Experimental Investigation of Sulfate Attack on Concrete in UAE's Nuclear Power Plants

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1. Introduction

Concrete degradation caused by chemical attacks has become a common issue in the United Arab Emirates (UAE), largely due to the region's environmental conditions, which feature high levels 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. To maintain the structural integrity of the Barakah Nuclear Power Plant (BNPP) throughout its lifespan, it is essential to implement aging management strategies tailored to the region's unique environmental conditions and the specific properties of the concrete used. This study focuses on investigating sulfate attack on concrete at BNPP in the UAE. The specimens used in the experiment are made from locally sourced raw materials to accurately reflect regional characteristics. The degradation caused by sulfate attack will be assessed through changes in compressive strength and the length of the specimens over 180 days. The study also examines the impact of different types of sulfate solutions and curing temperatures on concrete degradation. While the experimental plans were detailed in a previous paper, this paper will concentrate on presenting the experimental results.

2. Experimental Plans

The mix proportion of concrete for the containment building of BNPP is shown 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 Aggregate	HWRA
146	113	244	19	706	230	938	4.129

[*]GGBS(Ground granulated blast furnace slag), SF(Silica fume), HWRA(High range Water Reducing Admixture)

Table 2 lists the experiments conducted. Cylindrical specimens of $\phi 100 \times 200$ mm were used for the compressive strength tests. Three specimens were prepared for each test, and all specimens were cured in water for the first 28 days, after which they were immersed in different solutions or water, depending on the purposes of the experiments. The ages at which the tests were conducted were 7, 28, 91, and 180 days. The elastic modulus was measured at 91 days. The effects of curing temperature and sulfate solution were investigated. Two levels of temperature, 20℃ and 35℃, and two types of sulfates, sodium and magnesium, with a concentration of 10%, were used for the compressive strength experiments. Rectangular prism specimens of $100 \times 100 \times 400$ mm were produced for the length change experiments. One to three specimens were prepared for each test and cured in water for the first 28 days. Only the effect of curing temperature was investigated, using two levels of temperature, 20℃ and 35℃. The tests were conducted in accordance with the KS code [2].

Table 2: List of planned experiments

Test	Curing temperature	Immersion condition after 28 days	Age (day)	Remarks
Compressive strength	20°C	Water	7	
			28	
			91	Elastic modulus
			180	
		Sodium sulfate	91	Elastic modulus
			180	
		Magnesium sulfate	91	Elastic modulus
			180	
	35°C	Water	7	
			28	
			91	Elastic modulus
			180	
		Sodium sulfate	91	Elastic modulus
			180	
Change of length	20°C	Water	28	3 specimens
			91	
			180	
		Sodium sulfate	91	1 specimen
			180	
	35°C	Water	28	2 specimens
			91	
			180	
		Sodium sulfate	91	1 specimen
			180	

3. Experimental Results and Discussion

3.1 Compressive Strength

The compressive strengths of specimens cured in water are presented in Fig. 1. The results labeled as UAE in Fig. 1 are from the concrete mixture proportioning report by KEPCO [1]. The compressive strengths from the report and this research show a similar trend, indicating that the specimens were properly produced.

