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The Effect of Added Carbon Black to Concrete Mix on Corrosion of Steel in Concrete

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Abstract

The effect of added carbon black to concrete mix on corrosion of steel reinforcement was studied. This was achieved by inserting steel bars in different concrete mixes containing 0.1, 0.2, 0.3, 0.4, and 0.5, carbon black/cement. Samples were cured, immersed in 3.5% chloride solution for 6 months. Chloride permeability and corrosion rates were measured. Tests showed that corrosion rate and chloride ions penetration decreased with increased carbon black content. This was expressed due to filling effect of very fine particles of carbon black and was in the order less than 250 nm.

Keywords

Corrosion, Concrete, Carbon Black, Permeability

1. Introduction

Corrosion is the destructive attack of a metal by chemical or electrochemical reaction with its environment [1]-[5]. Deterioration by physical causes is not called corrosion, but is described as erosion, galling, or wear. In some instances, chemical attack accompanies physical deterioration, as described by the following terms: corrosion—erosion, corrosive wear, or fretting corrosion. Nonmetals are not included in this definition of corrosion. Plastics may swell or crack, wood may split or decay, granite may erode, and Portland cement may leach away, but the term corrosion, in this book, is restricted to chemical attack of metals [6]-[9].

"Rusting" applies to the corrosion of iron or iron—base alloys with formation of corrosion products consisting largely of hydrous ferric oxides. Nonferrous metals, therefore corrode, but do not rust. Corrosion of steel in

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concrete is a slow process, due to the protective nature of concrete; it takes a reasonably long time for initiation and progress of reinforcement corrosion, even in the case of severe corrosive exposure conditions [10]-[13]. It is difficult to achieve a significant degree of reinforcement corrosion in a limited duration available for performing research studies evaluating 1) the loss of bond and loss of load-bearing capacity of corroding reinforced concrete members; 2) the effect of mineral admixtures in reducing reinforcement corrosion; 3) the performance of coated or alloyed reinforcing bars against reinforcement corrosion; 4) the effectiveness of electrochemical techniques applied for the prevention of reinforcement corrosion. For this reason, various techniques for inducing accelerated corrosion of steel in concrete are used by the researchers. In this paper, an attempt has been made to firstly describe the impressed current technique commonly used for accelerating reinforcement corrosion in small- as well as large-sized concrete specimens in the light of state-of-the-art information available in the literature [12]-[18]. Then, the procedure for calculating degree of induced corrosion in percentage by mass and in terms of average corrosion current density using the intensity and duration of the applied current is presented. The benefits of using high-volume fly ash in resisting corrosion damage in concrete structures. It considers the usefulness of current fly ash concrete technology and prevention techniques, and advances a new approach for making concrete resist the deleterious effects of corrosion.

Corrosion of concrete takes place when carbon dioxide (CO_2) and chlorides penetrate concrete. As the chlorides and CO_2 penetrate concrete, the pH level of the concrete begins to drop from 12 - 13 to about a value of 9. In concrete construction, the 1.5 to 2 inches of concrete cover over the rebar acts as protective layer from the chlorides/CO_2 reaching the rebar. Once the threshold is reached, the concrete cover is compromised and the pH of the concrete surrounding the rebar allows for corrosion. This weakens the concrete and reduces its service life. This subsequently increases costly maintenance on repair and restoration projects for the damaged concrete structure. The aim of this project is to study the effect of carbon black (Nano carbon) addition on corrosion minimization in concrete.

2. Experimental

Concrete cylinders with different carbon black addition were cast in plastic tubes of 9 cm diameter, concrete mix design used in this study is shown in **Table 1**. Carbon black was added to cement prior to concrete mixing and casting. The addition of carbon black was made on cement content volume basis; carbon black/cement ratios considered were as follows: 0.1, 0.2, 0.3, 0.4, and 0.5. The concrete mix design/m³ is shown in **Table 1**.

