CHAPTER VI
ANALYSIS OF RESULTS

6.1 Introduction

The purpose of this chapter is to formulate the empirical equations that describe the relationship between compressive strength, saline concentration, and immersion time. The presented equations serve as predictive tools for estimating the reduction in the compressive strength of concrete subjected to varying concentrations of brine and immersion durations. The analysis involves the regression of the experimental test data utilizing IBM SPSS Statistics /software (Wendai, 2000). The final section of this chapter introduces the application of equations for estimating the lifespan of concrete under continuous immersion in saline water, which presents the relationship between the lifespan of the concrete and the saline concentration.

6.2 Compressive strength

To demonstrate the reduction in percentage of compressive strength of concrete over time, the normalized compressive strength (σ_c') are ploted as a fuction of immersion time for vaious of saline concentraion. The calculation of σ_c' is outlined as follows:

$$\sigma_c' = \frac{\sigma_c}{\sigma_{c0}} \times 100\% \tag{6.1}$$

where σ_{c0} is the compressive strength of concrete before immersion in saline solution (in ksc). This value represents the compressive at 28 days of curing time (σ_{c0} = 181 ksc). σ_c is the compressive strength of concrete after immersion in saline solution (in ksc), summaried in Chapter 5 (Table 5.2).

It is observed that the normalized compressive strength (σ'_c) decreases from 100% of the original value (181 ksc) after immersion in salt water. At 0% salinity, there was no significant change in compressive strength; it seemed constant for all time. However, for the samples soaked in salt water at 25%, 50%, 75%, and 100%, the normalized concrete strength decreased to 88%, 78%, 70%, and 63%, respectively, after 12 months.

The exponential relationships are proposed to correlate the percentage normalized compressive strength (σ'_c in %) with immesion time (t in months). The increase in salinity decreases the percentage of normalized compressive strength. Good correlations are obtained, as shown in Figure 6.1. The following equations represent their relationship:

$$\sigma'_c = 100 + \left\{\left(\frac{1}{\alpha}\right)\left(1 - e^{-\beta t}\right)\right\} \tag{6.2}$$

where β and γ are constants parameters (shown in Figure 6.1), and t is immersion time. Regressions analysis using SPSS software is performed to determine the above empirical constants from the test data. Figure 6.1 compares the test data with the predictions from Eq. (6.2). Good correlations are obtained ($R^2 > 0.98$).

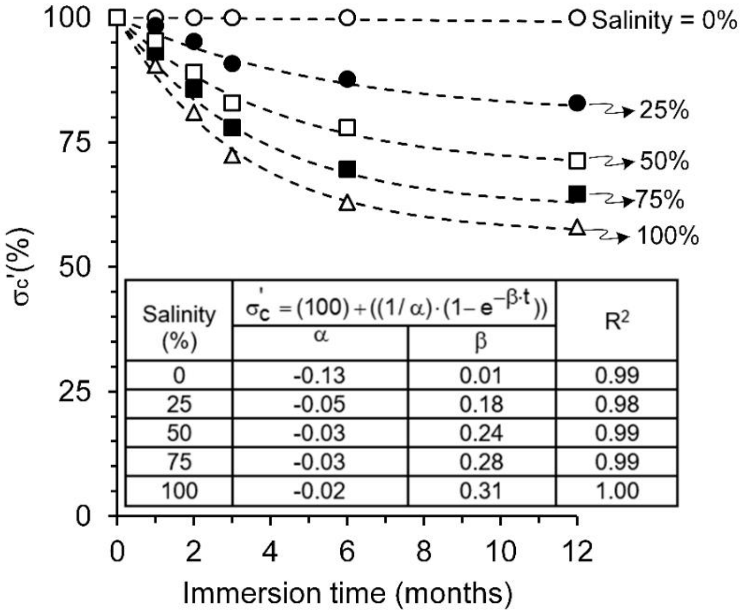
The multiplier α and β increases with the salinity (%), as depicted by the linear equation illustrated in Figure 6.2.

$$\alpha = 0.0010X-0.1018 \tag{6.3}$$

$$\beta = 0.0028X+0.0648 \tag{6.4}$$

where X is salinity (%). Substituting Eq. (6.3) and (6.4) into (6.2) the percentage normalized compressive strength (%) under different salinity and immersion time can be represented by:

$$\sigma'_c = 100+\left\{\left(\frac{1}{0.0010X-0.1018}\right)\left(1 - e^{-(0.0028X+0.0648)\cdot t}\right)\right\} \tag{6.5}$$



