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Effects of DC Stray Current on Concrete Structure

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ABSTRACT

Effects of DC stray current on concrete structures were studied concentrating on effect of concrete, instead of effects on corrosion of steel bars. Concrete samples prepared with different water/cement (w/c) ratio and silica fume content were submerged in distilled water for 30 days while subjected to the application of a voltage of 50 VDC. The effects DC stray current on the properties of concrete were determined by resistivity, Electrochemical Impedance Spectroscopy, chloride diffusion depth and Rapid Chloride Penetration tests. The results showed DC stray current increased permeability of the concrete. The critical role of w/c ratio and silica fume additive on the degradation effects created by DC stray current was investigated. A mechanism based on the migration of calcium and hydroxyl ions out of the pore solution and the dissolution of $Ca(OH)_2$ precipitates from the hydrated phase was proposed for the explanation of DC potential on the degradation of concrete.

KEYWORDS:

Stray Current, Concrete, Permeability

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1- Brief Introduction And Contribution

It is well known that severe corrosion problems may be encountered in concrete structures which are exposed to electrical fields induced by DC stray current. The studies conducted on the role of DC electrical field on concrete structures can be grouped under two headings:

1- Studies related to effects of DC stray current on the corrosion of the embedded steel reinforcing bars (rebar) [1].

2- Studies related to the effects of electrochemical chloride removal (ECR) parameters on pores sizes of the concrete and chloride migration [2,3]. In most of these studies, the EIS test method was employed to study microstructural changes of concrete due to ions migration.

Studies available in the literature are mainly concentrated on the protection of rebar from corrosion. However since the concrete itself acts as an electrolyte to allow the flow of the DC current, there is a high probability of promotion of the chemical reactions (in the pore solution as well as in the solid phases, e.g. alkali silica reaction) that would eventually affect the microstructure and permeability of the concrete. In spite of this, there are no studies in the literature specifically devoted to the investigation of the effect of DC stray current or DC electric field on the concrete structure free from chlorides.

This research it is aimed at studying the role of DC stray current on concrete samples in chloride-free environment, concentrating on its effects on the concrete microstructure. Concrete samples with different initial permeability were produced by varying w/c ratio and silica fume content and the effect of DC stray current on the permeability and microstructure was investigated by using electrical resistivity, chloride depth evaluation, Rapid Chloride Penetration (RCP). Furthermore, EIS tests were mainly utilized for the explanation of microstructural changes induced by the application of DC current through the concrete.

2- Methodology

Different concrete mix designs were used for the production of the concrete specimens. After curing, and before applying DC stray current, resistivity, electrochemical impedance spectroscopy (EIS), and rapid chloride penetration (RCP) tests were carried out on one of the sample of each mix design. The other concrete samples were assembled in the cell and subjected to the application of a voltage of 50 VDC for 30 days (Fig 1). After 30 days the DC potential was interrupted and resistivity, EIS and RCP test were performed on the water-saturated concrete samples. After RCP tests, the concrete samples were cut along a axes and the chloride penetration depth was determined. Then the test results obtained before and after applying 50 VDC were compared to each other.

According to the results, application of 50 VDC potential resulted in a decrease of resistivity of the concrete samples. This effect is most prominent in the sample with high w/c ratio, whilst adding silica fume and reducing w/c ratio in the concrete mix design, increased the stability or resistance of the samples against 50VDC stray current.

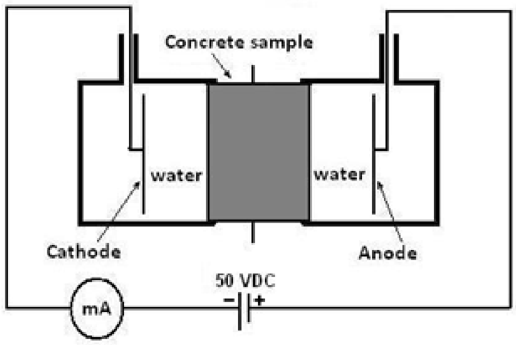

Figure 1. Applying 50 VDC in water environment on concrete sample for 30 days

DC potential exerts its main effect on the pore solution since it is the most conductive path in the concrete. Positive and negative charged ions within the pore solution move toward cathode and anode respectively. Therefore it could be supposed that during application of 50 VDC the migration of Ca^{+2}, Na^+, K^+ and OH^- out of the pores solution is cause for the dissolution of Portlandite and hydrated phase which will eventually leads to increasing pores size and creating new pores interconnections. Results of the test conducted with varying w/c ratio and addition of silica fume further supports the above proposed mechanism.

With reducing w/c ratio more calcium compounds appear in C-S-H [4] and therefore in samples with higher w/c ratio, the amount of $Ca(OH)_2$ in the hydrated phase is higher and, they are the ones that are most negatively affected by the application of DC potential. In these samples the dissolution of calcium hydroxides from the hydrated phase may result in the decreasing the wall thickness of hydrated phase surrounding the pores that will lead to an increase of the total pore volume of the concrete. Additives that result in a decrease in the amount of $Ca(OH)_2$ within the hydrated phase exerted a positive role against the destructive effects of DC potential. It is well known that silica fume (SF), due to the pozzolanic reaction, reduces the amount of free $Ca(OH)_2$ and also increases the volume of hydrated phase by reacting with $Ca(OH)_2$. Thus the positive role of SF additions against the effects of DC potential can also be explained by the decrease of the amount of reactive Ca(OH)2 as a result of its reaction with SF.

The changes observed in the EIS spectra can be attributed to an increase in the volume of pores, e.g. due to the increase in the volume of existing pores and/or formation of new pore networks. According to table 1, RC (total resistance of solid and liquid phases of concrete) after application 50 VDC decreased. A second indication for the increasing the volume of pores of the concrete after the application of DC potential is the change in the chloride diffusion coefficients. The increase in the value of these coefficients is directly related to the increase of porosity (volume of pores) in the concrete [5].

Table 1. RC before and after applying 50 VDC stray current

Before applying 50 VDC stray current					
Sample	1	2	3	4	5
RC (Ohms)	1681	1198	795	1330	1810
After applying 50 VDC stray current					
Sample	1	2	3	4	5
RC (Ohms)	1627	1056	590	1308	1805

3- Conclusion

According to the results of this study, exposure condition and DC stray current flowing through concrete for a long time in a chloride free environment have an accelerated leaching effect on Portlandite and increase pore size and create new pore network in concrete. They resulted in a decrease in the electrical resistivity and an increase in the permeability of concrete. In samples with a more porous concrete (high w/c ratio) these effects were more prominent. In samples with addition of silica fume that lower the calcium hydroxide content within the hydration products and increase the amount of C-S-H hydrated phase, the effects of DC current were negligible. A mechanism based on the inducing effect of DC potential on the dissolution of calcium hydroxide from the hydrated phase has been proposed for the explanation of the experimental observations.

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