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The influence of EAF dust on resistivity of concrete and corrosion of steel bars embedded in concrete

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Abstract. Essentially, when electrical current flows easily in concrete that has large pores filled with highly connective pore water, this is an indication of a low resistivity concrete. In concrete, the flow of current between anodic and cathodic sites on a steel reinforcing bar surface is regulated by the concrete electrical resistance. Therefore, deterioration of any existing reinforced concrete structure due to corrosion of reinforcement steel bar is governed, to some extent, by resistivity of concrete. Resistivity of concrete can be improved by using SCMs and thus increases the concrete electrical resistance and the ability of concrete to resist chloride ingress and/or oxygen penetration resulting in prolonging the onset of corrosion. After depassivation it may slow down the corrosion rate of the steel bar. This indicates the need for further study of the effect of electric arc furnace dust (EAFD) addition on the concrete resistivity. In this study, concrete specimens rather than mortars were cast with different additions of EAFD to verify the electrochemical results obtained and to try to understand the role of EAFD addition in influencing the corrosion behaviour of reinforcing steel bar embedded in concrete and its relation to the resistivity of concrete. The results of these investigations indicated that the corrosion resistance of steel bars embedded in concrete containing EAFD was improved, which may link to the high resistivity found in EAFD-concrete. In this paper, potential measurements, corrosion rates, gravimetric corrosion weight results and resistivity measurements will be presented and their relationships will also be discussed in details.

Keywords: potential measurements; corrosion of reinforcing steel bar; polarization resistance testing; gravimetric corrosion; resistivity of concrete; electric arc furnace dust; SCM

1. Introduction

Deterioration of any existing reinforced concrete structure due to corrosion of reinforcement can be assessed by many tests. Potential measurements, polarization resistance testing and resistivity of concrete measurements are electrochemical methods and all these methods are non-destructive techniques. Essentially, when electrical current flows easily in concrete that has large pores filled with a highly connective pore water this is an indication of a low resistivity concrete (Polder 2000). In concrete, the flow of current between anodic and cathodic sites on steel reinforcing bar surface is regulated by the concrete electrical resistance. Together with potential

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measurements, resistivity of concrete could be used to assess the severity of deterioration of reinforced concrete structures due to the corrosion of the reinforcing bar (Gowers and Millard 1999). In many cases, a higher corrosion rate is likely to be associated with low resistivity concrete rather than with high concrete resistivity (Polder 2000). Resistivity measurements can be easily carried out and performed on the surface of a concrete structure at the site or on concrete samples prepared in the laboratory.

2. Factors affecting resistivity of concrete

There is a wide range in the electrical resistivity values of concrete. It may vary from 101 to 106 Ωm. Electrical resistivity of concrete is a complex property and it was found to vary over a wide range depending on the combination of many factors including moisture content, hydration time, temperature, w/c ratio, carbonation and cement type. Hope *et al*. (1985) carried out experimental work to assess the influence of the moisture content on the resistivity of concrete. In their investigation results indicated that the resistivity of concrete increases with the decrease of moisture content. Also, it was found by Enevoldsen *et al*. (1994), that the electrical resistivity of concrete is dependent on the relative humidity and the concentration of chloride ions in the pore solution. The chloride ion can reduce the resistivity of concrete by increasing the conductivity of the pore solution. Hunkeler (1996) concluded that the moisture content in the concrete influences the resistivity and it is much more important than chloride content in terms of corrosion of reinforcement. Furthermore, addition of chlorides results in a more open structure and this allows easier and faster diffusion rates and increases electrical conductivity (Hansson *et al*. 1985)

The resistivity of concrete is also a function of other parameters and it was found to increase with an increase in time of hydration (Hope *et al*. 1985) and decrease with the increase in temperature (Millard 1991). Water to cement ratio was found to be a factor influencing the resistivity of concrete which was confirmed experimentally by Hope *et al*. (1985). Glass *et al*. (1991) studied the factors that affect the corrosion rate of steel bar embedded in mortar after carbonation. It was revealed that the resistivity of mortars increased after carbonation. This may be due to the action of carbonation in reducing the quantity of ions in pore solution which are responsible for current flow and may also lead to a denser concrete (Polder *et al*. 2000).

Another factor found to have a major effect on the electrical resistivity of concrete is cement type. The use of SCMs in concrete has been found to improve the durability of concrete in many aspects e.g. resistivity of concrete. In research carried out by Hussain and Rasheeduzzafar (1994), who investigated the use of 30% fly ash as cement replacement, it was found that the inclusion of fly ash caused a significant pore refinement, resulting in an increase in electrical resistivity. Also, inclusion of ground granulated blast-furnace slag into concrete caused an increase in the resistivity of concrete to a magnitude of one order compared to plain concrete (Hansson and Hansson 1983). Another investigation of two levels of blast furnace slag (BFS) i.e. 42 and 74% by weight of cement was undertaken by Geiseler *et al*. (1995) on the effect of BFS cements on concrete durability. The replacement of 74% cement by BFS resulted in a pronounced increase in the resistance of the concrete compared to 42% BFS-concrete. A further study conducted by Polder and Peelen (2002) considered two types of blended cements e.g. 75% slag cement and 27% fly ash cement and found that both blended cements increased the concrete resistivity and that slag concrete was the highest throughout an exposure period of 52 weeks. Polder and co-worker (2002) attributed this increase in resistivity of fly ash concrete to a higher density of the pore structure.

