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Utilization of fly ash concrete in marine environment for long term design life analysis

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ABSTRACT

This paper presents the performance of 7-year fly ash concrete exposed to hot and high humidity climate in marine conditions. Control concrete and fly-ash concrete cube specimens of 200 mm were cast and steel bars of 12 mm in diameter and 50 mm in length were embedded at various cover depths. The concrete specimens were exposed to tidal zone of marine environment in the Gulf of Thailand. The concrete specimens were tested for chloride penetration profile, chloride content at the position of embedded steel bar, and corrosion of embedded steel bar after being exposed to tidal zone of sea water up to 7 years. Consequently, these experimental data were used to generate the empirical equation for predicting long term required cover depth of cement and fly ash concretes to protect against the initial corrosion of reinforcing steel in a marine environment.

The results showed that the increase of fly ash replacement in concrete clearly reduced the chloride penetration, chloride *penetration* coefficient, and steel corrosion in concrete. Interestingly, concretes with the fly ash replacement of 25–50% by weight of binder with a W/B ratio of 0.65 did not have corrosion of embedded steel bar at 50 mm concrete cover depth at 7-year exposure in a marine environment and presented the corrosion resistance as good as the cement concrete with a W/B ratio of 0.45. In addition, the empirical model indicated that all predicted data were within ±15% error of the tested data (up to 7 years). Also, the model was verified by using the investigated data of concrete exposed to a marine environment up to 10 years from other researchers; most predicted results were within ±25% error of the investigated data.

1. Introduction

Presently, there has been a renewed emphasis on improving durability and increasing service life of concrete structures. Since, the financial impact of rehabilitating structures that have failed prematurely due to improper design and construction methods is enormous. Therefore, the study on material design method for supporting concrete structures under the severe condition is very important. Under the severe condition, marine concrete structure is widely concerned for long term serviceability. It is well known that the destroying of concrete structure in marine environment is mainly due to sulfate attack and the corrosion of steel under chloride attack. However, all of these mechanisms are combination of many influences, such as moisture, temperature, impacted force, abrasion by sand in sea water and [1,2]. One way to increase service life is to design, specify, and build structures using concrete with particular properties. These properties can easily be improved by using concrete with a low water–binder (W/B) ratio or by using fly ash to replace some of Portland cement in concrete [3,4]. Throughout, the compromise between material and durable design method are necessary. The field indicator of concrete in marine site is preferred to achieve the suitable design and development for high durability concrete.

Many researchers have obtained the durability data of marine concrete structure in long-term exposure [5–7]. However, a few researches studied on the corrosion of fly ash concrete relating to fly ash replacement level, various concrete cover depths, corrosion of steel, and chloride penetration profile [7,8]. Moreover, it has not been found the long term durable data of concrete in a marine environment of Southeast Asia which is in a hot and high humidity climate. Besides, the prediction of long term performance of marine concrete is needed for durability design. Furthermore, the development of empirical model to predict the corrosion of steel reinforcement in fly ash concrete over long-term exposure to a marine environment requires investigated data gathered from experimental sites. Thus, the performances of 7-year fly ash concretes exposed to a hot climate in marine condition were presented

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Table 1
Chemical composition of Portland cement type I and fly ash.

Chemical composition (%)	Sample	
	Cement type I	Fly ash
Silicon dioxide, SiO_2	20.80	44.95
Aluminum oxide, Al_2O_3	5.50	23.70
Iron oxide, Fe_2O_3	3.16	10.80
Calcium oxide, CaO	64.97	13.80
Magnesium oxide, MgO	1.06	3.47
Sodium oxide, Na_2O	0.08	0.07
Potassium oxide, K_2O	0.55	2.38
Sulfur trioxide, SO_3	2.96	1.31
Loss on ignition, LOI	2.89	0.52
Tricalcium silicate, C_3S	56.50	–
Dicalcium silicate, C_2S	17.01	–
Tricalcium aluminate, C_3A	9.23	–
Tetracalcium aluminoferrite, C_4AF	9.62	–

in this study. Consequently, the prediction of cover depth of fly ash concrete required to protect reinforcing steel against initial corrosion in a marine environment for a specified period was developed based on experimental data. The model's validity was verified using data obtained from specimens in a marine environment in Thailand and from previous researches.

2. Specimen preparation and testing

The specimens used were 200 mm concrete cubes containing 0%, 15%, 25%, 35%, and 50% fly ash as a replacement of Portland cement type I. Concrete samples had W/B ratios of 0.45, 0.55, and 0.65. Round bars (grade SR 24 yield strength of 240 MPa) with a diameter of 12 mm and a length of 50 mm were embedded in the concrete samples at cover depths of 10, 20, 50, and 75 mm. Tables 1 and 2 list the chemical properties of cementitious materials and mix proportions of concretes, respectively. After casting for 28 days, the concrete specimens were transferred to a seashore at Chonburi Province, Thailand (Fig. 1). Concrete samples at this marine site were exposed to two wet-dry conditions daily. Annual temperatures at this site range from 25°C to 35°C. Table 3 lists the chemical analysis of the sea water. After exposure to this environment for 2, 3, 4, 5 and 7 years, the samples were dry-cored and tested to determine the chloride penetration profile and chloride content at the position of the embedded steel bar. Chloride concentrations were determined using the acid-soluble chloride method set out by ASTM C1152 [9], resulting in the total chloride content (by weight of binder) in concrete. Besides, the concrete cubes were cored to obtain cylindrical concretes of 50 mm in diameter and 100 mm in height. The compressive strength of the cored concretes were determined and the result was the average of 3 samples. Finally, the 200 mm concrete samples were then crushed, and the corrosions of the embedded steel bars were measured in term of the percentage of rusted area.

3. Experimental results

3.1. Chloride penetration

Fig. 2 shows the chloride penetration profiles of cement concrete and fly ash concretes with a W/B ratio of 0.45 at 7-year exposure in a marine environment. It is seen that fly ash concretes provide lower chloride content than concrete without fly ash. This result is confirmed by several researches that the pozzolanic reaction of fly ash in concrete performs lower permeability, thus leads to lower chloride ingress than normal concrete [10–16]. Interestingly, all fly ash concretes with a W/B ratio of 0.65 had chloride penetration at 7-year exposure lower than that of cement concrete

Table 2
Mixture proportions of concrete samples.

Water to binder ratio	Fly ash replacement (%)	Mixture proportion of concrete (kg/m^3)					28 days strength (MPa)
		Cement	Fly ash	Fine aggregate	Coarse aggregate	Water	
0.45							
	0	478	–	639	1024	215	50.4
	15	406	72	639	1004	215	47.4
	25	359	119	639	990	215	43.2
	35	311	167	639	977	215	45.0
	50	239	239	639	957	215	33.8
0.55							
	0	478	–	639	971	262	37.0
	15	406	72	639	948	262	32.0
	25	359	119	639	933	262	30.3
	35	311	167	639	918	262	32.7
	50	239	239	639	897	262	20.9
0.65							
	0	478	–	639	922	311	29.0
	15	406	72	639	898	311	19.9
	25	359	119	639	881	311	21.0
	35	311	167	639	864	311	22.9
	50	239	239	639	840	311	16.6