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Periodica Polytechnica Civil Engineering, 64(3), pp. 647–657, 2020

Experimental Investigation on Chloride Diffusion Coefficient of Self-compacting Concrete in the Oman Sea

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Received: 26 November 2019, Accepted: 30 March 2020, Published online: 06 May 2020

Abstract

Chloride ion penetration is an important parameter influencing the service life of a concrete structure, especially in aggressive environments. Severe chloride-induced corrosion of reinforced concretes has been reported in the southern part of Iran in the region of Oman Sea. In this paper, the effect of different environmental conditions of the Oman Sea on chloride penetration and mechanical properties of self-compacting concrete (SCC) and normal concrete (NC) is investigated. For this purpose, a number of prismatic specimens were exposed to various environmental conditions such as tide, submersion and atmospheric conditions. Surface chloride concentration and diffusion coefficient of SCC in these zones were calculated based on Fick's second law, at 28, 90 and 150 days and compared with NC. Based on the values obtained in this study, relationships are proposed for concrete permeability and surface chloride of self-compacting concrete (SCC) at different ages in different aggressive environments. By determining the corrosion time based on these relations, it is observed that for a given water-to-cement ratio, the self-compacting concrete (SCC) has higher durability compared to normal concrete (NC).

Keywords

concrete, durability, diffusion, empirical model, Oman Sea

1 Introduction

Concrete, a composite material mainly composed of cement, aggregate and water uses approximately 20 billion tons of raw materials annually [1]. So, production of concrete with high durability is so important. The durability of hardened concrete greatly depends on the quality and permeability of concrete [2]. Corrosion caused by chloride is one of the most common and serious causes of concrete deterioration that affects the durability of concrete [3, 4]. In particular, chloride-induced corrosion is recognized to be the major cause of reinforced concrete deterioration subject to de-icing salts or located in marine environments [5, 6].

In marine conditions, the penetration of chloride ion into concrete and consequently the corrosion caused by its diffusion is the main cause of failure and shortening the service life of reinforced concrete structures. Hence, concrete structures situated in aggressive environments should be durable enough to withstand various aggressive factors such as diffusion of chloride ions and corrosion. Costa and Appleton [7] studied chloride penetration into concrete using fifty-four concrete specimens that were exposed to the marine environment for 3–5 years. In their research, three concrete mixes and five different exposure conditions were studied. Results indicated that both concrete diffusion coefficient and surface chloride is time-dependent.

Song et al. [8] showed that increasing the water-to-cement ratio leads to an increase in the diffusion coefficient of concrete. They also indicated that it is possible to reduce this coefficient by using additives with hydrating capacities. It was also revealed that diffusion coefficients of concrete and surface chloride are different in splash and tidal zones.

Moreover, the initial corrosion of reinforced concrete is mainly dependent on the chloride threshold penetration depth of concrete exposed to the marine environment. Cheewaket et al. [9] found that the threshold of chloride penetration depth increased more rapidly during the first five years, after which the rate of increase declined.

Valipour et al. [10] studied the penetration of chloride ion into concrete in various environmental conditions in the Persian Gulf. Results indicated that increasing the concrete density contributes to the enhancement of concrete

Cite this article as: Nosratzehi, N., Miri, M. "Experimental Investigation on Chloride Diffusion Coefficient of Self-compacting Concrete in the Oman Sea", Periodica Polytechnica Civil Engineering, 64(3), pp. 647–657, 2020. https://doi.org/10.3311/PPci.15335

durability in aggressive environments. Another study was performed by Safehian and Ramezanianpour [11] on the permeability of concrete in the Persian Gulf marine environment. Results indicated that the concrete diffusion coefficient (D_c) depends on the concrete type and mix design.

Self-compacting concrete (SCC) is a particular type of concrete that can be placed and compacted under its own weight [12, 13]. The use of SCC has become popular during the past decade [14]. SCC is needed for modern buildings [15] and can be used without a need for externally or internally induced vibration [16].