Further investigations were carried out by Smith *et al*. (2004) who compared the effect of three different SCMs on the concrete resistivity. These SCMs were 30% fly ash, 35% slag and 3% silica fume as a replacement by weight of cement. The results indicated that replacement of Portland cement by SCMs was very effective in enhancing concrete resistivity. Similar enhancement of concrete resistivity due to incorporation of SCMs such as fly ash and slag was reported by Osterminski *et al*. (2006) who concluded that cement type is the strongest factor influencing the resistivity.

3. Relationship between corrosion rate and resistivity of concrete

Numerous parameters have been found to have an effect on the corrosion rate and many of them are interrelated (Angst 2009). It is likely that the resistivity of concrete is one of the parameters that have a major influence on the corrosion process of steel reinforcing bar embedded in concrete. Resistivity of concrete is considered a physical/electrochemical property of concrete that determines its ability to resist the passage of electrical current. Higher electrical resistivity concrete is more difficult for current to flow through between anodic and cathodic sites, consequently giving lower corrosion rates (Gowers and Millard 1999). This hypothesis was supported by Glass *et al*. (1991) who studied the factors that affect corrosion rate of steel bar embedded in carbonated concrete and found that the corrosion rates in steel bar embedded in carbonated mortar was limited by the resistivity of the mortar.

Resistivity of concrete can be improved by using SCMs and thus increases the ability of concrete to resist chloride ingress and/or oxygen penetration resulting in prolonging the onset of corrosion. After depassivation it may slow down the corrosion rate (Cabrera and Ghoddoussi 1994). This indicates the need for further study of the effect of bag house dust (BHD) (BHD is a local name of EAFD) on the concrete resistivity. Therefore, it was decided to undertake this study with concrete specimens rather than mortars, to try to understand the role of BHD/EAFD in influencing the corrosion behaviour of reinforcing bar embedded in concrete and its relation to the resistivity of concrete.

4. Experimental procedure

4.1 Steel bars and corrosion cell preparation

Twenty four mild steel bars were prepared for electrochemical measurements. Prior to casting, all steel bars were masked as described by Lambert *et al*. (1991). The greatest practical problem that is associated with the type of specimens is the initiation of crevice corrosion at the ends of the steel bar. The avoidance of crevice corrosion in the specimens is very challenging (Page and Treadaway 1982). The working electrode surface area exposed to the corrosive action of the concrete was 11.3 cm^2. Fig. 1 shows a typical steel bar used in corrosion electrochemical measurement.

Twenty four gel bridges were prepared for electrochemical measurements. Electrolyte gel bridges were made and inserted into the mortar/concrete specimens to provide contacts with external reference electrode. The ends of the gel bridges were kept in distilled water to prevent them from drying out before being cast in concrete specimens.

