded. They were tested with the RCPT as shown in Figure 1. The 100 mm diameter and 50 mm thick epoxy-coated cylindrical specimens were conditioned and tested at the age of 28 and 90 days with the RCPT in accordance with the method described in ASTM C1202 (2001). The reported result is an average of two samples.

Table 1. Mortar mix proportions

Mix	OPC	POA	RHA	SP (%)
OPC	100	-	-	2.0
20POA	80	20	-	2.1
40POA	60	40	-	3.2
20RHA	80	-	20	2.2
40RHA	60	-	40	3.9

2.5 Open circuit potential (OCP)

The OCP test for the different systems was periodically monitored using a voltmeter with a high input impedance of 10 MÙ. The half-cell potential of the rebar was measured versus immersion time using a saturated calomel electrode (SCE) as a reference electrode. The corresponding potentials were recorded. A sponge soaked with distilled water was placed between the tip of reference electrode and the surface of the mortar, to provide ionic conduction. The measurements were made at sites on the surface, at a minimum distance from the rebar.

Mortar prisms 40 × 40 × 160 mm with embedded steel rebar of 10 mm in diameter and 160 mm in length were used. The steel rebar was secured such that it protruded from the top surface of the prism by 15 mm, thus provided sufficient mortar cover of 15 mm at the bottom and the sides of the prism. The mortar bar was cast in two layers and compacted using a vibrating table. After 28 days of curing, the mortar bars were placed in the environmental chamber. The mortar bars in the chamber were sprayed with a 5% NaCl solution every 3 days. The tests were continued over a period of 180 days. In this study, specimens in triplicate were used for each system and the average of these values was reported and interpreted based on ASTM C876 (2001). The mixed proportions of mortar are given in Table 1.

3. Results and discussions

3.1 Characteristics of OPC, POA and RHA

The chemical constituents are given in Table 2. The main chemical components of POA are 63.6% of SiO_2, 7.6% of CaO and 6.9% of K_2O. The high CaO and K_2O contents are most likely from lime and fertilizer (Chindaprasirt *et al.*,

Table 2. Chemical composition and characteristics of OPC, RHA and POA

Physical properties and oxides	OPC	RHA	POA
Median particle size (μm)	15.0	10.0	7.0
Retained on a sieve No. 325 (%)	-	1-3	1-3
Specific Gravity	3.14	2.23	2.25
Blaine Fineness (cm^2/gm)	3,600	11,200	11,800
SiO_2	20.9	93.2	63.6
Al_2O_3	4.8	0.4	1.6
Fe_2O_3	3.4	0.1	1.4
CaO	65.4	1.1	7.6
MgO	1.3	0.1	3.9
Na_2O	0.2	0.1	0.1
K_2O	0.4	1.3	6.9
SO_3	2.7	0.9	0.2
LOI	0.9	3.7	9.6
SiO_2+ Al_2O_3+ Fe_2O_3	-	93.7	66.6

2008). The loss on ignition (LOI) is 9.6%, which is not too high, indicating a reasonable burning temperature and time. The sum of SiO_2, Al_2O_3 and Fe_2O_3 is 66.6% which is slightly less than 70% as required for natural pozzolan, according to ASTM C618 (2001). RHA, on the other hand, consists mainly of SiO_2, and the other components are not significant. The SiO_2 content of 93% satisfies the ASTM C618 (2001) requirement as a natural pozzolan and a LOI of 3.7% indicates complete burning (Chindaprasirt *et al.*, 2008). The fineness characteristics of Portland cement and pozzolanic materials are given in Table 2. The Blaine fineness of OPC is 3600 cm^2/gm. The finenesses of POA and RHA are 11800 and 11200 cm^2/gm, respectively. The specific gravity of the OPC, POA and RHA are 3.14, 2.25 and 2.23, respectively. The percentage of POA and RHA retained on a 325 sieve is 1-3%. The particle size distribution of Portland cement and pozzolanic materials are given in Figure 2. The median particle sizes of the POA, RHA and OPC are 7.0, 10.0 and 15.0 μm, respectively.

