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Accelerated short-term techniques to evaluate the corrosion performance of steel in fly ash blended concrete

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Abstract

In this investigation, the influence of mineral admixture, namely fly ash (FA) on the corrosion performance of steel in mortar and concrete was studied and evaluated by some accelerated short-term techniques in sodium chloride solutions. Electrochemical techniques such as open circuit potential measurements and anodic polarization studies were carried out. An impressed voltage technique and macrocell corrosion study was also carried out to understand the optimum level of replacement of FA with better corrosion resistance properties. Results are compared with conventional gravimetric weight loss measurements. The alkalinity and the free chloride contents are estimated. The FA replacement levels namely 10%, 20%, 30% and 40% with respect to ordinary Portland cement (OPC) was chosen for the present study and the results are compared with OPC specimens without FA.

Keywords: Mineral admixture; Fly ash; Reinforcement corrosion; Accelerated techniques

1. Introduction

The development and use of blended cements is growing rapidly in the construction industry mainly due to considerations of cost saving, energy saving, environmental protection and conservation of resources. Fly ash (FA), a siliceous material obtained from different thermal power stations is now being considered as a cementitious ingredient for concrete. The use of FA in mortar and concrete, as a partial replacement of Portland cement, appears to constitute a very satisfactory outlet for this industrial by-product. The use of FA to replace a portion of the cement has resulted in significant savings in the cost of production of concrete. Mineral admixtures are finely divided siliceous materials, which are added to concrete in relatively large amounts [1,2]. Power generation units using coal as fuel and metallurgical furnaces producing cast iron, silicon metal and ferrosilicon alloys are the major source of by-products, namely FA, blast furnace slag (BFS) and silica fume (SF), [3] respectively. Dumping away these by-products represents a waste of the material and causes serious environmental pollution problems. Industrial countries such as the United States, Russia, France, Germany, Japan and the United Kingdom are among the largest producers of FA, volatilized silica and granulated BFS. ASTM classifies fly ashes into two categories, namely class-C and class-F according to their calcium contents. Class-C FA contains more than 10% calcium and class-F contains less than 10% calcium contents. Paya et al. [4–6] conducted studies on mortars containing 15–60% FA as a replacement of Portland cement with different particle size of FA on mechanical properties of concrete. Naik et al. [7] studied the influence of FA on chloride permeability of concrete. Thomas [8] reported that threshold chloride level decreased with increasing FA content. FA concrete was found to have increased resistance to chloride ion

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penetration and increased electrical resistance. Studies also reported that FA can accelerate the corrosion of steel in concrete [9–12]. In order to produce fly ashes with stable properties and adequate quality, many power plants have implemented their own sophisticated quality control measures. The property improvement of FA blended cements was extensively studied and it was reported that the physical and mechanical properties matched that of ordinary Portland cement (OPC) [13–16]. Corrosion-resistance properties of FA blended cement concrete are also important to consider along with the physical and mechanical properties of concrete for a durable structures. The objective of the present investigation is a systematic study on the influence of FA on the corrosion resistance of steel in concrete by various non-electrochemical and electrochemical accelerated short-term techniques in 3% NaCl solution.

2. Methods and materials

2.1. Materials used

OPC conforming to KS: L 5201:1989 was used throughout this investigation. ASTM class F-type FA was used. The composition of OPC and FA used was as follows:

Constituents	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	LOI	Others
Cement	63.8	22.8	5.1	3.7	1.7	2.0	0.8	0.1
Fly ash	3.26	51.63	30.40	5.20	2.80	0.40	5.30	1.00

Natural fine aggregates of normal gravity and maximum size of the coarse aggregate was 10 mm conforming to KS F 2526: 2002 was used.

The mix proportions used for casting is as follows:

1:1.71:3.1
OPC: 415 kg/m^3
Fine aggregates: 710 kg/m^3
Coarse aggregates: 1287 kg/m^3
Water–cement ratio: 0.50
FA: 10%, 20%, 30% and 40% replacement level of OPC by weight of cement.

2.2. Techniques adopted

2.2.1. Weight loss method

Cylindrical mortar specimen of size 55 mm diameter and 60 mm height were cast using OPC and OPC containing various FA replacement levels. A cold twisted rod of 12 mm diameter and 45 mm long was embedded centrally. Initially the rebar samples were cleaned in hydrochloric acid, degreased with acetone and washed with double distilled water and dried. The initial weight of the rebar sample was taken before casting for gravimetric weight loss measurements.

Mortar specimens were prepared using 1:3 mix with a w/c ratio of 0.45. The specimens were mechanically vibrated. After 24 h, the specimens were demoulded and cured for 28 days in distilled water in order to avoid any contamination. After the curing period was over, all the specimens were completely immersed in 3% NaCl solution. The specimens was maintained in the same condition for 15 days and then subjected to drying in open air at room temperature for another 15 days. Each wetting and drying cycle thus consisted of 30 days. All the mortar specimens were subjected to 6 complete cycles (180 days) of test period. Tests were conducted on a minimum of 6 replicate specimens and the average values are reported.

2.2.2. Open circuit potential (OCP) measurements

The rebar specimens were cut to the required size. They were polished and degreased and embedded in mortar specimens. Electrical connections were taken by screwing a 3 mm mild steel rod on the rebar. The OCP of the different systems was periodically monitored using a voltmeter with a high input impedance of 10 MΩ. Saturated calomel electrode (SCE) was used as a reference electrode. The positive terminal of the voltmeter was connected to the working electrode i.e., mild steel rods. The common terminal was connected to the reference electrode. The corresponding potentials were recorded. OCP for all the specimens were monitored over an exposure period of 180 days. In this study, specimens in triplicate were used for each system and the average of these values are reported and interpreted based on ASTM C-876-1994 [17] and the half-cell measurement set up is shown in Fig. 1.

2.2.3. Anodic polarization technique

Rebar specimens were embedded in cylindrical mortar specimens of size 58 mm diameter and 60 mm height using a w/c ratio of 0.45. The mortar specimens only with OPC (control) and OPC replaced by FA at 10%, 20%, 30% and 40% replacement levels were subjected to anodic polarization studies using a 3-electrode system which consists of embedded steel in mortar as anode, stainless steel ring electrode as cathode and SCE as reference electrode. Anodic polarization studies have been carried out in 3% NaCl solution using a Gamry Instruments, Inc., CMS 100 Framework software analyser. The currents flowing at anodic potentials, namely +300 and +600 mV were recorded for all the specimens at a fixed duration of 12 h. A duplicate experiment was made for these measurements at an ambient temperature of 25±1 °C.

2.2.4. Impressed voltage technique

The impressed voltage technique is an accelerated corrosion testing technique which indirectly gives information about the permeation characteristics of the concrete. Cylindrical concrete specimens were made using 1:1.71:3.1 mix proportion with a w/c ratio of 0.5. Specimens with OPC and various FA replacement levels were made with embedded rod as an anode and cylindrical stainless steel