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Chloride Corrosion of Reinforcement in Concrete Containing Fly Ash

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Abstract— Corrosion of embedded steel rebars is a worldwide problem that occurs in the reinforced concrete and greatly affects the concrete durability. To avoid chloride-induced corrosion, chlorides must be hindered from reaching the steel surface. This can be rechead by using pozzolanic materials that enhance the microstructure of the concrete and make it too dense to be penetrated by chloride ions. This paper compares the corrosional behavior between OPC concrete mix and concrete containing fly ash as a partial replacement of OPC. The experimental program includes carrying out half-cell potential test and accerelated corrosion test to assess the corrosion resistance between the two mixes. Results indicated that fly ash concrete mix has much better corrosion resistance than OPC concrete mix.

INDEX TERMS— Steel corrosion, Chlorides, Pozzolanic materials, Fly ash, Corrosion resistance, Corrosion potential, Concrete durability.

1. INTRODUCTION

Steel corrosion is a common problem that affects the durability of the reinforced concrete. The corrosion process results from carbonation or it may be chloride-induced corrosion [1]–[5]. The sources of chlorides may be external like in marine environment or enternal such as chloride-contaminated aggregate or water have high percentage of salts. To avoid chloride corrosion problems, standars have put limits on the critical shloride content in reinforced concrete [6]. Using pozzoanic materials in the concrete has become very common nowadays as they improve the concrete properties greatly [7]–[11]. Also, those materials have a great role in protecting reinforcing steel from corrosion [1], [3], [12], [13]. This paper studies the corrosional behavior of concrete containing both fly ash as a partial replacement of OPC and a relatively high chloride content. For this approach, half-cell potential test and accelerated corrosion test were carried out to assess the corrosion resistance of such concrete containing fly ash and high chloride content.

2. EXPERIMENTAL PROGRAM

2.1 Material Properties

Fly ash (type F) is utilized as a partial replacement of OPC. The chemical composition of these materials is shown in Table 1. The physical properties of the used aggregate are shown in

Table 2. NaCl (100% pure) was added to clean-potable water as a percentage of the binder weight.

Table 1: Chemical Composition of Cementitious Materials.

Oxides	CaO	SiO2	Al2O3	SO3	Fe2O3	MgO	Na2O	K2O	Cl	LOI[a]
OPC	61.45	19.31	4.59	3.35	3.12	2.59	0.28	0.2	0.05	3.73
FA	1.05	61.65	26.96	-	7.37	1.46	0.38	1.65	0.02	0.36

[a] LOI: Loss on ignition.

Table 2: Physical Properties of Aggregate.

Property	Specific gravity	Volumetric weight	% of fine materials	% of water absorption	Chloride ion content (% by weight)	Sulfate content (% by weight)
Fine aggregate	2.62	1.61	2.6	-	0.03	0.21
Coarse aggregate	2.677	1.531	0.7	2.2	0.015	0.18

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2.2 Mixtures Properties

Two mixes of concrete were poured with water to binder ratio equal 0.5, and the chloride content (as a percentage from the binders' weight) is chosen to be equal to the double of the limit of the chloride content in the Egyptian code (0.8%). The mix proportions for 1m3 of concrete are shown in Table 3.

Table 3: Mixes Proportions of Concrete (for 1m3).

Mix	OPC (kg)	Fly ash (kg)	Coarse agg. (kg)	Fine agg. (kg)	Water (kg)	NaCl (kg)	W/B	%Cl⁻
OPC mix	350	0	1117	558	175	2.8	0.5	0.8
Flyash (15%)	297.5	52.5	1474	317				

2.3 Test Setup and Procedures

Half cell potential and accelerated corrosion tests are carried out according to ASTM C876 [14] and [13], [15]–[17] respectively. Figure 1 and Figure 2 shows the test setup for both tests.