Some researchers have studied the mechanical properties of SCC mixes and compared the results with those of normal concrete (NC) mixtures [17–19]. Moreover, the durability of SCC has been studied by some researchers and the investigations indicated its excellent performance [20–26]. Tests used in these studies have included RCPT, water permeation, salt scaling resistance tests, chloride penetration and electrical, resistivity.

Calado et al. [27] compared the durability indicators of SCC and NC specimens in tropical coastal environments. The experiments developed in the laboratory at the construction site of the Pernambuco Arena. They showed that SCC presented better durability indicators than the normal concrete. The chloride diffusion factor was very low in the SCC samples at both 28 and 90 days. In other research, Rao et al. [28] investigated the mechanical properties and durability of self-compacting. They showed that the SCC mixes performed better than NC in the corrosion parameters.

da Silva and de Brito [29] examined the durability performance of self-compacting concrete. Results indicate that the penetration of chloride ion in SCC is affected by the amount of mineral additives. Nielsen and Geiker [30] proposed a model based on Fick's second law for prediction of the diffusion coefficient of chloride ion. In a study by Ghods et al. [31] the maximum diffusion coefficient of chloride ion (D_c) and concentration of surface chloride (C_s) were obtained from the tide and splash zones, respectively.

Lin et al. [32] introduced a numerical model based on the finite element method for prediction of the service life of structures exposed to chloride environments. They used a model to study the effects of parameters such as humidity, temperature, and concentration of chloride ion. Wang and Lee [33] proposed a model for the penetration of chloride ion into concrete containing fly ash. In their model, concrete behavior was assessed based on chloride ion penetration and hydration models.

Ryan and O'Connor [34] utilized the results of chloride diffusion testing and probabilistic deterioration modeling to compare the predicted time of initiation of corrosion for self-compacting concretes. Kim et al. [35] investigated chloride diffusion in marine conditions. It was confirmed that the chloride diffusion factor was sensitive to environmental conditions. Also, they found that the time of corrosion can be evaluated in each zone using the error function solution and modified physical model.

The Oman Sea is experiencing a more intense crisis compared to other seas around the globe due to its corrosive nature. The Southern coasts of Iran impose high annual financial losses to the economy of this country due to problems associated with the composition of concrete are not durable enough [36]. Therefore, more research on the durability of concrete seems more necessary, as many concrete structures are to be built in this area.

Most of the aforementioned studies [7–10, 30–33, 37–40] addressed the diffusion coefficient only for normal concrete. In addition, most of the samples were built, cured, and tested in lab conditions. The authors couldn't find any research with samples cured in the real conditions in southeast Iran, especially on self-compacting concrete in the Oman Sea.

The aim of this study is to investigate chloride penetration and mechanical properties of self-compacting concrete and normal concrete under different environmental conditions in Chabahar Port, which is located in southeastern Iran, north of Oman Sea.

2 Experimental programs

2.1 Materials

Ordinary Portland Cement (OPC), type II, according to ASTM C150 [41], were used in this study. The specific surface area of cement was 2900 cm^2/g, and chemical analysis of cement as presented in Table 1. River sand as fine aggregate with fineness modulus of 3, specific gravity of 2.57 g/cm^3, and water absorption of 1.5 % were used in this study. Moreover, crushed limestone as coarse aggregate with a maximum nominal diameter of 19 mm, the specific gravity of 2.52 g/cm^3 and water absorption of 0.9 % were used. The grading of fine and coarse aggregates is presented in Fig. 1 and compared with ASTM C33 [42] requirements. Moreover, superplasticizers or High Range Water Reducers (HRWR) according to Type G of ASTM C 494 [43] were utilized.

