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Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash

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Abstract

This paper presents a study of the resistance to chloride penetration of blended Portland cement mortar containing ground palm oil fuel ash (POA), ground rice husk ash (RHA) and fine fly ash (FA). Ordinary Portland cement (OPC) is partially replaced with pozzolan at the dosages of 20% and 40% by weight of cementitious materials. The water to cement ratio is kept constant at 0.5 and the flow of mortar is maintained at $110 \pm 5\%$ with the aid of superplasticizer (SP). Compressive strength, rapid chloride penetration test (RCPT), rapid migration test (RMT) and chloride penetration depth after 30 days of immersion in 3% NaCl solution of mortars were determined.

Test results reveal that the resistance to chloride penetration of mortar improves substantially with partial replacement of OPC with POA, RHA and FA. The resistance is higher with an increase in the replacement level. RHA is found to be the most effective pozzolan followed by POA and FA. The use of FA reduces the amount of SP required to maintain the mortar flow, while the incorporations of POA and RHA require more SP. The use of a blend of equal weight portion of POA and FA, or RHA and FA produces mixes with good strength and resistance to chloride penetration. They also require less amount of SP in comparison to that of normal OPC mortar.

Keywords: Fine fly ash; Palm oil fuel ash; Rice husk ash; Chloride penetration; Mortar

1. Introduction

The resistance to chloride penetration of mortar and concrete is one of the most important issues concerning the durability of concrete structures. When the chloride concentration of mortar or concrete exceeds a certain threshold value, depassivation of steel occurs and reinforced steel starts to corrode [1,2]. It is generally accepted that incorporation of a pozzolan improves the resistance to chloride penetration and reduces chloride-induced corrosion initiation period of steel reinforcement. This is mainly due to the reduction of permeability/diffusivity, particularly to chloride ion transportation of the blended cement concrete [3–5].

Pozzolans from agricultural waste are receiving more attention now since their uses generally improve the properties of the blended cement concrete, and reduce the environmental problems. Palm oil fuel ash and rice husk ash are two promising pozzolans and are available in many parts of the world. In Thailand alone, approximately 100,000 ton of palm oil fuel ash are produced annually [6]. It is a by-product obtained from a small power plant using the palm fiber, shells and empty fruit bunches as a fuel and burnt at 800–1000 °C. The main chemical composition of palm oil fuel ash is silica which is a main ingredient of pozzolan. Research indicates that ground palm oil fuel ash (POA) can be used as a pozzolan in normal and high strength concrete [7]. In addition, partial replacement of OPC with POA helps improve permeability and sulfate resistance of concrete [6,8].

Rice husk is also abundant in many parts of the world. When properly burnt at temperature lower than 700 °C,

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reactive amorphous silica is obtained [9]. The silica content in rice husk ash is high at approximately 90%. Silica in amorphous form is suitable for use as a pozzolan. With proper burning and grinding, ground rice husk ash (RHA) can be produced and used as a pozzolan. Even for higher burning temperature with some crystalline formation of silica, good RHA can still be obtained by fine grinding [10]. The reactive RHA is used to produce good quality concrete with reduced $Ca(OH)_2$ and higher resistance to sulfate attack [11,12].

An industry by-product which is now being used quite extensively as pozzolan in blended cements is fly ash. The incorporation of fly ash enhances the performance of concrete in terms of durability. The use of fly ash usually leads to a less permeable paste, denser interfacial zone between aggregate and the matrix [13–15]. Concrete containing fly ash is, therefore, less susceptible to the ingress of the harmful solutions. It has been shown that the use of fine fly ash (FA) results in better mechanical properties of concrete than those with the coarser fly ash. It increases strength, resistance to sulfate solution and resistance to chloride penetration of concrete [16,17].

The objective of this research is to study the use of POA, RHA and FA to increase the resistance to chloride penetration of mortar. The knowledge would be beneficial for future applications of the material in increasing the durability of mortar and concrete.

2. Experimental details

2.1. Materials

Ordinary Portland cement (OPC), palm oil fuel ash from a thermal power plant from the south of Thailand, local rice husk, lignite fly ash from Mae Moh power plant in the northern part 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. Rice husk ash was obtained from open burning in small heap of 20 kg of rice husk with the maximum temperature 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 sieve No. 325 (opening 45 μm) was 1–3%. Fine fly ash (FA) with 1–3% retained on sieve No. 325 was obtained from air classification of original coarse fly ash. The SEM (scanning electron microscopy) and grading analysis were performed on POA, RHA and FA.

2.2. Mix proportions and curing

Ordinary Portland cement (OPC) is partially replaced with 20% and 40% of pozzolan. In addition to single pozzolan, a blend of equal weight portions of POA and FA (BPF), and a blend of equal weight portions of RHA and FA (BRF) were also used. Sand-to-binder ratio of 2.75 by weight and water to binder ratio (W/B) of 0.5 were used. SP was incorporated in order to obtain mortar mixes with similar flow of 110 ± 5% in accordance with ASTM C109. The cast specimens were covered with polyurethane sheet and damped cloth and placed in 23 ± 2 °C chamber. They were demoulded at the age of 1 day and cured in water at 23 ± 2 °C. The mortar mix proportions are given in Table 1.

2.3. Compressive strength

The 50 mm cube specimens were prepared in accordance with ASTM C109 [18]. They were tested at the age of 7, 28 and 90 days. The reported results are the averages of three samples.

2.4. Rapid test on resistance to chloride penetration

The 100 × 200 mm cylinders were prepared in accordance with ASTM C39 [19]. After being cured in water until the age of 27 days, they were cut into 50 mm slices with the 50 mm ends discarded. The 50 mm slices were epoxy-coated around the cylinder.

2.4.1. Rapid chloride penetration test

The 100 mm dia. × 50 mm epoxy-coated specimens were conditioned and tested at the age of 28 days for rapid chloride penetration test (RCPT) in accordance with the method described in ASTM C1202 [20]. The reported results are the averages of two samples.

2.4.2. Rapid migration test

At the age of 28 days, the 100 mm dia. × 50 mm epoxy-coated specimens were conditioned and tested for the chloride penetration depth using the rapid migration test (RMT) as shown in Fig. 1 [21,22]. The solutions employed in migration tests were 3% NaCl (in limewater) in the cathode side and limewater in the anode side. Applied voltage of 30 V dc at 8 h was employed. The chloride penetration depths were determined by breaking the specimens and by applying 0.1 M $AgNO_3$ solution [23].

Table 1
Mortar mix proportions

Mix	OPC	POA	RHA	FA	SP (%)
OPC	100	–	–	–	1.9
20POA	80	20	–	–	2.0
40POA	60	40	–	–	3.2
20RHA	80		20		2.2
40RHA	60		40		3.7
20FA	80	–	–	20	0.4
40FA	60	–	–	40	0.1
20BPF	80	10	–	10	0.8
40BPF	60	20	–	20	1.1
20BRF	80	–	10	10	1.1
40BRF	60	–	20	20	1.6

Note: sand-to-binder ratio 2.75, W/B = 0.5, flow 110 ± 5%.