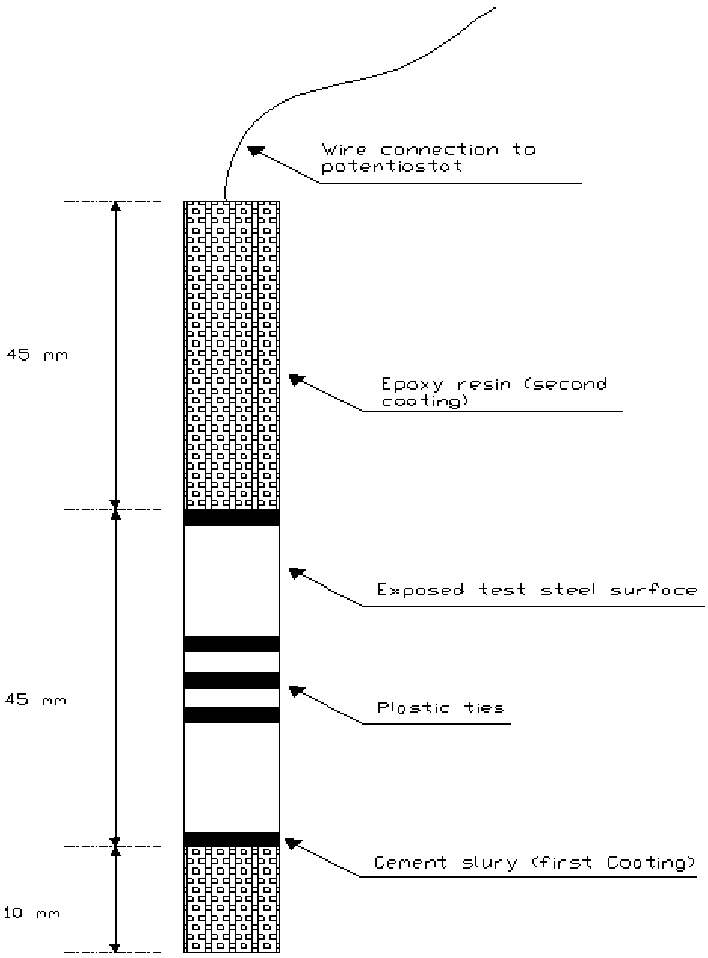

Fig. 1 Steel bar embedded in concrete for electrochemical monitoring

4.2 Preparation of concrete specimens and mix design

The concrete specimens were prepared without BHD (as control specimen) and with two levels of BHD, 2 and 3% by weight of cement. The concrete mixes were made with C:FA:CA ratio of 1:1.5:2.5 by weight of cement. The water to cement ratio was maintained at 0.4 and 0.5. From each mix, duplicate slabs (200 mm × 200 mm × 250 mm) were cast with four stainless steel rods, two smooth steel bars, two gel bridges and two stainless steel meshes in each slab for electrochemical measurements. A 25 mm concrete cover was maintained for the two smooth bars in all concrete specimens. In the same concrete specimen and between the smooth steel bars, the four stainless steel rods were spaced equally at 50 mm apart. After 24-72 hours of casting, the concrete specimens were demoulded. Immediately, the specimens were cured with wet burlap and then covered with a plastic sheet, to minimize the evaporation, at room temperature for seven days. The concrete specimen was designed as recommended by Gowers and Millard (1999). Fig. 2 illustrates the concrete specimens used in this research together with the casting direction.

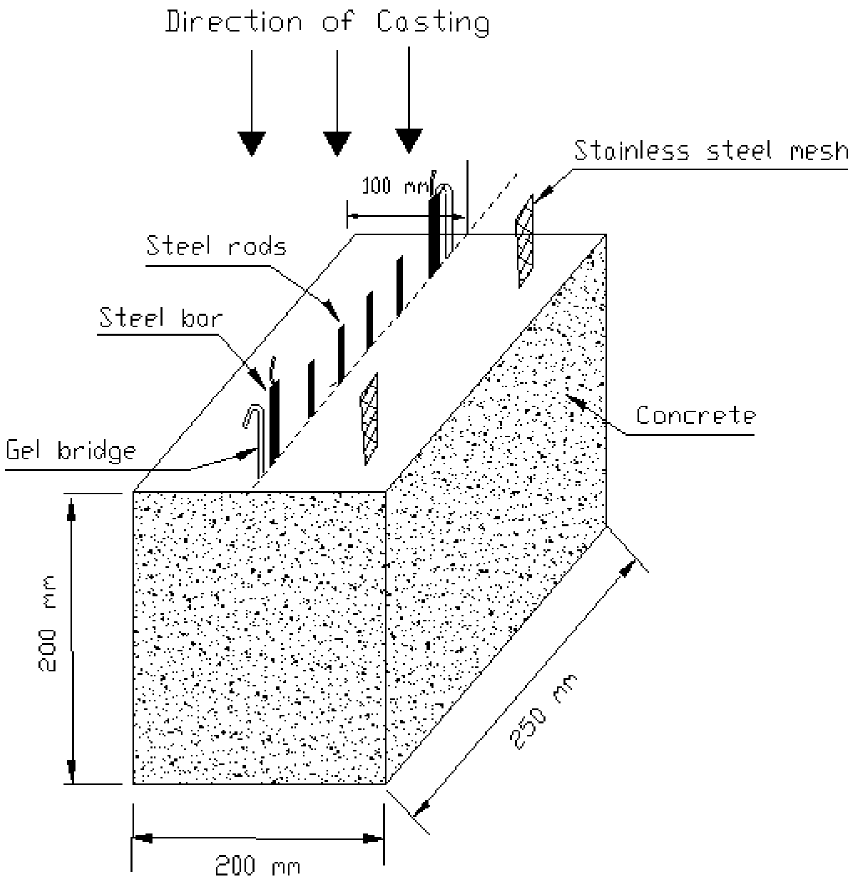

Fig. 2 Sketch of the concrete specimens used for resistivity and electrochemical measurements

4.3 Testing procedure

After curing, the slab specimens were kept at laboratory conditions for a period of 8 weeks (stage I) to achieve the maximum level of hydration since BHD is registered as a retarder (Al-Zaid *et al*. 1999). During this stage, the concrete resistivity and electrochemical measurements were performed to study the effect of BHD addition on the resistivity of concrete and its development at early ages. After the "stage I" testing period, "stage II" then started by subjecting the specimens to wet-dry cycles. The second stage of this test studied the relationship between the resistivity of concrete and the corrosion rates in the presence of different levels of BHD. The concrete specimens were immersed in 3.5 M NaCl solution for 2 days. After that, the concrete specimens were, removed from the solution and allowed to dry out at room temperature for 5 days. On the fifth day of each drying period, the corrosion rate and the resistivity of the concrete were measured to complete one cycle. This testing regime was repeated during the "stage II" period, from week 9 to the end of the experiment i.e. week 22.