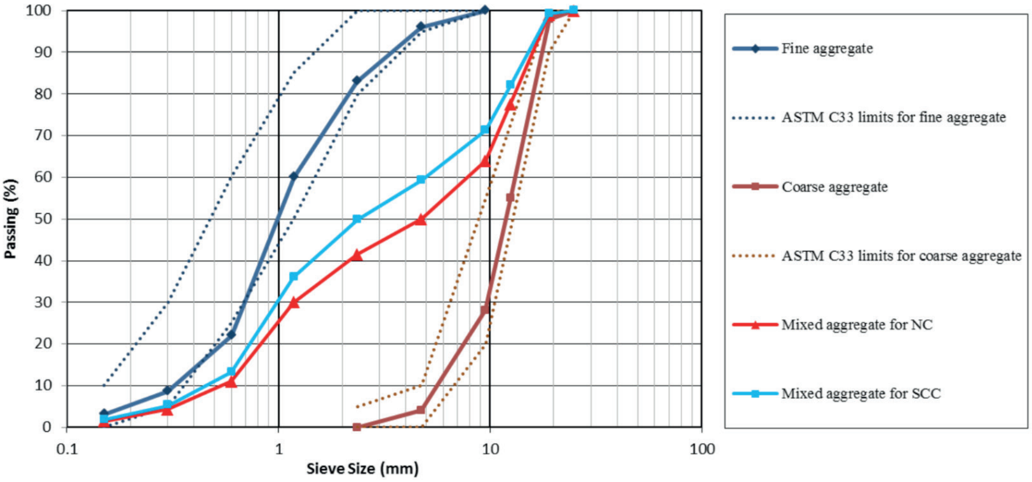


Fig. 1 Grading of aggregates and comparison with ASTM C33 requirements

Table 1 Chemical composition of cement (%)

CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	NaO_2
64	21.5	5	3.8	3	1.6	0.6	0.5

2.2 Mixture proportions

NC and SCC mixtures were the same in terms of materials but mixed with different ratios. The main difference between NC and SCC mixes was in the coarse aggregate content; SCC had less coarse aggregate content (660 kg/m^3) compared to NC (902 kg/m^3). SCC and NC mix designs are presented in Table 2.

2.3 Specimen preparation, casting and curing

In this study, two types of specimens including cubic and prismatic specimens were prepared to investigate the effect of environmental conditions. Compressive strength tests were conducted at the ages of 28, 90 and 150 days on cubic specimens with side lengths of 150 mm. Prismatic specimens of size 150 mm × 150 mm × 500 mm for in-situ chloride penetration investigations were cast.

Two specimens for each type of concrete were made for different exposure conditions. After the curing phase, to achieve one-dimensional penetration of the chloride ion in the diffusion test, the other lateral surfaces of samples were coated with polyurethane-based epoxy (Fig. 2). This material is resistant to the aggressive environment of the Oman Sea.

For in-situ exposure conditions, after a week of moisture-curing in the laboratory, specimens were transferred to the durability research site (Fig. 3) and exposed to the following three conditions: submersion, tidal and atmospheric. Some of the cubic specimens were continued moisture curing in the laboratory.

Table 2 Concrete mix design (kg/m^3)

Mix Design	Sand	Gravel	Cement	Water	Limestone	HRWRA
NC	902	902	425	170	-	0.4
SCC	993	660	425	170	150	2.9

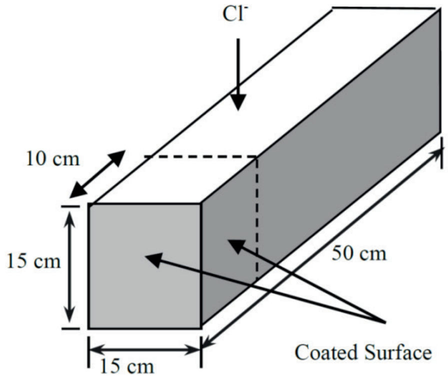


Fig. 2 Typical concrete prism specimen and preparing the slice for powder sample

Fig. 3 Location of the concrete durability research site, the Oman Sea (Chabahar Port)

Moreover, two cylindrical specimens with a height and diameter of 10 cm were prepared from each mix design to determine the concrete permeability according to NT Build 443 standard [44] for laboratory conditions. As instructed by the standard, the test samples were cured in saturated limewater for 28 days in a laboratory environment. After curing, the test specimens were removed out of the water and prepared as instructed by the NT Build 443. The specimens were then cured in saltwater with a concentration of 16.5 wt.% for 35 days, after which their chloride ion profiles were determined.