Salinity (%)	$\sigma_c' = (100) + ((1/\alpha)\cdot(1-e^{-\beta \cdot t}))$ α	β	R^2
0	-0.13	0.01	0.99
25	-0.05	0.18	0.98
50	-0.03	0.24	0.99
75	-0.03	0.28	0.99
100	-0.02	0.31	1.00

Figure 6.1 Relationships between normalized compressive strength (%) and immersion time for concrete subjected to different saline concentrations.

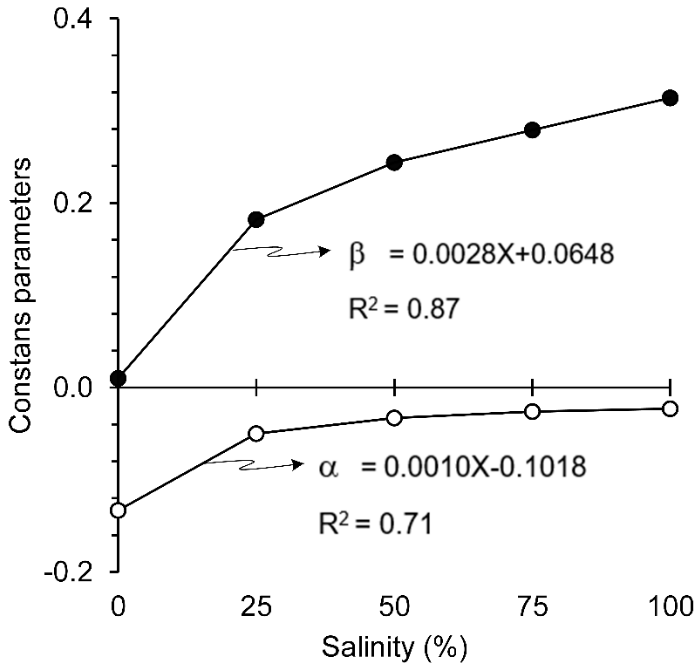


Figure 6.2 Constant parameters as a function of salinity (%).

The equation presented in Equation 6.5 serves as a tool to determine the percentage of concrete compressive strength at any given time relative to its initial strength before immersion in saline solution. This equation provides clear insight into the discernible trend of strength reduction over time.

6.3 Factor of Safety

The compressive strength of concrete is important for the stability of engineering structures that use concrete for construction. In general, the design lifespan of concrete is specified to be more than 100 years (Koh et al., 2014), and a general safety factor of 1.5 is specified according to EN 1992-1-1:2004 (E). The test results showed that the strength of concrete continuously immersed in saline water decreased with increasing time. At the same time, the inducing stresses on the concrete structure as initially designed remain the same and have not changed. Because of this, the safety factor (FS) set at the beginning also decreases over time. When the FS value decreases until it is equal to 1.0, it indicates that the structures fail under the design load. Hence, the ability to predict the lifespan of concrete in a saline environment holds practical significance for inspecting and monitoring concrete structure stability. Additionally, this predictive ability is helpful for engineers to plan and deal with future problems in a timely manner.

The mathematical expression for the factor of safety (FS) of concrete under applied uniaxial stress is given by:

$$FS = \sigma_c/\sigma \qquad (6.6)$$

where σ_c and σ are the ultimate compressive strength and compressive stress. With a safety factor of approximately 1.5, the average ultimate compressive strength (σ_c) is calculated as 181 ksc. Accordingly, the design load or compressive stress can be established at 120 ksc, considering variations in salinity and immersion time.

The compressive strength (σ_c) are plotted as a function of immersion time for various saline concentration as shown in Figure 6.3. The horizontal line extending along the x-axis corresponds to a concrete strength of 120 MPa, representing the stress value for safety factor (FS) of 1.5. Drawing a vertical line from the intersection point of each concentration's test result with the horizontal line allows for the identification of the specific time (concrete lifespan) at which the compressive strength starts decreasing, reaching the critical point of FS = 1.0. This point marks the onset of concrete failure. However, the lifespan of concrete at the critical point (FS = 1.0) under different saline concentrations can be determined through the utilization of the empirical equation detailed below.