Instantaneous corrosion rate measurements were carried out using the DC Linear Polarization Resistance (LPR) method. The Wenner technique was utilized in this study to measure the resistivity of concrete as described by Gowers and Millard (1999). An AC power supply was utilized to obtain the concrete resistivity. Approximately 0.2 mA ac current (at a frequency of 100 Hz) was passed between the two outer rods. The potential difference between the inner rods was measured using a high impedance Voltmeter. From the applied current and the resulting potential difference, the concrete resistivity was obtained using the following equation:

$$\rho = \frac{2\,\pi\, a\, V}{I} \tag{1}$$

Where, ρ is the resistivity of the concrete (ohms.cm), a is the rod spacing (cm), V is the measured potential difference (volts) between the inner rods and I is the applied current (amps).

5. Results analysis and discussion

5.1 Concrete resistivity data

Originally, the Wenner technique was developed and used to measure soil resistivity. In 1968, this technique was used in concrete to measure resistivity by Stratfull (1968). The influence of BHD additions on the resistivity of concrete prepared with 0.4 and 0.5 w/c ratio is presented in Fig. 3 and Fig. 4. The labelling system in all figures is as follows; for instance the "─■─2BHD0.4" curve presents the average resistivity measurements obtained from concrete specimens containing 2% BHD and prepared at 0.4 w/c ratio. The resistivity measurements were carried out during two different stages, as described above in Section 4.6. In each specimen the resistivity measurement was repeated three times. Each resistivity point on the graph is an averaged value from two specimens.

During "stage I", the resistivity measurements conducted on plain and BHD-concretes prepared at w/c ratio of 0.4 show a significant increase in the resistivity values during the first 8 weeks, as illustrated in Fig. 3. This was expected, since the concrete specimens were cured under laboratory conditions and this large increase in the resistivity could be attributed to the loss of water from concrete specimens with time. As concrete dries out the conductivity will be reduced progressively, resulting in a higher resistance to electrical current flow through the concrete and consequently, higher resistivity values. For 0.5 w/c ratio-concretes a similar trend in resistivity values was observed in stage I, as shown in Fig. 4, except that a considerable increase in resistivity values was noticed in 3% BHD-concrete during only the first 8 weeks where such behaviour was unexpected. This implies that there is a quick loss of water from the concrete pores leading to a very low moisture content, resulting in high resistivity values.

The main aim of exposing concrete specimens to wet/dry cycles (stage II) was to simulate the concrete structures located in marine environments. Therefore, stage II is more relevant to real conditions. After the first cycle of NaCl exposure, a major drop in resistivity values in plain and BHD-concrete was observed in specimens prepared at w/c ratio of 0.4 and 0.5. As discussed in section 2, one of the main factors affecting resistivity of concrete is moisture content and this drop is mainly due to high moisture content in the pore structure. Furthermore, immersion of concrete specimens in NaCl solution will increase the chloride ion concentration, leading to an increase in the electrical conductivity of the pore solution consequently, reducing the resistivity of concrete (Polder 2009) (Angst 2011). After week 8 and at the end of the experiment, i.e. week 22, the

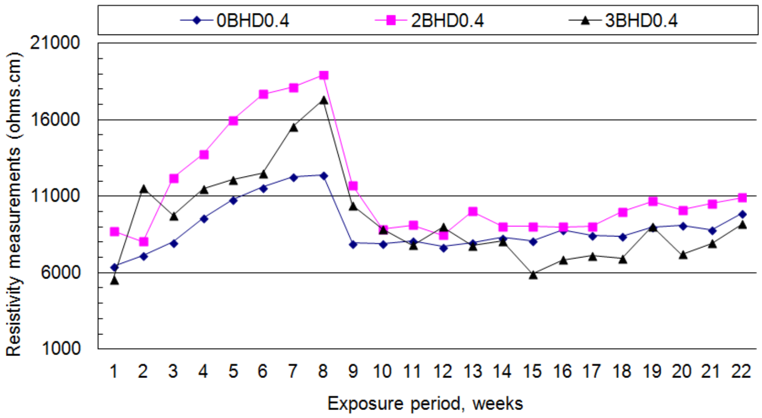

Fig. 3 Resistivity measurements of concrete specimens containing 0, 2 and 3% BHD addition and prepared at w/c ratio of 0.4

