

Mortar resistivity as a parameter for monitoring steel corrosion in alkali-activated materials

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Abstract. The development of novel binders with a longer service life than ordinary Portland cement (OPC) is a cost-effective and environmentally friendly option. Alkali-activated material (AAM), one of the available alternative binders, offers a lot of potential for development and is widely regarded as a viable alternative to OPC due to its low carbon emissions and promising performance. However, existing understanding is insufficient to assure long-term reliability due to discrepancies in the reaction processes of AAM and OPC, as well as a wide range of unique AAM compositions. In this study, the long-term corrosion behaviour of reinforcing steel embedded in three different alkali-activated mortars was monitored in chloride rich environments throughout the test period. The half-cell potential and corrosion rate were determined by linear polarisation (LP) and the individual resistance of the mortar was determined by electrochemical impedance spectroscopy (EIS). The objective of this study is to determine an indirect method for evaluating the corrosion conditions of steel embedded in AAM. The mortar resistance (R_{mortar}), determined by fitting the EIS data, can roughly determine the condition of the steel and is a suitable tool for indirect measurements as an alternative to monitoring the corrosion potential (E_{corr}), which is very sensitive to the composition of the pore solution and the availability of oxygen.

1 INTRODUCTION

The development of novel binders with a longer service life than OPC is a cost-effective and environmentally friendly option. AAM, one of the available alternative binders, offers a lot of potential for development and are widely regarded as a viable alternative to conventional Portland cement due to their low carbon emissions and promising performance [1]. However, existing understanding is insufficient to assure long-term reliability due to discrepancies in the reaction processes of AAM and OPC, as well as a wide range of unique AAM compositions. Indeed, the pH and chemical composition of the surrounding pore solution, as well as oxygen availability, have a significant impact on passive film development and stability [2]. In the case of OPC and AAM, all three parameters are considerably different, and have a considerable impact on the electrochemical parameters used for corrosion detection. The aim of this study is to determine indirect method to evaluate the corrosion conditions of steel embedded in AAM.

2 METHODOLOGIES

Table 1 described the systems studied in this research. The mortars were prepared with $w/b = 0.45$ and $binder/aggregate = 0.33$. After mixing the mortar was cast into $\varnothing 50$ mm - 100 mm plastic moulds that had

smooth steel rebar placed in the middle. A conventional cell with three electrodes was used to perform the electrochemical measurements, using a steel rod embedded in the cylindrical mortar as the working electrode (WE), a graphite rod as the counter electrode (CE) and a saturated calomel electrode (SCE) as the reference electrode (RE). Electrochemical measurements were performed using the PAR VMP2 potentiostat. Measurements were made after 28 days of curing up to 360 days, during which the material was subjected to cycles of wetting, drying, and spraying with chloride solution simulating the marine environment in a salt spray chamber. The temporal evolution of the following parameters was monitored throughout the test period: the corrosion potential and polarization resistance determined by LP and the individual resistance of mortar and steel using EIS.

Table 1. Mix design of the mortars developed in this study.

Mass (%)	SN3	BN3	FN9
Blas furnace slag	87.6	41.1	0
Fly ash	0	46.6	68.7
NaOH	7	7	7.7
Na-silicate	5.2	5.2	23.5

3 RESULTS

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Figure 1 shows the Nyquist plots, obtained by EIS to discriminate between mortar and reinforcing steel resistance. The electrical equivalent circuit was used to match the impedance data, which is defined by two time constants: the behaviour in the high frequency range related to the mortar cover properties, while the lower frequency range associated with the steel/electrolyte interface [3]. R_{mortar} was investigated as a critical metric to determine the mortar capacity to prevent aggressive ions from penetrating electrolytes [4]. Corroded steel frequently occurs in places with poor resistivity, suggesting more chloride anions penetration and more open pores [5]. R_{mortar} of SN3 increased up to 268 $k\Omega cm^2$ at 250 days and moved to 55 $k\Omega cm^2$ after 50 days, while R_{mortar} of BN3 increased up to 253 $k\Omega cm^2$ at 200 days and moved to 66 $k\Omega cm^2$ after 100 days. This trend is probably connected to the cracking process of mortar layer due to the corrosion product growing on the steel surface, as it is confirmed by the capacitance values. While R_{mortar} of FN9 was stable at $\sim 1 k\Omega cm^2$, indicating corrosion already at 150 days.

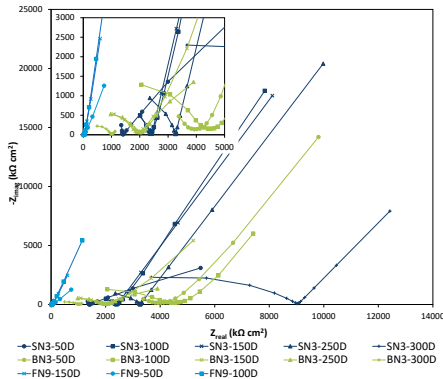


Figure 1. Nyquist plots of AAMs reinforced in salt spray chamber after different exposure times.

Figure 2 (top) shows the correlation between the half-cell potential (E_{corr}) and mortar resistivity (R_{mortar}) obtained by EIS fitting from this study (red dots), as well as the same correlation for OPC from the literature (black triangle). Figure 2 (bottom) shows the correlation between the current density (i_{corr}) obtained by LP and R_{mortar} obtained by EIS fitting with correlation coefficient of 0.52. The mortar resistivity decreased, while E_{corr} did not always agree with the R_{mortar} results. In addition, it is possible to identify areas of passive and corrosive conditions that are shifted to lower values compared to the observation in OPC. Increasing the corrosion rate the mortar resistivity reduced, while E_{corr} was not always coherent with R_{mortar} results. Furthermore, it is possible to identify region of passive and corroding conditions, which are shifted to lower values compared to observation in OPC. R_{mortar} is less affected by humidity and oxygen availability than E_{corr} and it is possible to define the boundaries of passive and active conditions. Compared to Elsener et al [6], the results obtained with AAMs are shifted to lower E_{corr} and higher R_{mortar} values.

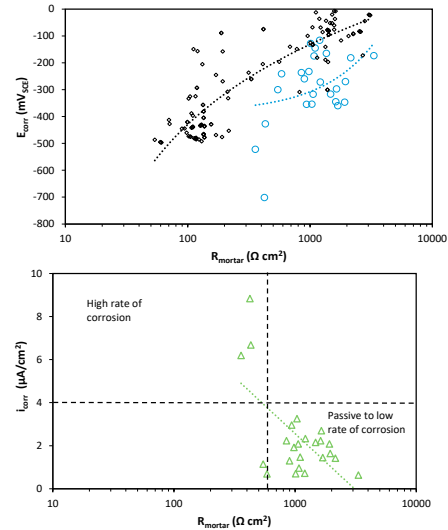


Figure 2. Relation between half-cell potential (E_{corr}) and mortar resistivity (R_{mortar}) obtained by EIS fitting, compared with results obtained by Elsener et al. [6] for OPC (top) (black dots) and relation between mortar resistivity (R_{mortar}) and corrosion rate (bottom).

4 CONCLUSIONS

Mortar resistivity (R_{mortar}) can roughly identify the condition of the steel and be a valid tool for indirect measurements as an alternative to E_{corr} monitoring. Notwithstanding the fact that R_{mortar} can be strongly influenced by the chemical composition of the systems, in particular by the OH^- concentration [7], the results presented for AAMs show a visible distinction between areas of high corrosion activity ($R_{mortar} < 600$) and passive or negligible corrosion activity ($R_{mortar} > 600$).

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