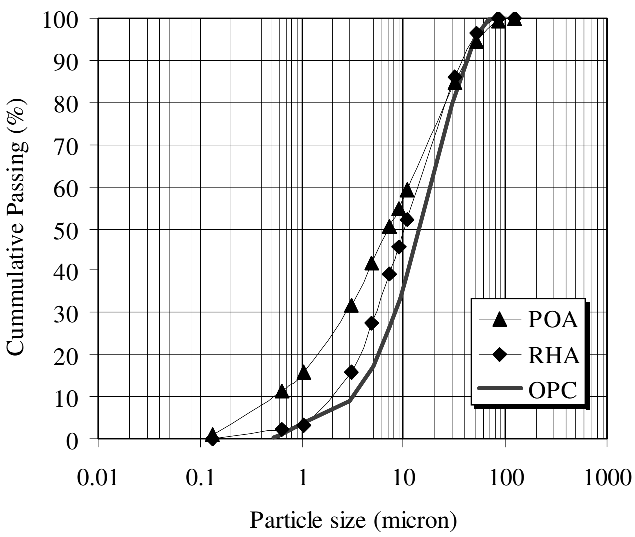

Figure 2. Particle size distributions of POA, RHA and OPC.

3.2 Compressive strength

The compressive strength and normalized (strength activity index) of mortars are given in Figure 3. The strength development of OPC mortar is rather good. The 7, 28 and 90 day strengths are 43.5, 57.0 and 60.0 MPa, respectively (Figure 3a). At a replacement dosage of 20%, the strengths of mortar containing POA and RHA are also high, between 102% and 106% of those of OPC mortar at the same age (Figure 3b). For a 40% replacement dosage, reductions in strength at 7 days are apparent for mixes containing either POA or RHA. The 7 day strengths are 76-77% of that of OPC mortar at the same age. At the age of 90 days, strengths of POA and RHA mortar are 103% of that of OPC mortar at the same age (Figure 3b). The low early strength and later age strength development exhibited by the 40% replacement dosage mortar samples is a common feature of pozzolanic materials. The results of the compressive strength test of the mortar suggest that POA and RHA have a high potential for being used as a pozzolanic material in a ternary blended cement system when the material is ground and classified as a fine particle size. The increased fineness of the pozzolans resulted in a greater pozzolanic reaction efficiency. In addition, smaller particles are more effective at filling in the voids of mortar mixture, thus increasing the compressive strength of mortar

3.3 RCPT results

The RCPT method usually causes the temperature of the mortar specimens to rise. However, for the specimens used here, the temperature rise is not large as the mortar speci-

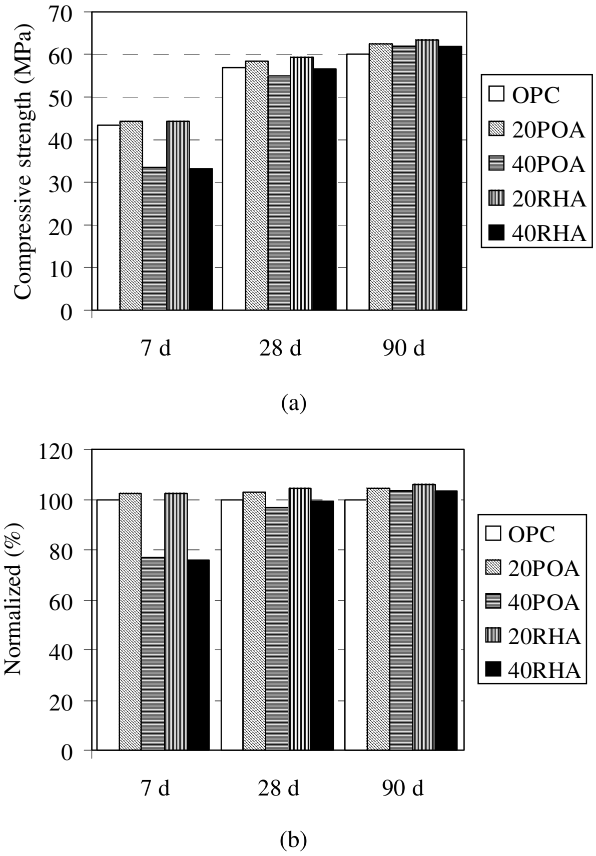

Figure 3. Results of (a) compressive strength and (b) normalized (normalized or strength activity index).