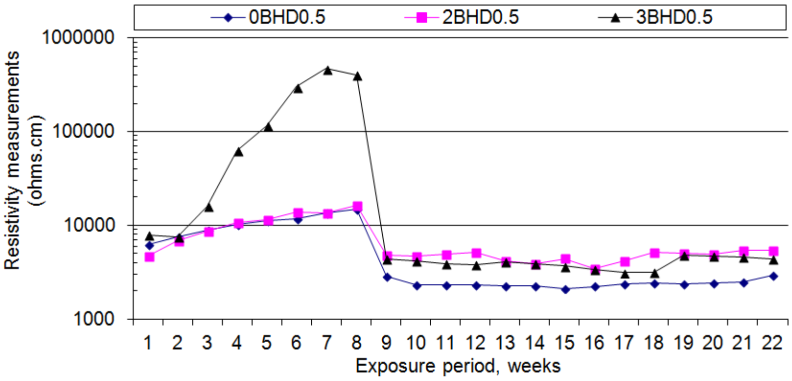

Fig. 4 Resistivity measurements of concrete specimens containing 0, 2 and 3% BHD addition and prepared at w/c ratio of 0.5

resistivity values obtained from all 0.4 w/c ratio concrete specimens varied between 6000 and 11000 Ω.cm. For 0.5 w/c ratio concretes, the corresponding resistivity measurements were between 2114 and 5400 Ω.cm.

Incorporation of 2% BHD resulted in slightly higher resistivity values when compared to plain concrete, while the resistivity values measured on 3% BHD-concrete fluctuated widely and so no conclusion could be drawn from concrete prepared with a w/c ratio of 0.4. The influence of BHD addition on concrete, which was prepared with 0.5 w/c ratio, was clearer when 2 and 3% BHD were incorporated into the material, indicating the effectiveness of BHD addition in improving the resistivity of concrete, as shown in Fig.4.

A study carried out by Al Mutlaq and Page (2011) reveals that the addition of more BHD material, 2 and 3% BHD, resulted in less workable concrete, and this reduction in the resistivity may be related to the low consistence found in BHD-concrete. Consequently, a more dense concrete structure leads to an increase in concrete resistivity. In addition to the above, the addition of BHD material into concrete may lead to improvement in the physical properties e.g. pore refinement, to a certain extent hindering the current flow through concrete media.

5.2 Electrochemical measurements data

5.2.1 Corrosion current density measurements

The DC linear polarization resistance method was used to monitor the corrosion current density. The results of I_{corr} measurements on steel embedded in control (0% BHD) and BHD-concretes contaminated with different levels of BHD are plotted against the period of exposure in Fig. 5 through Fig. 6. All the points on the graphs represent an average value of four measurements.

During "stage I" of exposure (week 1 → 8), the corrosion rates in control and BHD-concretes, which were prepared with 0.4 w/c ratio, decreased gradually as exposure time increased and they were less than the I_{corr} threshold value, which was assumed in this investigation to be 0.2 μA/cm^2. According to Andrade *et al*. (1990), the steel bar that has an I_{corr} value of 0.2 μA/cm^2 and above is assumed to be in the active state of corrosion and the steel bar that has an I_{corr} value of 0.1 μA/cm^2 and lower is assumed to be in the passive state. It can be observed during the first two weeks, that the Icorr values of steel bar embedded in 3% BHD-concrete dropped from a high value (e.g. ≈ Icorr = 0.15) to a lower value of 0.05 μA/cm^2, which suggests repassivation of the metal.

Exposing concrete specimens to NaCl solution (stage II) caused a substantial increase in the Icorr values on all steel bars embedded in control and BHD-concretes. This increase in Icorr values is due to the supply of chloride ions, oxygen and water. Furthermore, the availability of chloride ions will increase the conductivity of pore solution, resulting in a higher corrosion rate (Hansson *et al*. 1985). After week 10, the steel bar embedded in the plain concrete exhibited higher I_{corr} values than the BHD-specimens (more than 1 μA/cm^2) and remained in the active corrosion region to the end of the experiment, i.e. week 22.

Incorporation of 2 and 3% BHD reduced corrosion current densities much more than in control specimens as illustrated in Fig. 5. The corrosion rates, between week 10 and 12, on steel bars embedded in 2% BHD-concrete were much higher than 0.2 μA/cm^2 but after week 12, Icorr values started to decrease gradually, indicating a tendency to repassivation. Furthermore, the steel bars achieved I_{corr} values lower than 0.2 μA/cm^2 at week 15 and remained more or less stable until week 22. This indicates the steel bars were in a region between the passive and the active state of corrosion during this period. From Fig. 5, it can also be seen that the behaviour of steel bar embedded in 3% BHD-concrete was not stable, showing high variation in I_{corr} values from week 12 until week 22, where a similar trend of variation in resistivity measurements was observed in the same specimen, as shown in Fig. 3.