2.4 Exposure conditions

Table 3 shows the mean monthly temperature and relative humidity of the Chabahar port (located in the Oman Sea) [45]. The specimens were exposed to three types of exposure environments including tidal, submerge and atmospheric, on Chabahar port (Fig. 3) for different exposure time (28, 90 and 150 days).

Table 4 compares the chemical properties of the Oman Sea with other seas [46]. As can be seen, the Oman Sea has more chloride ions.

2.5 Sampling and testing

At the ages of 28, 90 and 150 days, chloride diffusion was determined in prismatic specimens. Each time, 100 mm was cut from the end of the prisms. The cut section of the remaining part was coated, as shown in Fig. 2, and the specimen was moved back to the exposure conditions.

A hole with a nominal diameter of 45 mm was drilled from the finished surface of the slice to an estimated depth of chloride penetration.

Powders were collected from different layers of concrete surfaces and analyzed separately for measuring the content of acid-soluble chloride, according to ASTM C1152 [47] and ASTM C114 [48].

2.6 Chloride diffusion

The penetration of chloride ion into the concrete members can be expressed by Fick's second law as [49]

$$\frac{\partial C}{\partial T} = D_C\left(\frac{\partial^2 C}{\partial x^2}\right). \tag{1}$$

The Eq. (2) is the solution of the above differential equation:

$$C(x,t) = C_s \times \left(1 - erf\left(\frac{x}{2\sqrt{D_c t}}\right)\right), \tag{2}$$

where x denotes the distance from the concrete surface (meter), t is the exposure duration (second), D_c is the diffusion coefficient (m^2/s). C_s shows the weight percentage of concentration of chloride on the concrete surface, and $C(x,t)$ is the weight percentage of chloride ion in a depth of x from the surface during time t. Moreover, *erf* is the error function which is expressed as follow:

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-\beta^2} d\beta. \tag{3}$$

To estimate the diffusion coefficient D_c and the surface chloride C_s, firstly, the concentration of chloride (C_L) at different concrete depths of the prepared samples should be determined according to powder making and titration test. For this purpose, chloride ion profiles were measured at nine depths of NC and SCC samples. Then, D_c and C_s values were obtained by using the fitting toolbox of Matlab.

Table 3 Mean temperature and relative humidity of Chabahar port in different months of the year

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Mean temperature (°C)	19.9	20.9	23.6	26.8	29.8	31.4	30.8	29.5	28.8	27.6	24.5	21.6	26.3
Mean relative humidity (%)	62	68	72	73	75	78	79	80	78	75	68	63	72

Source: Iran Meteorological Organization website [45]

Table 4 Chemical analysis of the water of the Oman Sea -Chabahar Port as compared to water of other seas (mg/l)

Content	Baltic Sea [46]	Atlantic Sea [46]	North Sea [46]	Mediterranean Sea [46]	Persian Gulf [46]	Oman Sea*
Ca^{2+}	190	410	430	470	430	401
Mg^{2+}	600	1500	1330	1780	1460	1519
SO_4^{2-}	1250	2540	2780	3060	2720	3336
Na^+	4980	9950	11050	11560	12400	13800
Cl^-	8960	17830	19890	21380	21450	21625
Salt	16200	32600	35900	38700	38900	39331

* From chemical test results

3 Results and discussion

3.1 Compressive strength

Summary of the compressive test results for cubic samples, after being exposed to the aforementioned environments, is presented in Table 5. The results are prepared for three different ages (28, 90 and 150 days). Each value is the average of three compressive measurements. As can be seen from Table 5, SCC concrete showed higher strength than normal concrete in different environments.

The strength of the SCC specimens cured under laboratory, submerged, tidal, and atmospheric conditions at the age of 150 days was 50.2, 43.9, 49.5, and 47.1 MPa, respectively, while these values were 48.1, 41.5, 46.5, and 44.2 MPa for the NC. As shown, the SCC results in a lower decrease in strength compared to NC at high ages. However, the trend of strength variations in SCC under different environments is similar to compressive strength in NC. On the other hand, under atmospheric conditions, the compressive strength of concrete is lower compared to submerged and tidal conditions.

