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Performance of alkali-activated slag and pumice mortars against chloride ions penetration in the Persian Gulf

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ABSTRACT: Considering the successful usage of alkali-activated mortars in several countries and limited research on the durability of these materials, in this paper, the permeability and durability of alkali-activated slag and pumice mortar in chloride environments have been studied. To investigate the mechanical properties and permeability of alkali-activated slag and pumice mortars tests such as workability, compressive strength, capillary water absorption, water absorption, chloride ion penetration in the Persian Gulf environment and mercury intrusion porosimetry have been conducted. The results show that the compressive strength of alkali-activated slag mortar containing potassium hydroxide was slightly higher than the compressive strength of samples containing sodium hydroxide. In addition, the use of 10% pumice instead of slag has increased the compressive strength of alkali-activated slag mortar. Also, the 91-day compressive strength of alkali-activated mortars cured in the water was 48.4% higher than those cured in the air. In general, the diffusion coefficient of chloride ions in alkali-activated slag mortars was lower than the diffusion coefficient of chloride ions in Portland cement mortar, which was due to less porosity in alkali-activated slag mortars and the denser structure. Also, alkali-activated mortars containing 90% of slag and 10% of pumice had the lowest diffusion coefficient of chloride ions and Portland cement mortar showed the highest one, which was well matched with the result of capillary water absorption coefficient.

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1- Introduction

Reinforced concrete has higher durability when compared to steel, but this material is severely exposed to damage in corrosive and harsh environments such as marine environments. The penetration of chloride ions in concrete is the most important factor in reducing the alkalinity of concrete and destroying the passive layer on the rebar [1].

Shi [2] has reported that water penetration in alkali-activated slag concrete containing sodium silicate is 1000 times lower than Portland cement concrete. While Wongpa et al showed that in the same compressive strength range, activated alkali slag is 100 to 10,000 times more permeable than Portland cement concrete.

Adam [3] has performed salt pond and rapid chloride ions penetration test (RCPT) on slag and fly ash-based alkali-activated concretes. The results of RCPT show more penetration of chloride ions in alkali-activated fly ash compared to Portland cement, slag cement and alkali-activated slag, while the salt pond test shows less penetration of chloride ions in alkali-activated fly ash. Hu et al. showed that the results of the rapid chloride ion migration test (RCMT) in alkali-activated mortars containing slag and fly ash are affected by the pores' structure, but the results of RCPT are affected by the chemical properties of pore solution [4]. These differences and errors in the RCPT results are due to the presence of very high alkali ions in the pore solution of alkali-activated samples. Therefore, it can be said that the RCPT is not an appropriate method for evaluating the permeability of alkali-activated materials against chloride ions.

The main objective of this paper is the investigation of chloride ions penetration in alkali-activated mortars containing slag and pumice together with the comparison to cement-based mortars. Also, mercury injection porosimetry (MIP) was used to investigate pores' structures.

2- Methodology

2- 1- Material

Alkali-activated mortars were made with ground granulated blast furnace (GGBF) slag and natural Pozzolan throughout this work. The ordinary type I Portland cement was used to prepare reference mortar.

Potassium hydroxide (KOH) and sodium hydroxide (NaOH) pellets were dissolved in deionized water to produce the 6 molar alkaline solutions for alkali activation of raw materials. Sodium silicate (water glass) was provided by Iran

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Table 1. Alkali-activated mortar mixture proportion

Mix	Alkali Solution	Based Material (kg/m^3)	Pumice (%)	Activator to Based Material	Aggregate to Based Material
Na6-Pu0	NaOH	463.8	0	0.9	2.75
Na6-Pu10	NaOH	463.8	10	0.9	2.75
K6-Pu0	KOH	463.8	0	0.9	2.75
K6-Pu10	KOH	463.8	10	0.9	2.75

Table 2. OPC mortar mixture proportion

Mix	Cement (kg/m^3)	Water to Cement	Aggregate to Cement	Superplasticizer Dosage (Cement Weight Percent)
OPC	592.60	0.487	2.75	0.3

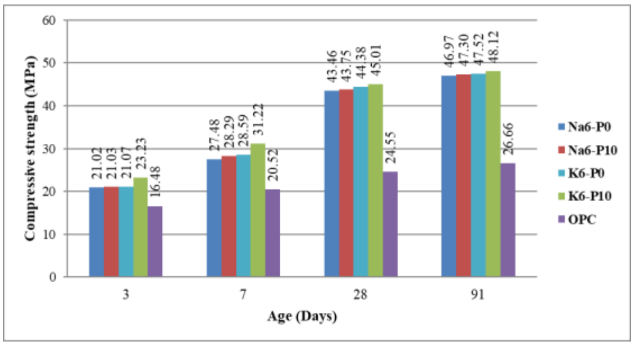

Fig. 1. Compressive strength results of alkali-activated slag/pumice and OPC mortars