Fig. 6 illustrates the evolution of corrosion current densities (I_{corr}) on steel bars embedded in concrete specimens contaminated with and without 2 and 3 % BHD and prepared with w/c ratio of 0.5. The I_{corr} values on steel bars embedded in plain and 2% BHD-concrete were less than the current density threshold value from the beginning of the experiment to the start of wet/dry cycles "stage II". Border-line I_{corr} values were observed on steel bars embedded in 3% BHD-concrete for the first four weeks followed by a drop in I_{corr} values at week 5 and then a gradual decrease until week 8. Again, in "stage II" a sudden increase was seen in Icorr values for all steel bars embedded in plain and 2 and 3% BHD-concretes. All the steel bars were in active states of corrosion, I_{corr} more than 0.2 μA/cm^2. No significant difference was noticed between I_{corr} values in steel bars embedded in plain and 2% BHD-concrete. On the other hand, addition of 3% of BHD evidently depressed I_{corr} values to less than that in the plain specimens and 2% BHD-concrete during the whole period of stage II.

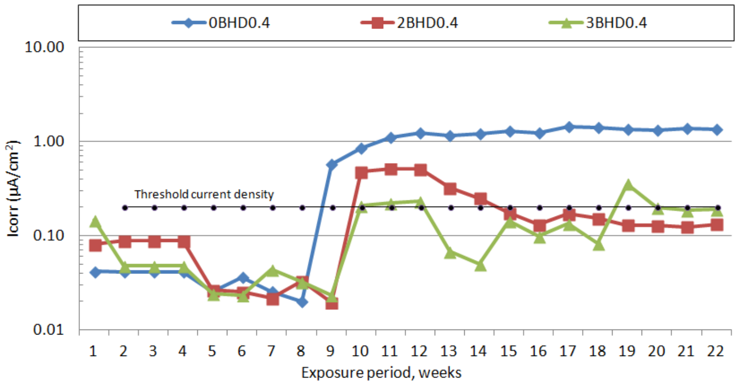

Fig. 5 Corrosion current density on steel bars embedded in concrete containing 0, 2 and 3% BHD and prepared at w/c ratio of 0.4

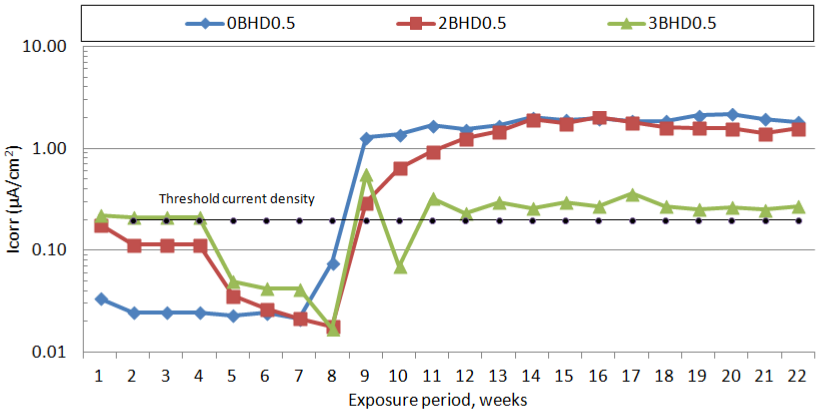

Fig. 6 Corrosion current density on steel bars embedded in concrete containing 0, 2 and 3% BHD and prepared at w/c ratio of 0.5

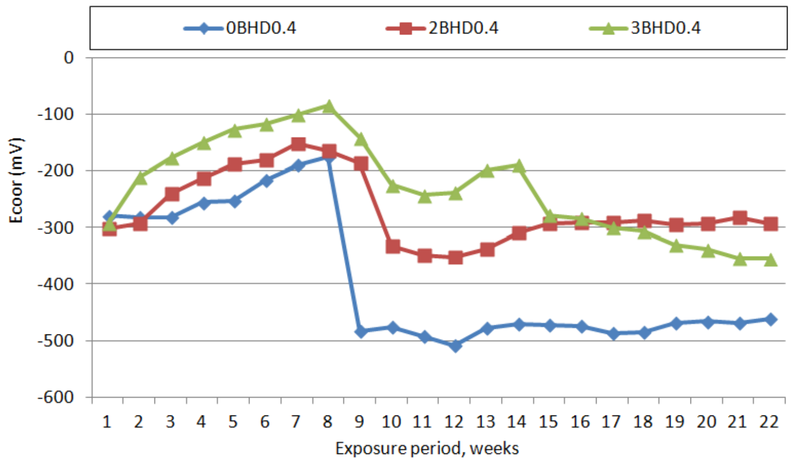

Fig. 7 Corrosion potentials on steel bars embedded in concrete containing 0, 2 and 3% BHD and prepared at w/c ratio of 0.4

5.2.2 Corrosion potential measurements

The corrosion potential (E_{corr}) values measured on steel bars embedded in plain concrete and concrete specimens that incorporated 2 and 3% BHD and prepared at w/c ratio of 0.4 and 0.5 are presented in Fig. 7 and Fig. 8, respectively. They show a gradual movement towards less negative E_{corr} values on steel bars embedded in plain and BHD-concretes that were prepared at 0.4 and 0.5 w/c ratio during “stage I”. Similar behaviour was found to that shown by I_{corr} values observed during the first week of exposure to NaCl solution. The corrosion potentials, during “stage II”, on steel bars embedded in 2 and 3% BHD-concrete, which were prepared at both w/c ratios, were less negative values compared to those of steel embedded in plain cement concrete.