The exponential relationships are proposed to correlate the compressive stress (σ_c) with immersion time (t). Good correlations are obtained from compressive strength, as shown in Figure 6.3. The following equations represent their relationship:

$$\sigma_c = \sigma_{c0} + \left\{ \left(\frac{1}{\alpha'} \right) \left(1 - e^{-\beta' t} \right) \right\} \tag{6.7}$$

where α', β' and are empirical constant parameters (shown in Figure 6.3), σ_{c0} is compressive stength, equal to 181 ksc, for concrete sample before immesion in saline water, and t is immersion time. Regressions analysis using SPSS software is performed to determine the above empirical constants from the test data. Figure 6.3 compares the test data with the predictions from Eq. (6.7). Good correlations are obtained (R^2 > 0.98).

The multiplier α' and β' increases with the salinity (%), as depicted by the linear equation illustrated in Figure 6.4.

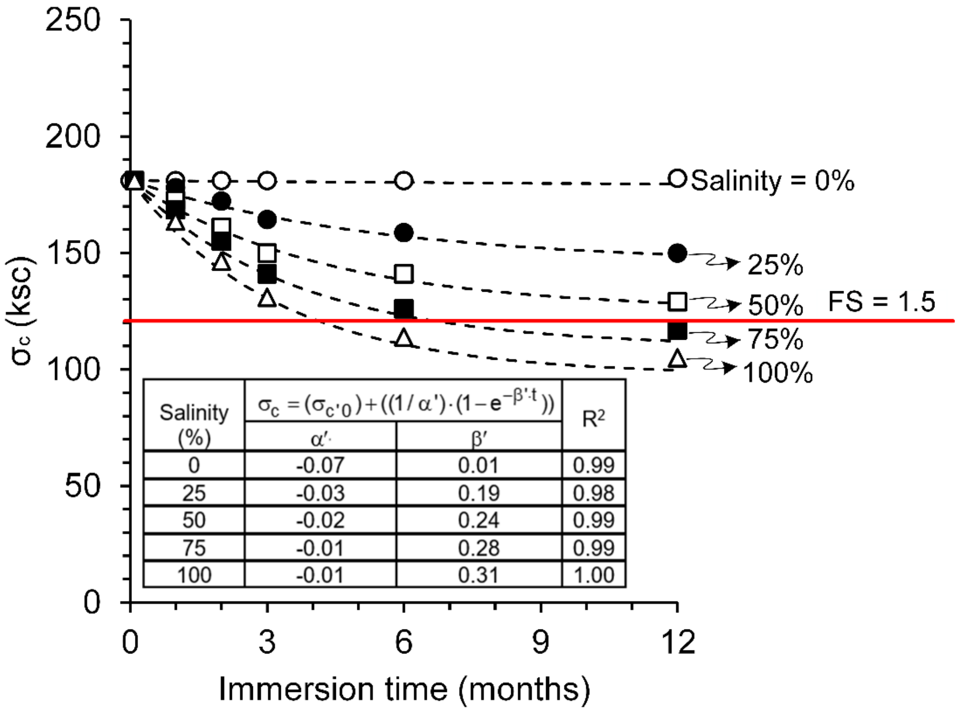
$$\alpha' = 0.0005X + 0.0544 \tag{6.8}$$

$$\beta' = 0.0028X + 0.0664 \tag{6.9}$$

where X is salinity (%). Substituting Eq. (6.8) and (6.9) into (6.10) the compressive strength under different salinity and immersion time can be represented by:

$$\sigma_c = \sigma_{c0} + \left\{ \left(\frac{1}{0.0005X + 0.0544} \right) \left(1 - e^{-(0.0028X+0.0664) \cdot t} \right) \right\} \tag{6.10}$$

The lifespan of concrete can be calculated using Eq. (6.7) by substituting σ_{c0} = 181 ksc, σ_c = 120 ksc (the remained strength of concrete where for FS = 1.5), X is ranging between 0% to 100%. The calculated value of 't' is the lifespan of concrete represents in Figure 6.5. Relationships between lifespan for concrete and salinity, when subjected to immersion in highly concentrated salt water, the durability of a concrete structure is adversely affected, potentially leading to a shortened lifespan. Conversely, under immersion in low-concentration saltwater, the steadfastness of concrete structures is maintained.



