Durability of cement-based and geopolymer coating mortars in the Persian Gulf simulated environment

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ABSTRACT

Due to the importance of coastal structures and the existence of destructive environmental conditions near the shores, the maintenance of these structures is more important. One of the ways to maintain such structures is to apply a protective coating layer of mortar. While cement-based mortars are known as the most common materials for repairing damaged structures, in recent years, due to the importance of environmental impacts and also in order to reduce energy consumption, geopolymer mortars have been considered an appropriate alternative. Geopolymers are inorganic aluminosilicate compounds in which, instead of cement, a matrix of aluminosilicate materials (pozzolans), activated by alkaline activators, plays the role of cement paste in the mortar.

In this research, mechanical properties and durability of 6 mortar mix designs, including four cement-based mortar mixtures containing supplementary cementitious materials (SCMs) and two geopolymer mortar combinations with furnace slag and silica fume that cured in the simulated Persian Gulf environment, has been compared. In this regard, to compare the mechanical properties, compressive strength, tensile strength, and drying shrinkage tests were conducted. Also, the capillary water absorption, water penetration under pressure, and rapid chloride migration tests are performed to evaluate the durability.

The results of this study display that ternary cement-based mortar with higher amounts of SCMs is a better choice than binary cement-based mortars and geopolymer repair mortars for repairing damaged concrete structures in coastal areas such as the Persian Gulf coast. Among other mixtures, the geopolymer mixture with potassium hydroxide as an alkaline activator and the cement-based mixture with a replacement of 7.5% by weight of silica fume can be introduced as suitable materials for repairing marine structures.

KEYWORDS

Durability, Persian Gulf simulated environment, Chloride ions attack, Supplementary cementitious materials, Geopolymer mortar.

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1. Introduction

Repairs of coastal concrete structures that have been damaged by coastal environmental conditions have been a significant issue in various countries in recent decades. Reinforcement corrosion due to the penetration of chloride ions in coastal areas, including the southern coast of Iran, is one of the important causes of the failure of concrete structures. After determining the cause of failure in these structures, the most important task is selecting appropriate repair materials, the main features of which are low permeability and high adhesion to the concrete surface. According to various researches, using cement-based mortar by replacing different percentages of furnace slag and silica fume instead of Portland cement and geopolymer mortar can be suitable for repairing structures damaged by chloride ion attacks and corrosion of reinforcement.

Most of the research that has been done so far in the field of durability in coastal environments has used concrete samples, and fewer repair mortars have been studied. In addition, no laboratory research has been performed to compare the durability of cement-based mortar containing supplementary cementitious materials (SCM) and geopolymer mortar coatings under Persian Gulf simulation conditions. Therefore, the results of this study can be effective for the final choice between these materials for damaged structures.

2. Experimental program

In this study, Portland cement Type 2, normal sand, furnace slag, and silica fume (SF) as SCM were used for making cement-based mortar samples. Besides, furnace slag and SF as base material and sodium hydroxide, potassium hydroxide and sodium silicate (SS) as alkaline activator solution (AS) were utilized for producing geopolymer mortars.

Based on the previous research, four cement-based mixtures containing SCMs with water to cement ratio of 0.33 and two geopolymer mixtures with alkaline activator concentrations of 6 molars were selected as the final mix designs. The mix proportion of cement-based mortar and geopolymer mortars are indicated in Table 1 and Table 2, respectively.