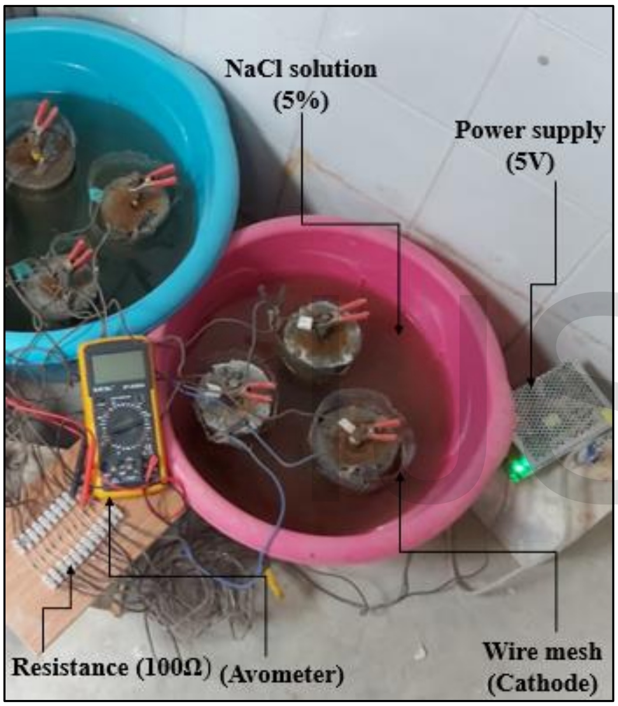

Figure 1: Accelerated Corrosion Test Setup.

Figure 2: Half-cell Potential Test Setup.

3. Results and Discussions

3.1 Half Cell Potential Test

This test was implemented after 28 days to determine the probability of reinforcement steel to corrode in each concrete mix [13], [18]and test results are presented in Figure 3.

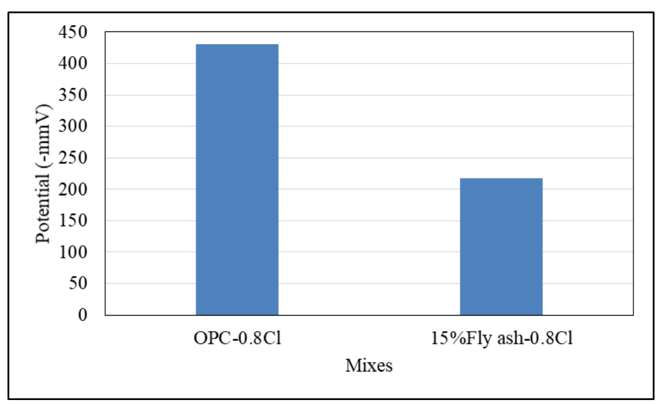

Figure 3: Half Cell Potential Test Results

As indicated in Figure 3, the corrosion potential in mix containing 15% fly ash is lower than its value in OPC mix and even lower than -350 mV that is considered the value above which (-400,-450,…) the steel become active for corrosion process. This means that the embedded steel in fly ash concrete have lower corrosion probability much more than OPC concrete.

3.1 Accelerated Corrosion Test

The accelerated corrosion test was implemented to compare the corrosion behavior between the two concrete mixes [15], [16], [18]. Specimens were checked daily since the start of the test to observe and record the time of the cracking initiation that happens due to the volumetric increase in the steel rebar which in turn causes internal stresses on the specimen, consequently, it starts to crack [13]. The relation between electrical current in milliampere and time in days was determined for each mix as shown in Figure 4 and Figure 5.

