Electrochemical impedance and potentio-dynamic polarization of construction steel in cement extract, containing red mud and chloride contamination

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This work presents a preliminary study on the corrosion behavior of construction steel in cement-based materials, containing waste products, namely “red mud”, as partial replacement of the cement portion in the mixtures. The paper reports on the initial electrochemical tests in model solutions of cement extract (CEm), cement extract + 20% red mud (CEmRM) and chloride contaminated (adding 5% NaCl) solutions (CEmN and CEmRMN), thus aiming to study the behavior of the steel electrodes in such media, prior to the tests in mortar and concrete.

“Red mud” is the waste, generated during aluminum production from bauxite. It is reported that the annual production of 1 tone of metallic aluminum generates about 2 tones of red mud. Consequently, research on ways of making use of this residue is of significant importance. Moreover, in addition to the economic and ecological advantages, the use of “red mud” will not create new residues.

Materials: Steel electrodes (construction steel FeB500HWL) of 4cm² exposed surface were immersed in the above described solutions and monitored at different intervals. The solutions were prepared as follows: *cement extract* (CEm) by mixing water and Portland cement (OPC CEM 32.5), ratio 1:1, stirring for 24h and filtration; *cement extract+red mud* (CEmRM): CEm + 20% replacement of the cement portion with dry powder (105°C) of red mud; *chloride containing solutions*: by adding 5% NaCl to the already filtrated CEm and CEmRM. The red mud compositions, determined by XRF and the cement composition are given in Table 1.

Table 1 Red mud and OPC composition

Red mud (XRF)			OPC CEMI 32.5	
Z	wt.%	StdErr	StdComp.	Wt.%
Na ₂ O	14.25	0.39	Na ₂ O	0.24
MgO	0.124	0.014	MgO	2.00
Al ₂ O ₃	29.10	0.30	Al ₂ O ₃	5.03
SiO ₂	20.24	0.45	SiO ₂	21.00
P ₂ O ₅	0.155	0.003	P ₂ O ₅	0.16
SO ₃	0.525	0.058	SO ₃	3.00
Cl	0.142	0.016	Mn ₂ O ₃	0.06
K ₂ O	0.118	0.013	K ₂ O	0.65
CaO	3.54	0.21	CaO	63.90
TiO ₂	6.22	0.27	TiO ₂	0.30
Fe ₂ O ₃	24.85	0.48	Fe ₂ O ₃	2.83

Experimental methods:

Electrochem. impedance (EIS) and potentiodynamic polarization (PDP); SEM and EDX before and after immersion for defining morphology and composition of the product layers on the steel surface.

Results: hereby presented

are the recorded responses from PDP and EIS after 45 min, 3 days and 11 days of immersion (the latter only for chloride containing solutions).

The pH of all solutions is in the range of 12.9 to 13.2, therefore passivity of the steel surface is expected in CEm and CEmRM and localized corrosion in the chloride containing solutions CEmN and CEmRMN. Fig.1 presents the PDP curves in CEm and CEmRM (left) and the chloride containing solutions (right) after 45 min (i.e. after OCP stabilization). Although similar behavior is observed, the corrosion current density and anodic current for the steel surface in solutions containing red mud is lower, compared to cement extract only. In chloride containing solutions after 45 min immersion the behavior in both solutions is similar. Further, the above described electrochemical behavior

maintains similar trends for longer immersion time. The corrosion behavior of the steel electrodes after 11 days of immersion in the Cl-containing solutions already differs significantly, exhibiting much higher current densities for CEmN and significantly better corrosion resistance in the CEmRMN solution, containing red mud (Fig.2 right). EIS measurements support the PDP tests (Fig.3). The Rp values, derived from PDP tests are given in Table 2.

Table 2 Rp values after 45 min, 3 and 11 days

Electrolyte medium/conditioning		Rp [Ohm.cm²]		
Days of immersion		45 min	3 days	11 days
Chloride free solutions				
Cem.extract		92.60	11.17	
Cem.extract+red mud		172.76	16.69	
5% NaCl containing solutions				
Cem.extract+5% NaCl		9.07	1.88	0.36
Cem.extract+red mud+5% NaCl		7.83	10.36	26.58

^aalter OCP stabilisation

Morphology and composition of the product layers on the steel surface was investigated by SEM and EDX (only morphology presented here). Fig.4 presents the “as received” steel surface (a); steel surface after 11 days immersion in CEm (b) and CEmRM (c); steel surface after 11 days immersion in the chloride containing solutions of CEmN (d) and CEmRMN (e). Fig.4b visualizes the typical morphology of a product layer, formed in cement extract (e.g. well crystallized ettringite); Fig.4c depicts the adhered red mud particles. Fig. 4d reveals the significant amount of corrosion damage after 11 days immersion in CEmN (5% NaCl), while for the specimens, immersed in the same solution, but with red mud addition (CEmRMN), the corrosion damage and deposited amounts of corrosion products are significantly lower.

In conclusion, the preliminary tests on the electrochemical behavior of construction steel in chloride free and chloride containing cement extract with and without “red mud” additions show the positive influence of red mud in terms of increased corrosion resistance. This positive effect of red mud addition to cement extract, especially in the presence of chlorides, is most likely denoted to the adherence of the red mud particles on the steel surface, their further recrystallization with potential cycling and thus hindering the steel dissolution. Consequently, “red mud” addition to reinforced mortar (concrete) will most likely lead to increased corrosion resistance of the embedded steel, especially in chloride containing environment.