A Review of Material Properties and Environmental Conditions for Evaluating Sulfate Attack on Concrete in UAE Nuclear Power Plants

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***Keywords :** UAE Barakah Nuclear Power Plant, Concrete Degradation, Sulfate Attack, Chloride Attack, Durability of Concrete, Aging Management

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 environemntal conditions and concrete properties. This study aims to analyze the material properties of the BNPP and its unique environmental conditions, providing foundational data for assessing concrete degradation within the NPP.

2. Environmental Conditions

In this section, the UAE's climate and environemntal conditions are explored, presenting measured concentrations of sulfate and chloride ions at the Barakah site, along with their corresponding exposure classifications.

2.1 Environmental Conditions of UAE

The Arabian Gulf region is characterized by high temperature and humidity [1].

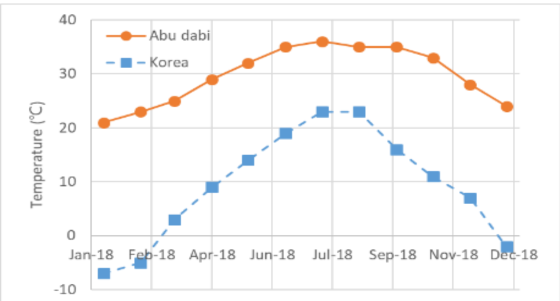

Fig. 1. Average temperatures of the UAE and Korea throughout the year

Fig. 1 shows the average temperatures of UAE and Korea throughout the year. The average temperature in UAE is around 15~30 ℃ higher than in Korea. The maximum air temperature in the summer is almost 50℃ and the minimum temperature in the winter is around 10℃. The relative humidity varies between 40% and 80% reaching up to 98% at times [1].

Precipitation is very low. The annual precipitation amount ranges from 80 to 160mm, with rainfall primarily occurring in winter from December to March.

2.2 Barakah Nuclear Power Plant in UAE

The concentration of sulfate and chloride ions at the Barakah site is as shown in Table 1[2]. The concentration of chloride ions in underground water is approximately 10 times higher than that at the Shin-Kori site in Korea. The sulfate ion concentration cannot be compared because it was not measured in Korea. According to the classification in ASME Sec.III Div.2 [3], this condition belongs to S2(severe) class for the sulfate category, and C2(severe) class for the corrosion of rebar category which is related to chloride ions.

Table 1: Concentration of sulfate and chloride ions at the BNPP site [2]

Unit: mg/L	Underground water	Seawater
Chloride	52,112	26,447
Sulfate	4,663	3,440

The layout of the BNPP is similar to that of the Shin-Kori NPP. The structure nearest to the sea, the CCW structure, and the intake/discharge structure tunnels face the highest risk of damage from sulfate attack [4].

3. Properties of Concrete

A comparison between the raw material properties of the UAE and Korea is provided, alongside summarized experimental results on compressive strength using Korean materials with identical mix proportions to those of the BNPP.

3.1 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 2 [5].

Table 2: 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) Type F

3.2 Properties of Raw Materials

Properties of raw materials such as GGBS and fine aggregates are compared, as shown in Table 3 and 4. The slag activity index and granulation grade used in BNPP are higher than those of the ordinary type of GGBS (type 3) in Korea. Dune sand, which has a small diameter and spherical shape, is mixed as fine aggregates in BNPP, and the fineness modulus is slightly higher.

Table 3: Material properties of GGBS

Test item	Unit	UAE	ROK
Slag activity index (7 day)	%	86	77
Slag activity index (28 day)	%	111	89
MgO	%		3.21
SO_3	%	0.3	1.76
S	%	0.76	
Total alkalies	%	0.44	
Chloride ion	%		0.003
Granulation grade	cm^2/g	4800	4229
Density	g/cm^3	2.86	2.90
Loss on Ignition	%		0.74

Table 4: Material properties of fine aggregates (sand)

Test item	Unit	UAE	ROK
Fineness Modulus		2.67	2.33
Absorption	%	CS – 1.2 DS – 0.7	1.03
The quantity passing the 0.08 mm sieve	%		1.8
Specific Gravity (Density)	g/cm^3	CS - 2.69 DS - 2.63	2.60
Chloride ion	%		0.007

3.3 Preliminary Compressive Strength Test

Cylindrical specimens of $\phi 100 \times 200$mm are used for compressive strength test. Test results are shown in Table 5 and Fig. 2. The results from the UAE are from the concrete mixture proportioning report by KEPCO [5].

Table 5: Compressive strength of specimens made with Korean raw materials

Age (day)	Curing	Compressive Strength (MPa)				
		1	2	3	4	Avg.
7	30°C, 50%	21.3	23.2	23.3		22.6
	20°C, Water	17.9	18.6	18.6		18.4
28	30°C, 50%	30.5	32.5	30.9		31.3
	20°C, Water	34.0	34.8	35.1		34.6
42	20°C, Water	39.4	39.8	38.2		39.1
	Na_2SO_4-10% solution (after 28 days of curing in water)	34.2	35.9	36.0		35.4
91	30°C, 50%	40.6	38.3	38.2	38.2	38.8
	20°C, Water	42.2	43.2	44.2	41.3	42.7
	20°C, Na_2SO_4-10% solution (after 28 days of curing in water)	35.8	35.4	36.8	34.1	35.5

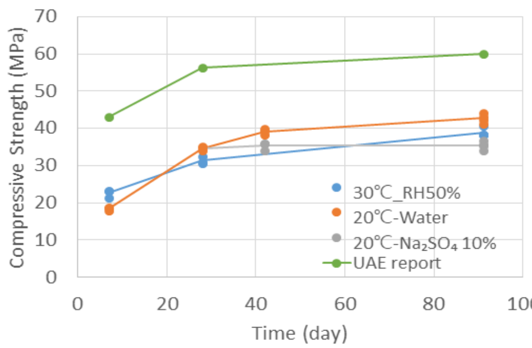

Fig. 2. Compressive strength of specimen made with Korean raw materials

Compressive strength in Korean material specimens with the same mix proportions as those in the UAE was around 30 percent lower due to differences in raw material properties, including aggregates and GGBS. The effect of sulfate solution on compressive strength can also be observed through the test results. The strength is reduced about 17 percent after the 60 days of immersion in a Na_2SO_4-10% solution.

4. Conclusions

The environmental conditions in UAE, especially at the BNPP site and the properties of raw materials and concrete strength used for the BNPP were reviewed.

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.

ACKNOWLEDEMENTS

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(Ministry of Science and ICT) (NRF-2022M2E9A3085593)

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