Table 1. Mixture proportion of cement-based mortars

Materials and proportion	OPC	7.5 SF	30Sl	7.5SF30Sl
Ordinary Portland cement (Kg/m^3)	720	666	504	450
Furnace slag (Kg/m^3)	-	-	216	216
Silica fume (Kg/m^3)	-	54	-	54
Free water (Kg/m^3)	237.6	237.6	237.6	237.6
Fine aggregate (Kg/m^3)	1381	1361	1358	1339
Superplasticizer (% of cementitious materials)	0.8	1.1	0.8	1
Flow table (mm)	170	160	160	150

Table 2. Mixture proportion of geopolymer mortars

Mixture ID	AS	Molarity	Agg to Pozz	AS to Pozz	SF (%)	SS to AS
KOH	KOH	6	2.75	0.6	5	0.4
NaOH	NaOH	6	2.75	0.6	5	0.4

Compressive strength test (CS), tensile adhesion resistance test (TR), shear adhesion resistance (SR) and drying shrinkage (DS) were used to evaluate the mechanical properties of hardened mortars. Also, in order to investigate their durability features, water penetration under pressure (WP) and rapid chlorides ions migration test (RCMT) were investigated.

3. Test results

The summary of mechanical and durability test results is demonstrated in Table 3. According to the results, geopolymer mortars, especially the mixture containing potassium hydroxide, had the highest compressive strength. Among the cement-based samples, due to the higher pozzolanic activity of SF, the compressive strength of the samples containing SF was highest. Over time, specimens containing furnace slag had more compressive strength than the OPC. Due to the more sticky nature of their paste, geopolymer mortars and 7.5SF30Sl have a higher tensile and shear adhesion resistance than other cement-based samples. Besides, the use of SCM increased both the tensile and shear adhesion resistance of cement-based mortars. After 90 days, geopolymer and SF mixtures have the highest drying shrinkage, while using slag reduces cement-based repair mortars' drying shrinkage.

As can be seen in Table 3, due to the pozzolanic activity of SCMs, the penetration of water is reduced in SCM mixtures. Also, both geopolymer mixtures reduced the water penetration of mortars compared to OPC. In RCMT, as predicted based on the other test results, geopolymer and SCM samples have the lowest diffusion coefficient. Better performance of geopolymer mixtures in mechanical and durability properties can be related to the less porosity of geopolymer paste due to the geopolymerisation. Also, the pozzolanic activity of SCMs enhances the SCM mixtures' mechanical and durability.

Table 3. Summary of test results

Tests	Time (Days)	Mixtures					
		OPC	7.5SF	30Sl	7.5SF30Sl	KOH	NaOH
CS (MPa)	28	56	68	58	66	75	63
	90	66	74	67.6	76	88	74
TR (MPa)	28	1.5	2.3	2	2.5	2.4	2.25
SR (MPa)	28	1.77	3.10	1.70	3.42	4.40	3.78
	90	2.23	3.35	2.63	3.83	4.55	4.18
DS (%)	90	0.13	0.16	0.08	0.10	0.19	0.24
DP (mm)	28	19	4.5	4	3	9	9
	90	8	3.7	3	1.6	5.8	6.5
RCMT (10^{-12} m2/s)	28	7.44	2.43	1.52	1.12	1.16	1.34
	90	3.86	1.45	1.45	0.42	0.48	0.61

4. Conclusion

The summarized experiment results of this research are mentioned as the following:

- Geopolymer repair mortars had the highest compressive strength, tensile and shear adhesive strength. They have also performed better in the RCMT test while their water penetration results under pressure were less than SCM mixtures. The worst performance of geopolymer mortars was related to the drying shrinkage test, in which they had the highest shrinkage. In general, the performance of the KOH activator was evaluated better than NaOH in geopolymer mixtures.
- SF as a high activity pozzolan had a significant effect on cement-based mixtures' mechanical and durability properties. Generally, its performance was less than geopolymer mortars. Using ternary cement-based mixtures containing 7.5% of SF and 30% slag had the best performance in cement-based mixtures.
- Although using 30% of slag reduced the compressive strength at early ages, its performance was evaluated better in the case of tensile and shear adhesion tests, water penetration, and RCMT tests.
- Finally, after reviewing all the obtained results, it can be concluded that ternary cement-based mortars with higher amounts of SCMs (7.5SF30Sl) can be a better option than binary cement-based mortars and geopolymer repair mortars for repairing damaged concrete structures, especially in the Persian Gulf marine environment.

5. References

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