3.2 Chloride diffusion profiles

3.2.1 Laboratory exposure

The test results obtained according to the NT Build 443 standard are presented in Table 6 to determine the permeability and concentration of chloride ions on the studied mix designs under laboratory conditions.

As shown in Table 6, the permeability of SCC specimens is lower compared to the NC, which is due to the high compactness of the SCC. Reducing the nominal maximum size of aggregates and using mineral powder as filler to modify the mix design reduces the permeability and increases the durability of SCC.

Table 5 Results of the compressive strength test (MPa)

	28 days		90 days		150 days	
Zone	NC	SCC	NC	SCC	NC	SCC
Laboratory	40.3	41.5	43.5	46.2	48.1	50.2
Atmosphere	36.6	38.6	38.1	40.5	41.5	43.9
Submerge	40.3	41.1	43.1	45.1	46.5	49.5
Tidal	38.6	39.8	40.9	43.2	44.2	47.1

Table 6 Apparent chloride diffusion coefficient and surface chloride concentration in the laboratory

Concrete type	D_c ($\times 10^{-12}$) (m^2/s)	C_s (% wt. of concrete)
NC	9.5	0.87
SCC	7.4	0.85

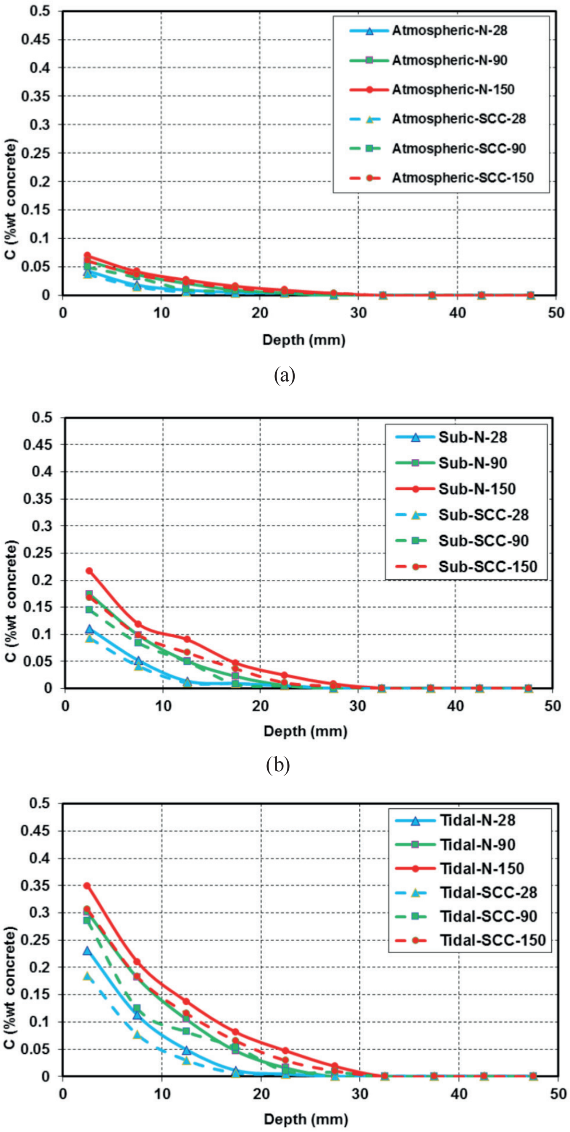
3.2.2 Field exposure

Chloride ion profiles obtained by fitting chloride concentrations at the corresponding depths of NC and SCC, as presented in Fig. 4.

The permeability and surface chloride for NC and SCC in different environments are presented in Table 7. The results obtained in each studied environment are discussed in the following.