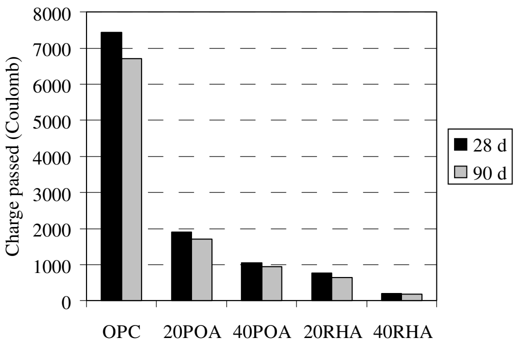

Figure 4. Results of the rapid chloride penetration tests (RCPT).

mens exhibit relatively high compressive strengths of 55-59.5 MPa (Figure 3a). The results of the RCPT are shown in Figure 4. From the results, it is shown that the resistance to chloride penetration of mortar is significantly increased with the incorporation of pozzolanic materials. This result is confirmed by other research (Chindaprasirt *et al.*, 2008; Gastaldini *et al.*, 2007). The increased chloride penetration resistance is due to reduced average pore size of the paste and the improved interfacial zone. RHA is the most effective, followed by POA and OPC. The relatively high resistance of the mortars (with pozzolanic materials) to chloride penetration can be partly explained by its expected lower median pore diameter and porosity values. Furthermore, normal OPC mortar will have a higher $Ca(OH)_2$ content in the hydrated structures.

3.4 Results of OCP

The results of the OCP tests are interpreted to according to ASTM C876 (2001), which provides general guidelines for evaluating corrosion in concrete structures as outlined in Table 3. The potential-time behavior of steel in mortars is shown in Figure 5. At 120180 days of exposure, mortar with and without various pozzolans replacement levels, namely OPC and 40POA, showed potential values ranging from -350 to -450 mV vs. SCE, indicating a 90% probability of depassivation of rebar embedded in mortar. From this figure it was inferred that initially up to 30 days of exposure, almost all the systems showed potential values ranging from 0 to -300 mV vs. SCE, reflecting the passive condition of the embedded steel anode. On the other hand, the rebar embedded in 20% POA (20POA), 20% RHA (20RHA) and 40% RHA (40RHA) replacement levels do not cross the threshold limit even after 180 days of exposure periods.

4. Conclusions

From these tests, it can be concluded that POA and

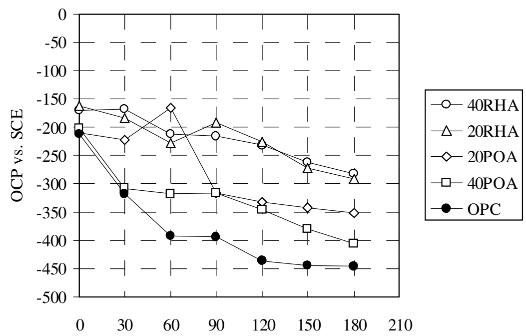

Figure 5. Potential corrosion of mortars.

Table 3. Probability of corrosion according to half-cell readings [8]

Half-cell potential reading vs. SCE	Corrosion activity
less negative than -200 mV	90% probability of no corrosion
between -200 mV and -350 mV	an increasing probability of corrosion
more negative than -350 mV	90% probability of corrosion

RHA can be used as pozzolans to replace part of Portland cement in making mortar of relatively high strength and good resistance to chloride penetration and corrosion. The RCPT is effective for measuring the resistance to chloride penetration of relatively high strength mortars containing pozzolans. The incorporations of POA and RHA decreases the chloride penetration of mortar by increasing nucleation sites for precipitation of hydration products, reducing $Ca(OH)_2$ and improving the permeability of mortar. RHA is the most effective followed by POA and OPC. The incorporation of POA and RHA can significantly improve the mortar corrosion resistance. RHA is the most effective followed by POA and OPC. RHA is the most effective and increases the corrosion resistance at 40% replacement levels. POA and RHA have high potentials to be used as a good pozzolanic materials.

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