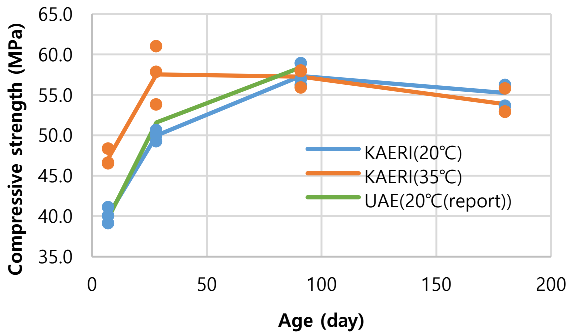
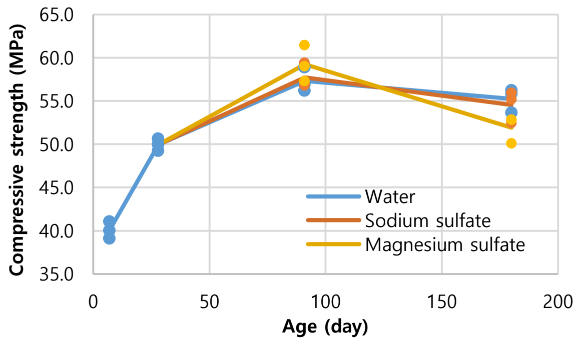
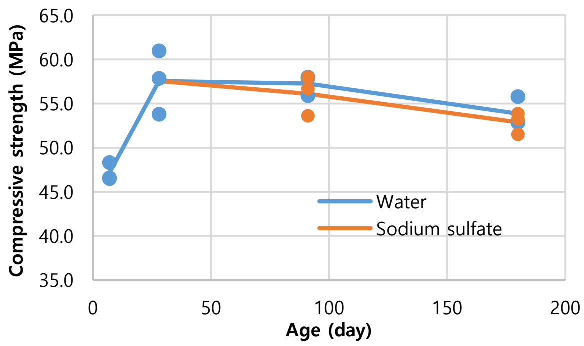


Fig. 1. Compressive strengths of specimens cured in water

The effect of sulfate solution on compressive strength is presented in Fig. 2. At the age of 180 days, specimens immersed in the sulfate solution showed a decrease in compressive strength. Compressive strength was more affected by the magnesium sulfate solution. The decrease in compressive strength was more significant at higher curing temperature.



(a) curing temperature of 20℃



(b) curing temperature of 35℃

Fig. 2. Effect of sulfate solution on compressive strength

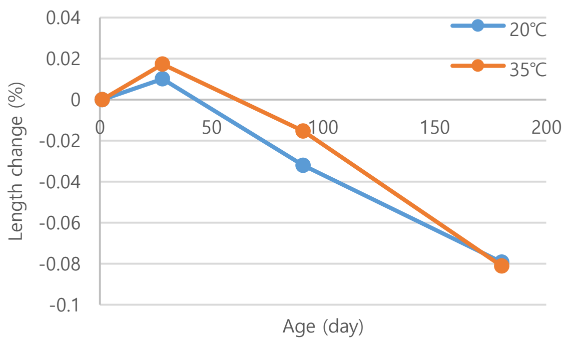
3.2 Change in Length

The change in length due to the sulfate solution is presented in Fig. 3. Length change in the graph is calculated by Eq. (1), where a positive value indicates expansion.

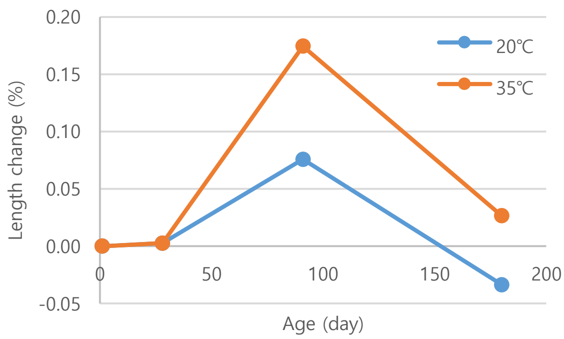
$$Length\ change(\%) = \frac{L_i - L_0}{L_0} \times 100 \qquad (1)$$

where L_0 is the initial length of the specimen, and L_i is the current length of the specimen.

Specimens in water served as the control group and showed shrinkage. Specimens in the sulfate solution exhibited expansion as expected, with higher expansion observed at the temperature of 35℃.



(a) specimen in water



(b) specimen in sodium sulfate solution

Fig. 3. Effect of sulfate solution on length of the specimens

4. Conclusions

Experiments to investigate the effect of sulfate attack on concrete in BNPP were conducted, and the results are presented in this paper. The results indicate that sulfate attack can decrease the compressive strength of concrete and cause expansion. The degradation was more severe at higher temperature and with the use of magnesium sulfate compared to sodium sulfate.

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

ACKNOWLEDEMENTS

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REFERENCES

[1] KEPCO E&C and KOCEN Concrete Lab. "Additional Concrete Mixture Proportioning Report Using Silk Road Improved HWRA", 2014
[2] KS F 2424, "Standard test method for length change of mortar and concrete"