Salinity (%)	$\sigma_c = (\sigma_{c'0}) + ((1/\alpha') \cdot (1 - e^{-\beta' \cdot t}))$		R^2
	α'	β'	
0	-0.07	0.01	0.99
25	-0.03	0.19	0.98
50	-0.02	0.24	0.99
75	-0.01	0.28	0.99
100	-0.01	0.31	1.00

Figure 6.3 Compressive strength as a function of immersion time subjected to different saline concentrations.

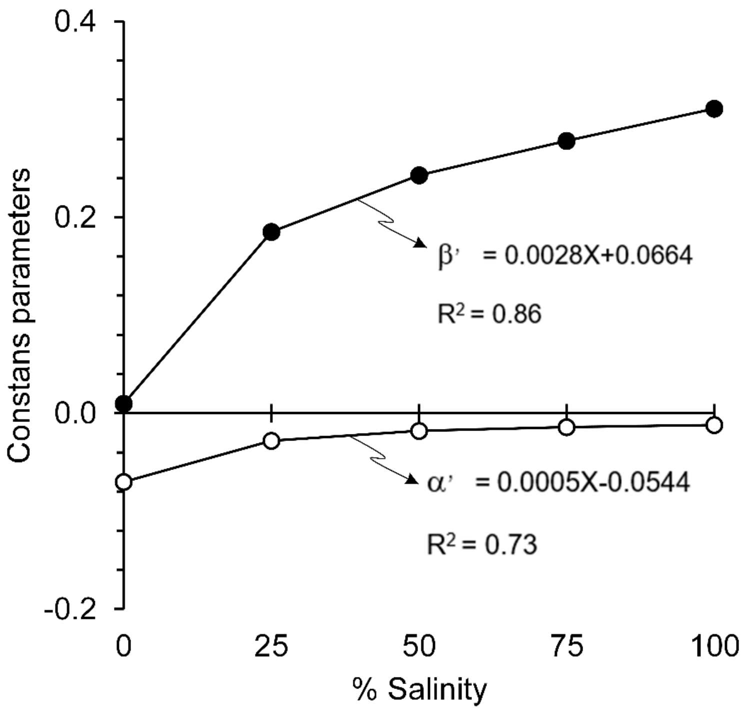


Figure 6.4 Constant parameters as a function of salinity (%).

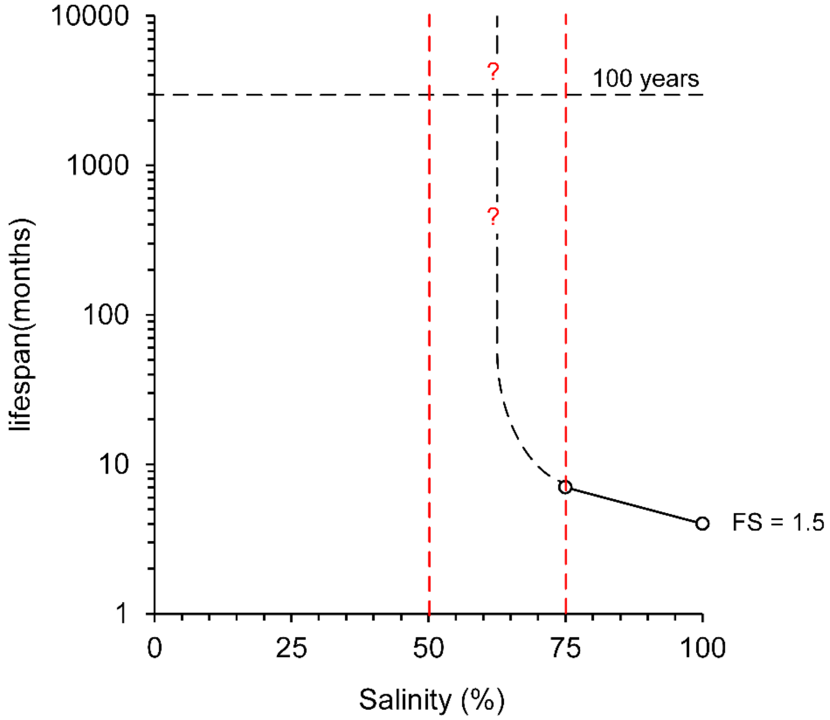


Figure 6.5 Relationships between lifespan for concrete and salinity (%).