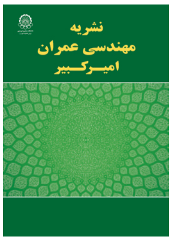

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Assessment of High Performance Concrete Containing Mineral Admixtures Under Sulfuric Acid Attack

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ABSTRACT: Concrete, as a main construction material has an alkali nature which makes it vulnerable to attack by acidic solutions. Therefore, investigations on performance of various types of concretes against different kinds of acid attacks are essential to achieve durable concretes in severe environments. Considering the significant effect of durability in sustainability of concrete structures, high performance concrete (HPC) which is characterized by its high compressive strength, low permeability and fine durability in many severe environments, is increasingly utilized in civil and infrastructural constructions. This paper presents an experimental study on durability of HPC and conventional concrete (CC) containing ordinary Portland cement (PC), ground granulated blast furnace slag (GGBFS) and natural pozzolan (NP) under sulfuric acid attack. Compressive strength, ultra-sonic pulse velocity determination, capillary water absorption test and evaluation of electrical resistivity were utilized to investigate mechanical properties and permeability of hardened concrete. The durability properties were studied through measurement of weight and compressive strength loss, ultra-sonic pulse velocity variations and length change of mortar prisms exposed to sulfuric acid. The results indicated that concretes containing less cementitious materials and mineral admixtures were more durable in acidic solutions, and incorporating higher volume of GGBFS and NP could improve performance of concrete against sulfuric acid attack.

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1- Introduction

High performance concrete (HPC) is characterized by its high compressive strength and fine durability in many severe environments due to dense structure and low permeability of it. Portland cement concrete has an alkali nature which makes it vulnerable to attack by acidic solutions [1].

Using supplementary cementing materials could improve concrete resistance against sulfuric acid by reducing calcium hydroxide crystals and decreasing permeability of concrete [2, 3]. Although contradictory effects of mineral admixtures on acidic resistance of cement based materials is reported [2, 4]. In addition, it has been reported that concretes containing higher cement content are more vulnerable to deterioration by sulfuric acid attack [3, 5]. This could bring about a dilemma about the performance of HPC in aggressive environments containing sulfuric acid; in comparison with ordinary used concrete, does lower permeability of HPC determines the performance against sulfuric acid attack or higher amounts of cementing materials in those mixtures?

2- Experimental Program

Type I Portland cement (PC), ground granulated blast furnace slag (GGBFS) and natural pozzolan (NP) were used as binders for making concrete mixtures. In this research, effect of incorporating supplementary cementing materials on sulfuric acid degradation intensity of concrete mixtures is studied through 12 concrete mixtures by partial replacement of PC by BFS and NP. High-range water reducing admixtures (HRWRA) was added to the concrete mixtures to obtain in S3 slump class (between 100-150 mm). Tables 1 and 2 demonstrate the mixture proportions of prepared HPC and conventional concrete (CC) mixtures, respectively (aggregates are assumed to be saturated surface dry (SSD) and WRWRA content is presented as a ratio of cementitious materials content).

Compressive strength (CS), ultra-sonic pulse velocity determination (USPV), capillary water absorption test (CWA) and evaluation of electrical resistivity (ER) were utilized to investigate mechanical properties and permeability of hardened concrete. The durability properties were studied through measurement of weight and compressive strength loss (WL and CSL), USPV variations and length change (LC) of mortar prisms exposed to sulfuric acid (pH=1).

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Table 1. Mixture proportions of HPC mixtures

Materials and proportions		HPC	HS20	HS30	HS40	HN20	HN25
PC	kg/m^3	450	360	315	270	360	337.5
BFS	kg/m^3	-	90	135	180	-	-
NP	kg/m^3	-	-	-	-	90	112.5
Fine aggregate (0-4 mm)	kg/m^3	1056	1051	1049	1047	1043	1040
Coarse aggregate (4-12.5 mm)	kg/m^3	704	701	700	698	695	693
W/B	-	0.32	0.32	0.32	0.32	0.32	0.32
HRWRA	%	0.63	0.5	0.44	0.37	0.55	0.6

Table 2. Mixture proportions of CC mixtures

Materials and proportions		OPC	OS20	OS30	OS40	ON20	ON25
PC	kg/m^3	360	288	252	216	288	270
BFS	kg/m^3	-	72	108	144	-	-
NP	kg/m^3	-	-	-	-	72	90
Fine aggregate (0-4 mm)	kg/m^3	1101	1098	1096	1094	1091	1088
Coarse aggregate (4-12.5 mm)	kg/m^3	734	732	731	729	727	725
W/B	-	0.4	0.4	0.4	0.4	0.4	0.4
HRWRA	%	0.5	0.51	0.53	0.5	0.61	0.62