Atmospheric conditions

In Figs. 5 and 6, the diffusion coefficient and surface chloride concentration for both the NC and SCC are compared in the atmospheric conditions. The surface chloride concentration for NC is about 0.054 % and 0.08 % at the ages of 28 and 150 days, respectively. Corresponding values



(a)

(b)

(c)

Fig. 4 Profiles of chloride ions of NC and SCC for different exposure conditions: (a) atmospheric; (b) submersion; (c) tidal

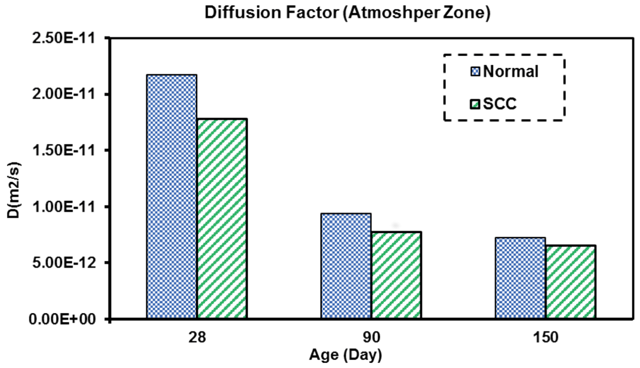


Fig. 5 Concrete diffusion coefficient at different ages in atmospheric conditions

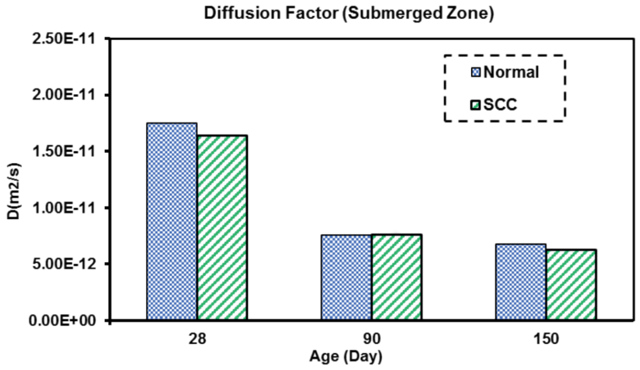


Fig. 7 Concrete diffusion coefficient at different ages in submersion conditions

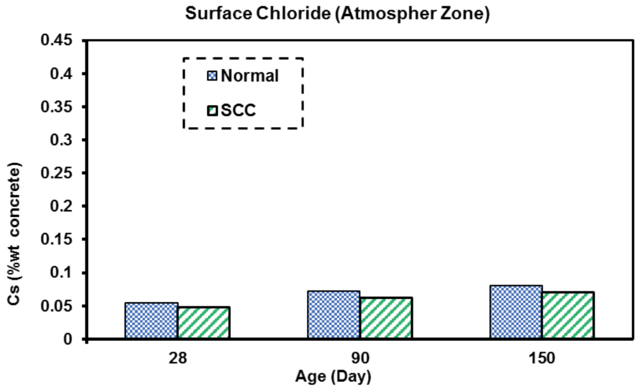


Fig. 6 Concrete surface chloride concentration at different ages in atmospheric conditions

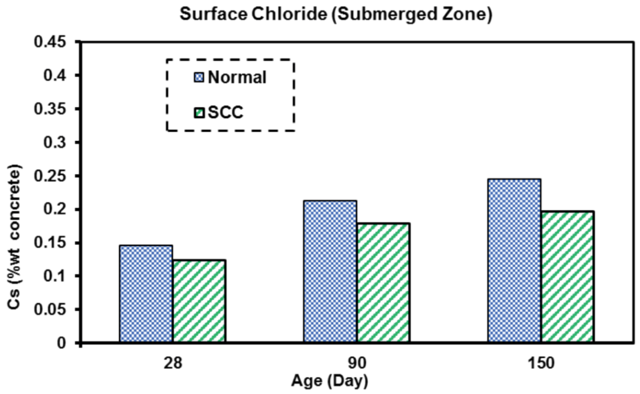


Fig. 8 Concrete surface chloride concentration at different ages in submersion conditions

for SCC is about 0.048 % and 0.071 % at the ages of 28 and 150 days, respectively. Based on the presented results, one can deduce that the diffusion coefficients for SCC are about 21 % and 10 % lower than NC at the ages of 28 and 150 days, respectively.