The effect of BHD addition on the corrosion potentials is more pronounced in 3% BHD concrete prepared at w/c ratio of 0.4, as shown in Fig. 7. The most negative corrosion potentials were observed on steel bars embedded in plain concrete, which varied between -509 and -461 mV for 0.4 w/c ratio concrete and between -548 and -561 mV for 0.5 w/c ratio concrete. Less negative potentials compared to plain concrete were also reported by Al-Sugair *et al*. (1996) when 2 and 3% BHD replaced cement.

An extensive field study was carried out by Chaudhary *et al*. (2003) to investigate the effect of the addition of 2% BHD by weight of cement on the corrosion process of steel reinforcing bar embedded in concrete. In their study, a total of 6 slabs were cast and exposed for 12 months to an aggressive industrial environment. 3 slabs contained 2% BHD and 3 slabs were without BHD as controls. Their findings indicated that there was no significant difference in the corrosion behaviour between reinforcing bars embedded in slabs without BHD and those embedded in 2% BHD-slabs.

The reduction in corrosion potentials was attributed to refinement in the pore structure and/or the presence of ZnO. Troconis de Rincón *et al*. (2002) and Saraswathy and Song (2007) investigated the performance of ZnO as a corrosion inhibitor and found an appreciable change in corrosion rates. They attributed this change to the formation of ($Ca(Zn(OH)_3)_2 . 2H_2O$) which helped in reducing the porosity. Maslehuddin *et al*. (2011) studied the effect of 2% BHD replacement of cement on properties of OPC and blended cement concrete. The results revealed

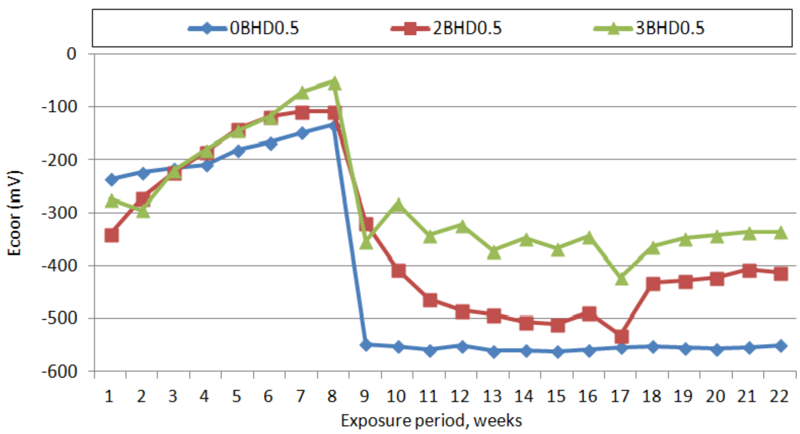

Fig. 8 Corrosion potentials on steel bars embedded in concrete containing 0, 2 and 3% BHD and prepared at w/c ratio of 0.5

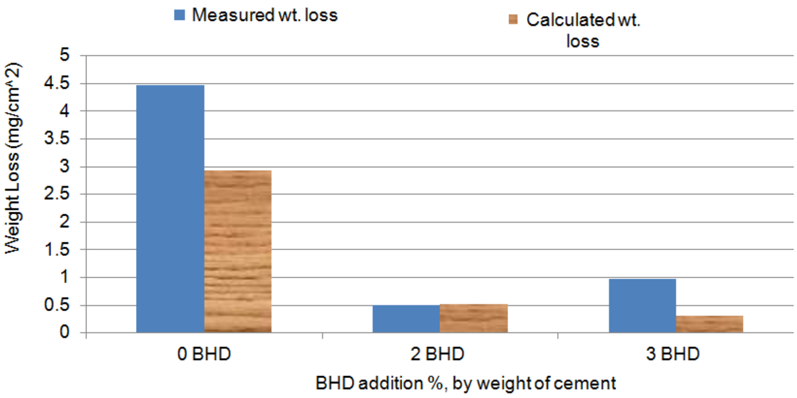

Fig. 9 Calculated and gravimetric weight losses obtained from steel bars embedded in concrete contaminated with BHD addition and prepared with w/c ratio of 0.4