After concrete were cast and hydration took place, concrete cylinders were removed from plastic molds, and then cured for 28 days. Samples then removed to in 3.5% NaCl tank and left there for 6 months. Specimen design is shown in **Figure 1**. Chloride permeability tests were performed for all specimens in order to measure the effect of added carbon black into concrete mix since chloride ion diffusion is related to permeability of concrete.

After six months of exposure, polarization tests were performed for all specimens for corrosion rate measurements, polarization testing experimental setup is shown in **Figure 2**.

3. Results and Discussion

Tafel extrapolation and polarization resistance are two methods to measure corrosion rates. Polarization methods are faster experimental techniques compared to classical weight loss estimation. For an electrochemical reaction under activation control, polarization curves exhibit linear behavior in the E Vs log (i) plots called Tafel behavior.

Table 1. Concrete mix design.

Cement		430 kg
Sand		1000 kg
Aggregate	(3 - 7 mm)	340 kg
	(7 - 15 mm)	860 kg
	Total	1200 kg
W/C		0.6

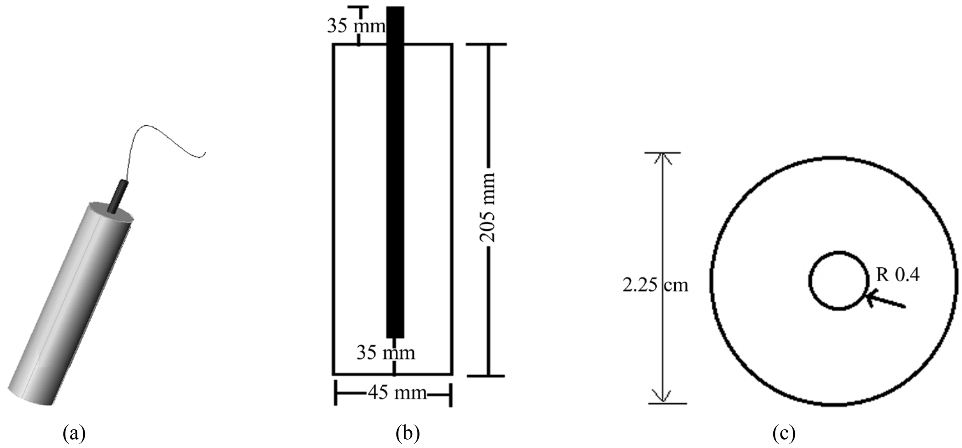

Figure 1. Specimen design and dimensions: (a) sample; (b) side-view; (c) top-view.

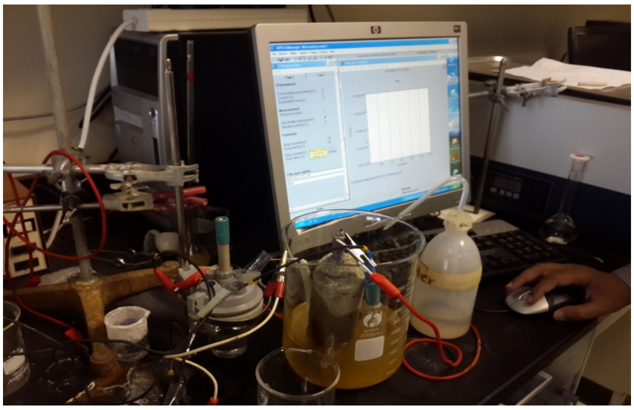

Figure 2. Polarization test experiment set up.

Potentiodynamic Polarization Curves (Tafel lines) of Steel reinforcement in different Types of concrete mixes after 6 months immersion in 3.5% NaCl solutionare shown in **Figures 3-7**. Corrosion potential showed a minor drop from −560 mV vs. SCE for carbon black/cement ratio 0.1, and −548 mV for 0.2 ratios, and was found −548 mV for 0.3 ratios. For higher carbon black/cement ratios, namely 0.4, and 0.5 more drops were observed. Values were −520 and −486 mV respectively. Variation of potential with carbon black addition is shown in **Figure 8**.

