

### Corrosion performance of reinforcing steel in modified concrete mixtures

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This work presents electrochemical monitoring and corrosion/hydration products investigation in reinforced concrete, modified with blended cement and waste products. The studied modified mixtures were concrete, using Blast Furnace Slag (BFS) cement and the waste Red mud as 20% replacement of Ordinary Portland cement (OPC). Red mud was previously investigated in reinforced mortar, showing very positive results in terms of delay of corrosion initiation in aggressive 10% NaCl at least 4 times, compared to the control, non-modified specimens. The main objectives of this work is to compare corrosion performance of the steel bars in the three investigated mixtures (two modified, compared to one control) and to prove the previously recorded, preliminary findings for the effect of red mud on corrosion initiation in cement-based materials.



Fig.1 The reinforced concrete specimens (red mud and BFS containing mixtures) after casting (before de-moulding).

**Materials and experimental methods:** The steel reinforcement (construction steel FeB500 HWL,  $d=12\text{mm}$ ,  $h=200\text{mm}$ ) was cast "as received" in concrete cylinders ( $d=700\text{mm}$ ,  $h=200\text{mm}$ ); casting was according EN 196-1, water-to-cement ratio 0.6 (effective 0.5). Three groups of specimens were prepared: 1) using OPC CEM I 42.5 as control group; 2) using BFS cement CEM III 42.5 and group 3) using red mud as 20% replacement of OPC CEM I. Group 1) is denoted OPC, group 2) is denoted BFS and group 3) is denoted RM. Each group has sub-groups of corroding (immersed in 5% NaCl specimens and reference (non-corroding specimens). Additionally, concrete cubes of  $100\times 100\times 100$  were cast from each mixture for standard compressive strength tests. All groups were cured for 28 days in fog room ( $20^\circ\text{C}$  and 98% humidity) and then placed in lab conditions: lab air,  $22^\circ\text{C}$  and  $1/3^{\text{rd}}$  of height immersed in water or 5% NaCl, 18 replicates per group and condition are monitored. The experimental methods involved are electrochemical (EIS, PDP) and surface analysis techniques (mainly ESEM, EDX)

**Results:** This is an on-going investigation (started Jan 2009), therefore the monitoring is still in progress. Figures 2 to 4 present the OCP mapping for all cells of the three groups of specimens (OPC, BFS and RM). As seen from the plots, there is a scatter within one group, since chloride-induced corrosion is a localized attack on the steel surface, and initiating and propagating period strongly depend on the bulk matrix microstructure. To this end, in an interval of 1 to 2,3 months, such a scatter is normal and as expected. At this point (April 2009), some cells in group OPC show already active behavior (Fig.2), whereas groups BFS and RM fall still in the passive region (OCP readings mostly below  $-270$

mV SCE). The reference (non-corroding cells) exhibit potentials from  $-160$  mV in Feb'09 to  $-80$  mV in Apr.'09.

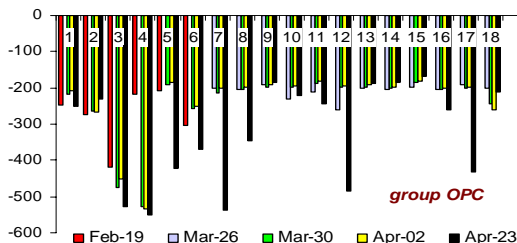


Fig. 2 Open circuit potentials (5% NaCl, 20C), group OPC

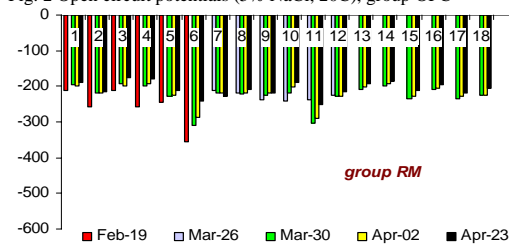


Fig. 3 Open circuit potentials (5% NaCl, 20C), group BFS

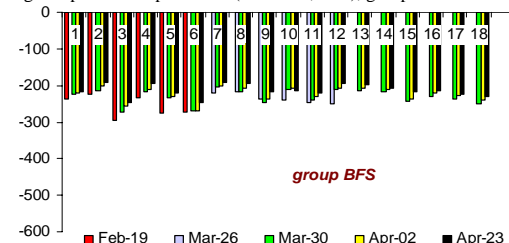


Fig. 4 Open circuit potentials (5% NaCl, 20C), group RM

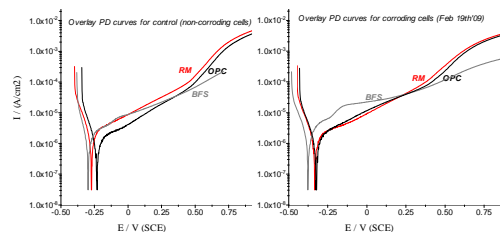


Fig.5 Potentiodynamic curves for control specimens (left) and corroding specimens (right), March '09

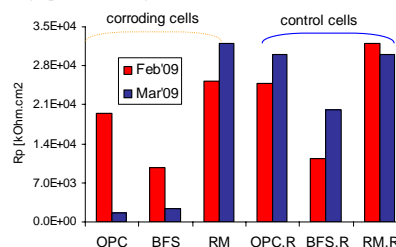


Fig.6 Comparison  $R_p$  [ $\text{k}\Omega\cdot\text{cm}^2$ ] for all cells

As seen from the OCP mapping and the PD curves (Fig.5), in the beginning of the test there is no significant difference in the electrochemical behavior of the steel bars for the different mixtures. Corrosion initiates first and relatively faster in the OCP group after approximately 60 days of immersion in 5%NaCl. Some of the cells from group BFS exhibit active behavior as well, while the corroding group RM behaves as control specimens, as evidenced by the derived polarization resistance values, depicted in Fig. 6. Obviously, Red mud causes delay in corrosion initiation (as previously recorded for mortar specimens). Further, the paper will present morphological and microstructural observations in the three investigated mixtures.