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ORIGINAL ARTICLE

Effect of mix proportions, seawater curing medium and applied voltages on corrosion resistance of concrete incorporating mineral admixtures

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Abstract Most reinforced concrete structures suffer durability problems during their service. The major durability problem is the corrosion of reinforcing steel which results in cracking and spalling of concrete. Nowadays, mineral admixtures, such as silica fume and metakaolin are used to enhance the corrosion resistance of reinforced concrete structures. In this research work, accelerated corrosion tests were carried out on reinforced concrete specimens made with plain, silica fume and metakaolin blended cements. The mineral admixtures were incorporated in the mixtures as a partial replacement by weight. The replacement percentages were 10%, 15%, and 25% of cement content by weight. Three types of cement were used in the program which were type I, type II, and type V Portland cement as classified by ASTM C150. Cement content of 350 and 450 kg/m^3 were used in concrete mixes with 0.40 and 0.50 water-binder ratios (w/c$_m$). The curing mediums of specimens were potable water and seawater medium. Also, the effect of applied voltage on the accelerated test was studied. The current intensity, visible cracking time, and critical time up to 2 mm crack width were recorded during testing. The weight loss of the steel was also determined after testing. The observed superior resistance performance of silica fume and metakaolin blended cement concrete as compared to plain cement concrete in terms of cracking time, critical time, weight loss, and corrosion intendancy factor was monitored. Also, concrete mixes made with type I Portland cement

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have a good corrosion resistance compared with that of type II and type V Portland cement concrete mixes both cured in potable water and sea water medium.

1. Introduction

The corrosion of reinforcing steel in concrete has received increasing attention in the recent years because of its wide spread occurrence in many types of structures and a high cost in repairing these structures [1]. Infact, corrosion of reinforcing steel in concrete is a growing international problem. It was estimated that the cost of corrosion damage caused by deicing and sea salt on high ways bridges exceeded up to $150 billion in the United States [12].

Corrosion of reinforcing steel can damage or reduce the serviceability of concrete structures. Corrosion products are highly porous, weak, and often around reinforcing steel, causing loss of bar cross section and it causes also loss of bond capacity due to concrete damage [6].

Corrosion activity is influenced by many factors, such as cement type, permeability of concrete, concrete cover, pH value of concrete, concrete carbonation, and the presence of corrosion inhibitors etc. Cement composition has a significant effect on the durability performance of concrete against corrosion of reinforcement where C_3A binds chloride ions to form calcium chloro-aluminate hydrate, thereby; causing it to be removed from the hazardous role of corrosion promotion [2]. Low permeability of concrete in addition to minimize the permeability of corrosion inducing agents increases the electrical resistivity of concrete which retards the flow of current associated with electrochemical corrosion and in turn the corrosion rate. The use of silica fume improves the mechanical and durability properties of concrete. Also, it increases the electrical resistivity of concrete. The use of silica fume leads to decrease the pH value of concrete. This is due to the fact that silica fume cement paste contains less calcium hydroxide compared with the control paste [11]. Addition of silica fume (in quantitative ranging from 5% to 30% by weight of cement) as a pozzolanic admixture has been shown to reduce concrete permeability and, therefore, enhances corrosion protection of the reinforcing steel provided by the surrounding concrete [16].

When metakaolin is used in concrete, the test results shall verify improved or comparable strength, sulfate resistance, corrosion protective properties and other durability performance properties of concrete, as compared to the performance of silica fume concrete [22]. There is a lack of information about corrosion resistance of concrete with metakaolin. Although the capability of metakaolin as pozzolanic material to improve mechanical and durability properties of concrete if used as partial replacement of Portland cement is well noted in concrete science, its utilization in building industry was limited to date [22]. Due to this lack of information about corrosion resistance of concrete incorporating metakaolin and also, to a certain extent, silica fume concrete, this study focuses on the effect of using silica fume and metakaolin as cement replacement and effect of changing C_3A content (cement type) on the corrosion resistance of concrete in two types of curing media (potable water and sea water media).

2. Experimental program

2.1. Materials

Three types of cements were used in this study. These cements were type I, type II, and type V (ASTM C 150). The chemical composition of these cements is given in Table 1. According to Bougue potentials, the hydration compound of tri-calcium aluminate (C_3A) was determined for used cement types I, II and V and found to be 8.80%, 6.5% and 0.20%, respectively. Silica fume and metakaolin were used as mineral admixtures. The chemical composition of silica fume and metakaolin is also given also in Table 1.

Crushed pink lime stone with nominal maximum aggregate size of 3/8″ and natural siliceous sand of 2.72 fineness modulus were used as coarse and fine aggregates. A high-range water reducing admixture, type F, with variable dosages was used to achieve constant workability (slump 10 ± 1 cm).

2.2. Specimens and accelerating corrosion cell

The specimens used for accelerated corrosion test were cylinders of 75 × 150 mm with steel bars of 10 mm diameter and 200 mm length placed at the middle of the specimens. After being demolded, the specimens were water cured for 3 months then they were immersed in corrosion cell. The electrolyte in this cell was 5.0% by weight of NaCl solution. A constant volt of 55.0 DC was applied between the anode (steel reinforcement) and the cathode (copper plate) for the majority of this

Table 1 Chemical analysis of cements.

Constituent percent by weight	Type I cement	Type II cement	Type V cement	Silica fume	Meta-kaolin
Silicon dioxide	20.10	20.87	20.20	94.5	79.12
Aluminum oxide	5.50	5.21	3.44	0.88	5.96
Ferric oxide	3.42	4.32	5.29	0.39	0.44
Calcium oxide	61.10	62.48	62.88	1.75	12.5
Magnesium oxide	4.03	1.15	2.66	–	–
Sulfur trioxide	2.57	2.84	2.09	0.80	0.2
Loss on ignition	2.75	2.01	1.93	1.50	1.4
C_3A	8.80	6.50	0.20	–	–