Permeability tests were performed, results were in agreement with potential of steel bars values; potential values indicate the possibility of corrosion of the reinforcement which, in turn, is related to the amount of corrosive species entering to the steel concrete interface, which are chloride ions in this case. Since the decrease in corrosion rate can be explained as a function of chloride ingress, then the filling effect of carbon black makes retardation of chloride ingress into concrete to steel-concrete interface [18].

Chloride permeability results of control (no carbon black) and high volume carbon black mixes at 28 days of curing are presented in **Table 2**. It can be seen that the samples with no carbon black had the highest chloride permeability while concrete samples with carbon black had much lower permeability values. As the amount of carbon black replacing cement increased, the chloride permeability rapidly reduced.

Longer-term chloride ion permeability tests were carried out on samples of concrete containing 0, 15, 30, and 50% carbon black replacing cement. The chloride ion permeability of the carbon black mixes was significantly lower than that of the no carbon black mix. The permeability reduced with increase in percent carbon black. Increase in curing time from one month to six months led to about 5.70% reduction in the permeability of the no carbon black mix, while the permeability of the carbon black mixes reduced 30% to 40% over the same time period. Even at six month of curing, the no carbon black concrete sample had moderate chloride ion penetrability while all the carbon black concrete samples had very low penetrability values. The high-volume carbon black mixes would be the most durable concrete mixes for preventing corrosion in reinforced concrete structures.

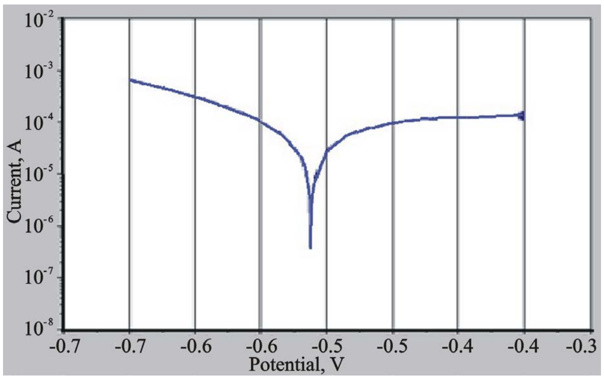

Figure 3. Polarization curve of steel in concrete with 0.1 carbon black/cement ratio.

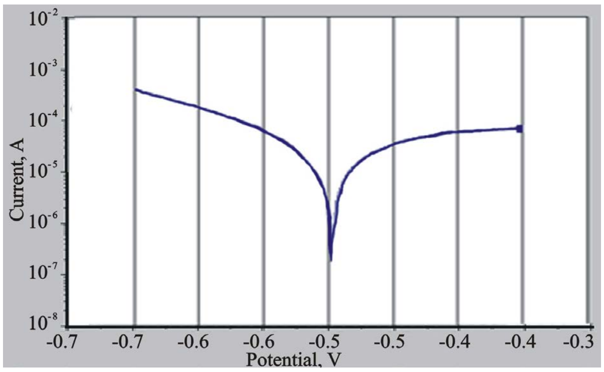

Figure 4. Polarization curve of steel in concrete with 0.2 carbon black/cement ratio.

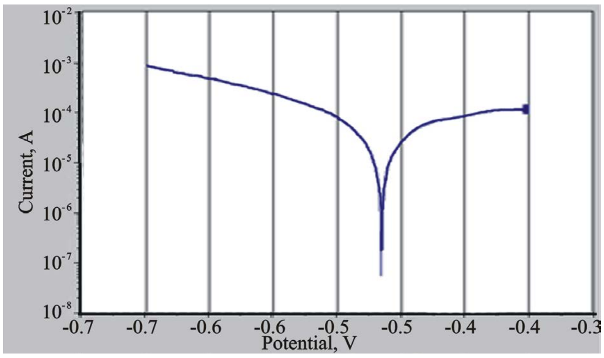

Figure 5. Polarization curve of steel in concrete with 0.3 carbon black/cement ratio.