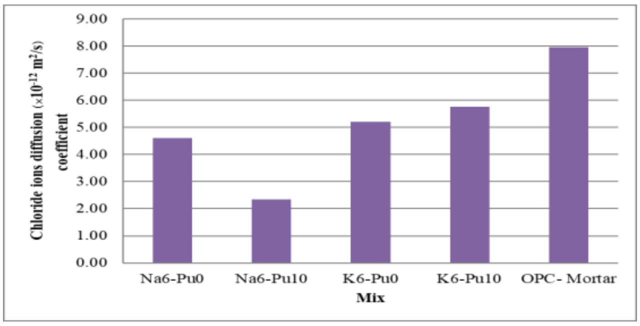

Fig. 2. Chloride ions diffusion coefficient (Ds) of submerged specimens in the Persian Gulf

Silicate Company in the form of a solution with a silicate modulus of 2.33.

2- 2- Mixture Preparation and Test Procedure

Alkali-activated and OPC mortars mixture proportions are presented in Tables 1 and 2, respectively. The optimum values of sodium silicate to alkaline solution, modulus of sodium silicate and alkaline solution concentration were taken from our previous study [5] are 0.4, 2.33 and 6 respectively.

Alkali-activated slag and OPC mortar cubes of 50×50×50 mm^3 dimensions were casted for the compressive strength test.

Alkali-activated slag and OPC mortar cubes of 100×100×100 mm^3 dimensions were cast for chloride penetration test to determine the apparent chloride diffusion coefficient of the specimens by bulk diffusion. The specimens were submerged in the Persian Gulf in Bandar Abbas. The chloride penetration profiles of specimens were measured after 12 months of exposure. The error function solution of Fick's second law was then fitted to the data, and a diffusion coefficient was determined by iteration. The Mercury injection (MIP) porosimetry test was used to investigate the condition of the cavities in mortar samples.

3- Results and Discussion

The compressive strength of alkali-activated slag and OPC mortars are presented in Figure 1. As can be seen in Figure 1, the alkali-activated slag mortar specimens containing potassium hydroxide had higher compressive strength at various ages up to 28 days when compared to the specimens containing sodium hydroxide. It can be concluded that 10% slag replacement with pumice increases the compressive strength of the alkali-activated slag mortars.

Figure 2 shows the chloride ions diffusion coefficient (Ds) of mortar specimens submerged in the Persian Gulf after 12 months. As can be seen, the chloride ions diffusion coefficient of alkali-activated slag mortar specimens is lower than the OPC mortar specimens and the best performance was exhibited by the Na6-Pu10 mix that contains sodium hydroxide solution and 10% pumice. It can be related to the lower pores in alkali-activated slag mortar specimens when compared to OPC mortar specimens.

Figure 3 shows the total amount of 10 nm to 10-micron pores in alkali-activated and Portland cement mortars. As can be seen, Na6-Pu10 mix has the lowest amount of pores and OPC mix has the highest. According to the results, it can be said that pumice particles reduce the micron pores. Also,

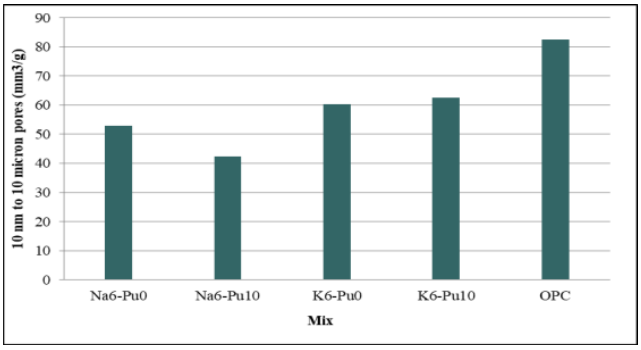

Fig. 3. 10 nm to 10 μm pores of mortars

nano-pores in the alkali-activated mortar containing pumice are less than those without pumice. It can also be said that samples activated with sodium hydroxide have fewer nano pores when compared to samples containing potassium hydroxide.

4- Conclusions

The following general conclusions can be drawn:

1- The compressive strength of alkali-activated slag mortars is greater than OPC mortars. Slag replacement with pumice increases the compressive strength of the alkali-activated slag mortar.

2- Because of lower pores, the chloride ions diffusion coefficient of alkali-activated mortars is lower than Portland cement mortar.

3- The best performance in the chloride diffusion was exhibited by the Na6-Pu10 mix which is in accordance with capillary absorption coefficient results.

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