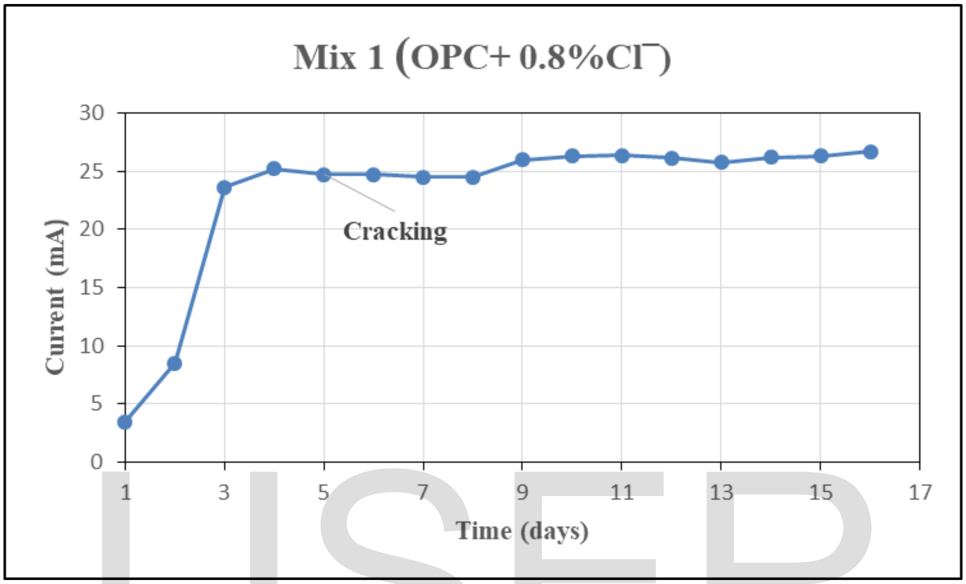

Figure 4: Csurrent-Time Relation for Mix 1

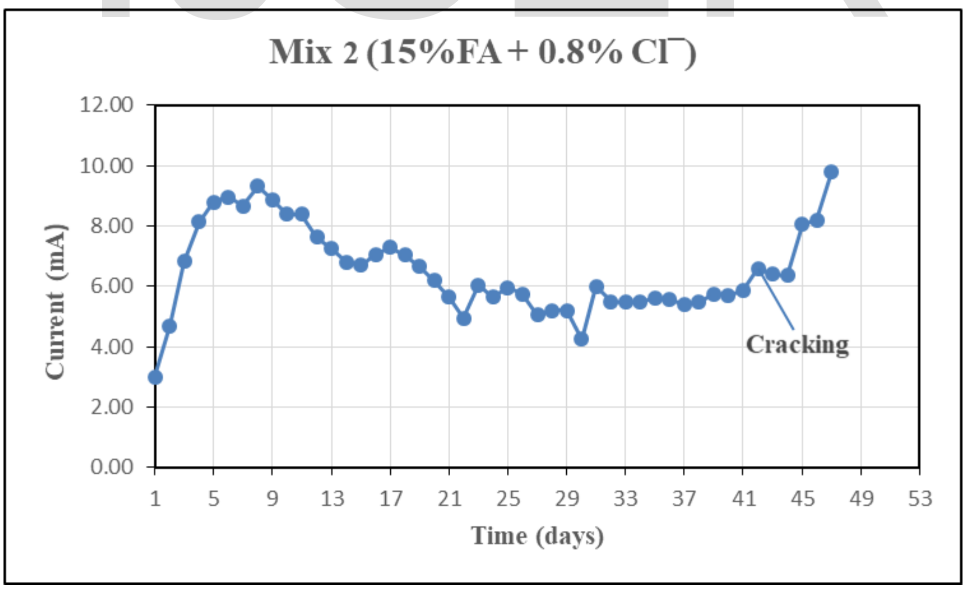

Figure 5: Csurrent-Time Relation for Mix 2

From the previous charts, the cracking time and the range of the electrical current for each concrete mix can be presented in Table 4.

Table 4: Cracking time and range of electric current for each concrete mix

	Mix no.	Cracking time (day)	Range of electric current (milliAmpere)
1	OPC-0.8%	6	4 to 26
2	15%FA-0.8%	42	3 to 10

From the previous results it is clearly shown that fly ash concrete has much better corrosion resistance than OPC concrete. A basic concept should be taken into account which is the corrosion process in such test occurs because of two main causes. The first one is the chlorides existing in the concrete mix. The other cause is the external solution of sodium chloride and to prevent the movement of such chlorides to steel rebar across concrete, the concrete must be of high quality and having a dense microstructure and this can be reachable by adding pozzolans in concrete mix [13].

4. Conclusions and Recommendations

- concrete mixes including 15% fly ash as a partial replacement of OPC has a lower corrosion probability than mixes containing OPC only which means more protection of reinforcement against corrosion.
- The concrete mix should be designed based on its ambient environment. For reinforced concrete intended to be poured with components containing chlorides, the main concern in choosing the type and the quantity of the binder is to have a high binding capacity. But for reinforced concrete intended to be located in chloride-rich environment, the main concern is to choose a binder that has a high pozzolanic reactivity to densify the microstructure of the concrete preventing external chlorides from getting into concrete and reaching the steel surface.

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