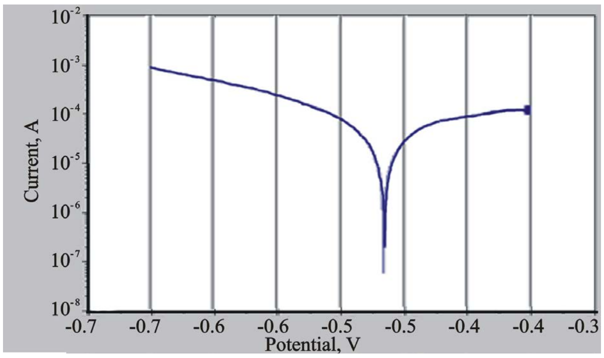

Figure 6. Polarization curve of steel in concrete with 0.4 carbon black/cement ratio.

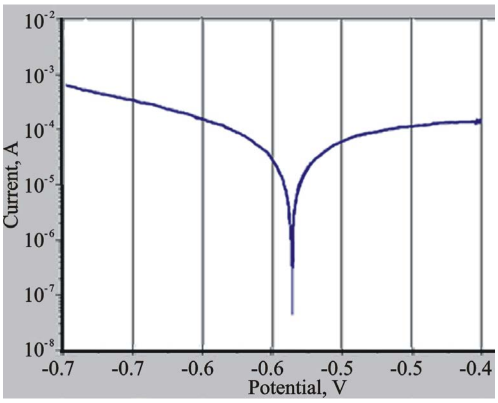

Figure 7. Polarization curve of steel in concrete with 0.5 carbon black/cement ratio.

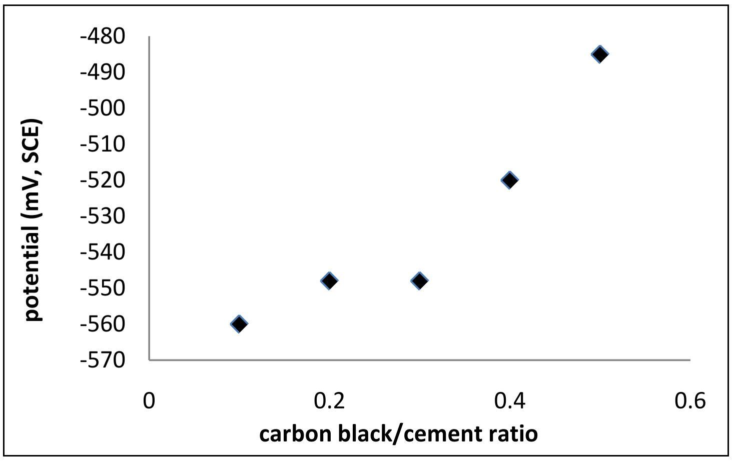

Figure 8. Steel reinforcement potential vs. carbon black content after six months exposure to chloride solution.

Table 2. Chloride permeability for carbon black concrete mixes.

Mix No.	Charge (coul)	Charge range	Cl^- permeability
1	6200	>6200	High
2	3850	3500 - 6000	Moderate
3	2230	2000 - 3500	Low
4	1100	400 - 2000	Very low
5	900	400 - 2000	Very low

4. Conclusions

1) Carbon black addition to concrete mix reduces significantly the permeability of chloride ions.
2) As permeability of chloride ions decreases, corrosion rate also decreases.
3) It is assumed that carbon black addition has a positive effect in carbonation corrosion of steel reinforcement in concrete.
4) Carbon black addition to concrete mix is an easy and cheap method of reducing corrosion of steel in concrete.
5) Permeability of chloride and corrosion rate in concrete decrease with increased carbon black content.
6) Carbon black addition to concrete mix can be used in combination with any other corrosion protection methods; this will enhance protection and reduce cost.

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