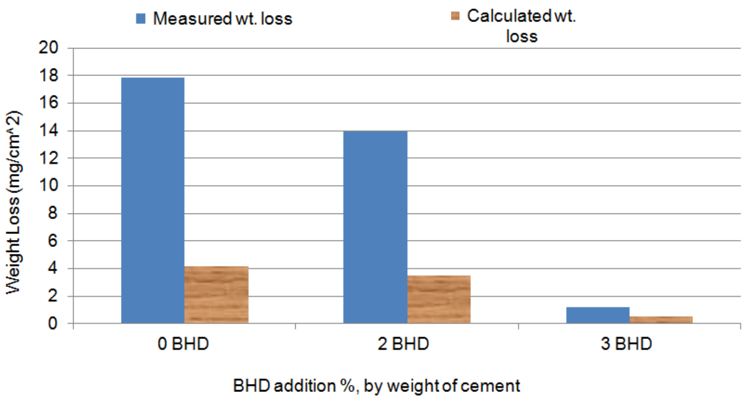

Fig. 10 Calculated and gravimetric weight losses obtained from steel bars embedded in concrete contaminated with BHD addition and prepared with w/c ratio of 0.5

that the addition of BHD reduces the corrosion potentials compared to control concrete and Maslehuddin and co-workers attributed this to densification of the cement matrix.

It was observed by Lopez and Gonzalez (1993) that there is an inverse relationship between the corrosion of reinforcement and the resistivity of concrete. After corrosion initiation, many researchers linked the corrosion process in the concrete to the resistivity of concrete and they observed that the corrosion rate has been affected by concrete resistivity (Enevoldsen *et al*. 1994, Hansson *et al*. 1985, Lopez and Gonzalez 1993). As discussed previously in section 0, the addition of 2 and 3% BHD by weight of cement improved the resistivity of concrete. Therefore, the reduction in corrosion rates and potentials measured in the BHD concrete could be attributed to the improvement in the resistivity of concrete due to the incorporation of BHD.

5.2.3 Gravimetric corrosion analysis

The corrosion weight losses per unit area (mg/cm^2) were measured. Figs. 9 and Fig. 10 illustrate the equivalent weight loss calculated from I_{corr} values together with weight loss measurements obtained from the same steel bars used for electrochemical measurements. Each column represents an average value of weight losses obtained from four steel bars.

The weight losses in steel bars embedded in 2 and 3% BHD-concrete, prepared at 0.4 w/c ratio, were found to be lower than those in control specimens, indicating less corrosion activity when BHD is incorporated into concrete, as shown in Fig. 9. The trend of these results is in agreement with both the measured corrosion potentials and corrosion rates, where the Ecorr and Icorr values were found to be lower in BHD-concretes compared to control specimens, as shown in Fig. 7 and Fig. 10, respectively. For those concretes prepared with w/c ratio of 0.5, there were no significant differences in weight loss between steel bars embedded in plain concrete and those bars embedded in 2% BHD-concrete. The addition of 3% BHD into concrete depressed the corrosion activity in the reinforcing bar when compared to plain concrete, which was confirmed by gravimetric analysis obtained from corresponding steel bars shown in Fig. 10.

6. Conclusions

This study conducted an experimental investigation in order to understand the role of BHD/EAFD in influencing the corrosion behaviour of reinforcing bar embedded in concrete and its relation to the resistivity of concrete. The main findings of the research described in this paper (drawn mainly from "stage II" since it is virtually simulating the real marine conditions), which apply to the specific mix materials and laboratory conditions that were used, are listed here.

(a) Incorporation of 2% BHD resulted in slightly higher resistivity values when compared to plain concrete. No conclusion could be drawn from 3% BHD-concrete prepared with a w/c ratio of 0.4 due to fluctuation in the resistivity results.

(b) In case of samples prepared with a w/c ratio of 0.5, clear improvement in the resistivity of concrete specimens when 2 and 3% BHD were incorporated in the mix.

(c) The addition of BHD i.e. 2 and 3 % prepared at 0.4 w/c ratio and 3% prepared at 0.5 w/c ratio depressed the Icorr values to less than that in the plain specimens. Exceptionally, there was no significant difference noticed between Icorr values in steel bars embedded in plain and 2% BHD-concrete.

(d) The corrosion potentials of steel bar embedded in 2 and 3% BHD-concrete, which were prepared at both w/c ratios, were less negative i.e. exhibited less corrosion activity compared to that of steel embedded in plain cement concrete.

(e) The higher w/c ratio specimens exhibited more negative corrosion potentials and when attributed to high porous concrete allow easy passage of corrosion agents.

(f) Concrete moisture content is found to be a major factor influencing the resistivity of concrete.

(g) The corrosion activities of embedded bars were validated by measuring the corresponding gravimetric weight loss. The trend of the electrochemical results is in agreement with the corresponding gravimetric weight loss.

(h) Considering all the above, the corrosion resistance of the steel bars embedded in concrete was improved slightly. Such improvement was attributed to the high levels in concrete resistivity due to the incorporation of BHD. This implies that the addition of BHD probably improves the refinement of the pore structure.

Acknowledgement

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