A study on the chloride diffusion and microstructure of alkali-activated mortar

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Abstract. The demand for durable building materials has become a compelling environmental issue due to the CO_2 emissions associated with the production of ordinary Portland cement (OPC) for the repair or replacement of damaged infrastructure. Alkali-activated materials (AAMs) can offer high durability properties with low carbon emissions. However, knowledge on the diffusion of chloride anions in AAMs remains limited. Various contradictory results can be found in the literature, and findings from studies on OPC or even blended cements cannot be directly applied to AAMs due to the differences and complexity of this system. The study considered nine mix design based on different feedstocks (blast furnace slag for high Ca systems and fly ash for low Ca systems) and activated with different Na_2O concentration in the alkali activator solution. The aim of the study was to establish a correlation between the microstructure and chloride diffusion, using NT BUILD 443 and data obtained by MIP curves.

Keywords: Alkali-activated materials; chloride diffusion; microstructure; porosity; critical pore radius

1 Introduction

Chloride diffusion is the first parameter to be evaluated for corrosion protection and simulation of reinforced concrete service life. Porosity and pore connectivity play a crucial role in chloride penetration resistance. However, the microstructure is still insufficiently studied in alkali-activated materials (AAMs), and it is not possible to transfer the knowledge available for Portland cement because of the complexity of the systems. The objective of this study is to evaluate the influence of the microstructure of AAMs on chloride transport properties.

2 Methodology

Table 1 summarizes the mix designs developed for this studies from RILEM TC 247-DTA [1]. The resistance of alkali-activated mortar against chloride ingress was measured according to NT BUILD 443 and the chloride was measured according to EN 14629.

Mercury Intrusion Porosimetry (MIP) was used to provide information regarding the pore size distribution and pore volume of the mortars and surface area, in the pore size range from 360 to 0.006 µm. The data obtained from MIP were used to determinate total porosity, critical pore radius entry (r_{crit}) and threshold pore entry radius (r_{th}) [2].

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

Mass (%)	SN3	SN5	SN7	BN3	BN5	BN7	FN5	FN7	FN9
BFS_E	87.7	81.9	76.5	41.1	38.4	35.8	-	-	-
FA_P	-	-	-	46.6	43.5	40.6	79.3	73.2	68.7
NaOH*	7	10.3	13.5	7	10.3	13.5	5.1	6.6	7.7
WG*	5.3	7.7	10.1	5.2	7.7	10.1	15.5	20.1	23.5
SS/SH	0.66	0.66	0.66	0.66	0.66	0.66	2.71	2.71	2.71

*The activator content refers to the sum of liquid and solid components

3 Results

Table 2 shows the results of apparent chloride diffusion coefficient, obtained by NT BUILD 443. Tables 2 additionally reports microstructure properties of alkali-activated mortars, obtained from MIP. The table shows the total porosity and the threshold pore radius (r_{th}) and the critical pore radius entry (r_{crit}), extrapolated from the cumulative curves.

Figure 2. Chloride diffusion and microstructural properties of AAMs.

Mix label	D_a (10^{-12} m^2/s)	Total Porosity (%)	Critical pore entry radius, r_{crit} (nm)	Threshold pore radius, r_{th} (nm)
SN3	7.2	4.6	29.4	18
SN5	3.0	6	23.7	28
SN7	2.5	5.9	10.8	10
BN3	8.2	18.2	2322.9	2350
BN5	7.0	16.5	494.6	1050
BN7	6.0	14.8	393	760
FN5	53	29.2	2894.9	2500
FN7	40	18.9	3440.1	2850
FN9	23	14	3427.4	3600

The activator content and the nature of the precursor affect the resistance to chloride penetration. Increasing the activator content prevented chloride penetration, samples containing blast furnace slag behaved similarly, while the low-Ca systems showed low resistance to chloride penetration, which is consistent with previously reported results for mixed slag-fly ash AAMs in various ratios [3]. The apparent chloride diffusion coefficient for high- and moderate-Ca AAMs was low compared to a conventional OPC concrete with similar water-solid ratio [4,5].

The alkali-activated slags (SN series) always had a measured porosity of less than 6%. Moreover, the SN series show no evident correlation between activator content and porosity. Alkali-activated fly ash and blended slag-fly ash systems show bimodal distribution in the differential curves. The first peak was located between 0.3 and 3 μm, the second one below 0.1 μm. Increasing Na_2O% content caused the reduction in porosity, as expected due to the higher extent of reaction of the fly ash.

From the MIP diagrams, r_{th} and r_{crit} can be obtained, and Figure 1 shows a comparison between these and D_a values for the samples studied. These parameters show a good Spearman correlation with the chloride diffusion coefficient: 0.9 for r_{crit} and 0.88 for r_{th}. This correlation has shown some limitations in previous studies when used for different binders, while in the present research it showed a strong correlation regardless of the type of precursor used [6].

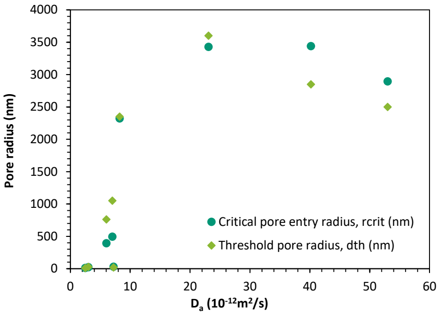

Figure 1. Correlation between chloride diffusion coefficient (D_a) and microstructure properties from MIP critical pore radius entry in nm and threshold pre radius in nm**.**

4 Conclusion

The activator dose, represented as Na_2O%, plays a crucial role in the development of chloride resistance. However, it has limited effects on microstructural properties, especially in terms of overall porosity. The microstructural study here showed a visible correlation between the chloride diffusion coefficient, D_a, and critical pore radius, r_{crit}. The critical pore radius represents the point of highest pore connectivity and path continuity in the binder matrix and, therefore, can be considered a key microstructural parameter that influences chloride diffusion.

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