3- Summary of Results

Table 3 demonstrates a summary of results. It should be noted that CWA results are summarized as absorbed water after 72 hours of contacting concrete specimen's surface with water. Given results indicates that partial replacement of PC by GGBFS could increase the CS. On the contrary, incorporating NP decreases CS in comparison with control mixture. Additionally, replacing PC by GGBFS he permeability of concrete but incorporating NP could lead to higher permeability by the means of CWA and ER test results. Besides, USPV was measured in lime solution cured and acid corroded specimens. The USPV was well correlated with CS (CS(MPa) = 64.4 USPV(km/s) - 227.5 with R^2=0.86 for HPC mixtures and CS(MPa) = 76.3 USPV(km/s) - 283.4 with R^2=0.79 for CC mixtures) but such a relation was not satisfactory in acid corroded specimens (CS(MPa) = 22.16 USPV(km/s) - 72.56 with R^2=0.42 for HPC mixtures and CS(MPa) = 32.34 USPV(km/s) - 119.25 with R^2=0.52 for CC mixtures). Moreover, the USPV variation of acid corroded specimens during immersion period was measured and it was concluded that USPV could not demonstrate an overview of degradation intensity of concrete specimens. Additionally, Table 3 are representing that incorporating supplementary cementing materials could improve durability of concrete against sulfuric acid attack by the means of WL, CSL and LC experiments.

Table 3. Summary of results

Tests	Time (days)		Mixtures											
			HPC	HS20	HS30	HS40	HN20	HN25	OPC	OS20	OS30	OS40	ON20	ON25
CS (MPa)	28	Limewater Curing	62.3	70.1	56.4	53.1	57	60.6	53.6	55.1	51.9	50.6	47.7	45.6
	180		72.5	83.7	77	68	70	73.8	67	72.7	67	65.1	63	63.9
CWA (g/mm^2)	28		2.9	2.8	2.8	3.0	3.3	3.4	4.1	3.8	4.2	4.5	4.2	4.5
	180		2.6	2	2.2	2.3	2.6	2.8	3.3	3.2	3.1	2.9	3.1	3.4
ER (kΩ.cm)	28		13	14.8	16	17.4	13.6	11	9.5	10.4	11.7	12.1	9.8	9.4
	180		22.4	31.2	35.1	45	41.6	57.9	15.6	25	31.4	37.5	28.3	40.8
WL(%)	180	Acidic Solution	48.3	43.9	41.4	36.6	45	41.7	40.4	31.6	30	21.9	32.1	29.2
CSL(%)	180		81.1	79	73.9	70.7	80.2	71.4	78.4	75	75	74.8	78	76
LC (ε)	90		0.72	0.60	0.48	0.50	0.56	0.48	0.40	0.27	0.21	0.2	0.32	0.28

4- Conclusions

Based on experimental results of this study, the following conclusions could be drawn:

By partial replacement of PC by GGBFS, CS and permeability of concrete mixtures was improved. It was concluded that using NP as a supplementary cementing materials could have negative effects on CS and permeability of concrete.

Degradation intensity of specimens were studied through WL and CSL of concrete samples, mortar prisms LC and variations of USPV in concrete specimens. As a result of these experiments, incorporating mineral admixtures could increase the concrete and mortar resistance against sulfuric acid invasion. Noticeably, although the permeability of HPC mixtures was lower than that of CC mixtures, durability of CC mixtures was superior to HPC mixtures. Considering the superior durability of HPC mixtures stated in many researches, it should be noted that this conclusion could not generalized to all durability aspects of HPC in comparison with CC mixtures. In addition, it was concluded that higher permeability of NP incorporated mixtures could not affect the durability of these mixers in sulfuric acid solution, and enhanced durability of mixtures containing NP in comparison with control mixtures was observed. This conclusion could indicate that in the case of durability of concrete against sulfuric acid attack, the effect of using pozzolanic materials and reducing calcium hydroxide amount by means of pozzolanic reactions was much more significant than reduction in the permeability of concrete. It was also concluded that USPV determination could only demonstrate an overall view about concrete's degradation intensity in sulfuric acid solution; i.e. an exact evaluation of acid corroded concrete specimens is not possible.

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