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Investigating Sulfate Attack on Concrete in a Nuclear Power Plant in the UAE: An Experimental Study

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1. Introduction

The degradation of concrete due to chemical attack has become a recurring issue in the United Arab Emirates(UAE), primarily attributed to the region's environmental conditions featuring high concentrations of sulfate and chloride ions. The dominant sulfate attack mechanism involves the reaction between ingressed sulfate ion and compounds in the cement matrix, resulting in the formation of ettringite, subsequent crack development due to volume expansion, and ultimately a reduction in compressive strength. Ensuring the structural integrity of the Barakah Nuclear Power Plant(BNPP) throughout its service life requires specialized aging management strategies that account for the unique environmental conditions and concrete properties. This study aims to investigate sulfate attack on concrete in NPP in the UAE. Specimens for the experiment are made of raw materials from the UAE to reflect regional characteristics. The degradation due to the sulfate attack will be investigated from the changes in the compressive strength and the length of specimens for 180 days. The effect of the type of sulfate solution and the curing temperature on the degradation of concrete are considered. The purposes and plans for the experimental research are included in this paper, and the results will be included in a follow-up paper.

2. Experimental Program

2.1 Mix Proportion of Concrete

Given the distinct high-temperature and harsh environmental conditions in the UAE, unlike the Korean NPP conditions, the ground granulated blast furnace slag (GGBS) and silica fume(SF) are used as admixtures, while fly ash(FA) is normally used for Korean NPPs.

The mix proportion of concrete for containment building of BNPP is represented in Table 1 [1].

Table 1: Mix proportion of concrete for the BNPP

Material (kg/m^3)							
Water	Cement	GGBS	SF	Crushed Sand	Dune Sand	Coarse Agg.	HWRA*
146	113	244	19	706	230	938	4.129

*HWRA(High range Water Reducing Admixture)

2.2 Raw materials for specimens

Most of the raw materials such as cement, GGBS, sand and gravel are imported from the UAE. However, SF from China which was included in concrete of BNPP was not used for the specimens in this research because of the delayed shipment. Instead, SF from a Korean company is used for the experiment. Table 2 shows the material properties of silica fume from UAE(China) and Korea. The chemical composition of HWRA was also adjusted based on the advice from the supplier of the HWRA located in Korea, because the original HWRA was taken off the market and the environmental condition during the placement of concrete is different.

Table 2: Material properties of silica fume

Test item	Unit	UAE (China)	ROK
SiO_2	%	86.0	94.4
SO_3	%		0.6
MgO	%		0.3
Total alkalies	%	2.4	
Moisture	%	0.3	
Loss on ignition	%	3.7	3.0
Over size	%	1.1	
Strength activity index (7 day)	%	124	97
Strength activity index (28 day)	%		108
Specific surface	m^2/g	23.9	
Specific Gravity (Density)	g/cm^3	2.16	
Chloride ion	%		0.005

2.3 Experimental Plans

Table 3 shows the list of planned experiments. Rectangular prism specimens of $100 \times 100 \times 400$mm are produced for the length change experiments. The other specimens except for the length change are prepared as cylindrical specimens of $\phi 100 \times 200$mm. Three specimens for each test were prepared and all the specimens were cured in water during the first 28 days, and then immersed into different solutions or water depending on the purposes of the experiments. Ages conducting the tests are also presented in Table 3. Elastic modulus and the compressive strength will be measured simultaneously at 91 days. The effects of the curing temperature and sulfate solution will be investigated. Two levels of temperature, 20℃ and 35℃, and two kinds of sulfates, sodium and magnesium sulfates, are used for the experiments. Some basic material properties such as the Poisson's ratio, splitting tensile strength and thermal expansion coefficient are also tested at the age of 91 days.

Table 3: List of planned experiments

Test	Curing temperature	Immersion condition after 28 days	Age (day)	Remarks
Compressive strength	20℃	Water	7	
			28	
			91	E*
			180	
		Sodium sulfate	91	E
			180	
		Magnesium sulfate	91	E
			180	
	35℃	Water	7	
			28	
			91	E
			180	
		Sodium sulfate	91	E
			180	
Change of length	20℃	Sodium sulfate	91	
			180	
	35℃		91	
			180	
Poisson's ratio	20℃	Water	91	
Splitting tensile strength		Water	91	
Thermal expansion coefficient		Water	91	

*E: Elastic modulus

2.3 Experimental Results at Early Age

Some experiments on compressive strength were conducted so far, and the procedures and results are presented in Fig. 1, 2 and 3. The results labeled as UAE in Fig. 3 are from the concrete mixture proportioning report by KEPCO [1]. The compressive strengths from the report and this research have similar trend, and this shows the proper production of the specimens. We will investigate the basic properties of concrete and the sulfate attack on these specimens for 180 days and the results will be provided in the follow-up paper.


Fig. 1. Photos of curing specimens

Fig. 2. Photos of compressive strength tests

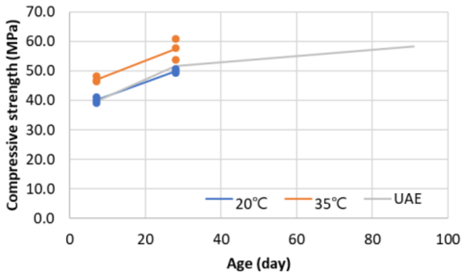

Fig. 3. Compressive strength of specimens

3. Conclusions

The experimental plans are introduced to investigate the sulfate attack on concrete in BNPP. Some experimental results at early age are also included, and the results show that the specimens are properly produced and suitable for demonstrating the degradation of concrete in BNPP.

The results of this study can be used to evaluate concrete degradation due to sulfate attack and design effective remedial strategies. To enhance the applicability of this study, additional experiments focusing on material characteristics and on-site investigation are necessary.

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[1] KEPCO E&C and KOCEN Concrete Lab. "Additional Concrete Mixture Proportioning Report Using Silk Road Improved HWRA", 2014