The concentration of the chloride ion in SCC is lower than NC in the atmospheric zone at similar times. Moreover, the results indicate that in the atmospheric zone, by increasing the time of exposure to an aggressive environment, the concentration of the surface chloride ion increases, whereas its diffusion coefficient decreases.

Submersion conditions

In Fig. 7, the diffusion coefficient for both the NC and SCC are compared in different ages. The diffusion coefficients for SCC are about 7 % and 9 % lower than NC at the ages of 28 and 150 days, respectively. As shown in Fig. 8, the surface chloride concentration in submersion conditions for SCC is about 17 % and 25 % lower than NC at the ages of 28 and 150 days, respectively.

The concentration of the surface chloride ion in the submerged zone in SCC at a given time is lower compared to that in NC. Moreover, the results show that in the submerged zone, by increasing the exposure time, the concentration of surface chloride increases, whereas the diffusion coefficient of concrete decreases.

Tidal conditions

The diffusion coefficient and surface chloride concentration of tidal condition are shown in Figs. 9 and 10, respectively. According to summarized results in Table 7, values of diffusion coefficient (D_c) for normal concrete samples in tidal condition at 28 and 150 days reduced to 20.71×10^{-12} m^2/s and 7.21×10^{-12} m^2/s, respectively.

On the other hand, in this condition, the diffusion coefficient of SCC samples for 28 and 150 days were 16.05×10^{-12} m^2/s (25 % lower than normal concrete) and 6.40×10^{-12} m^2/s (13 % lower than normal concrete). This reflects better performance and higher durability of SCC in tidal conditions.

In tidal zone, the concentration of surface chloride on SCC was lower at all ages. Moreover, surface chloride concentration reached from 0.298 % to 0.398 % from the age of 28 days to the age of 150 days. However, the surface chloride concentration at the same ages of SCC reached from 0.248 % to 0.357 %.

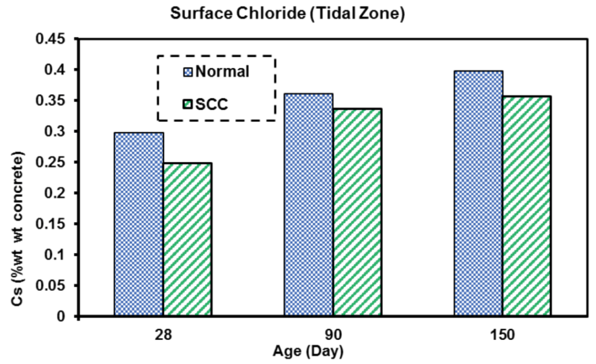


Fig. 9 Concrete diffusion coefficient at different ages in tidal conditions

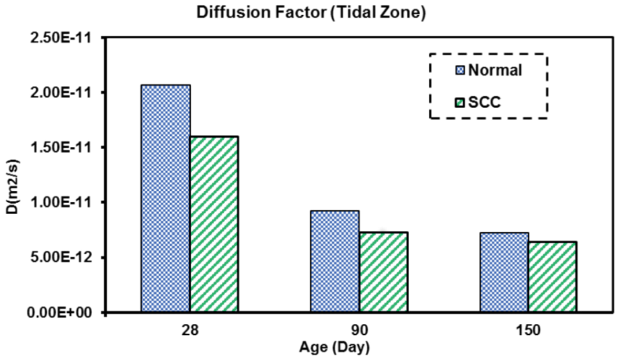


Fig. 10 Concrete surface chloride concentration at different ages in tidal conditions

Results show that the normal concrete has a higher diffusion coefficient in tidal, submersion and atmospheric conditions at all ages in the order of appearance. In most samples for all exposure conditions, due to the continuity of cement hydration, the microstructure of concrete was enhanced and the value of the diffusion coefficient was reduced.

3.3 Time to corrosion

The solution for the Fick's 2nd law of diffusion (Eq. 2) was used to model the permeation of chloride ion in concrete under submerged, tidal, and atmospheric conditions [50, 51]. According to the results, the concentration of the surface chloride ion and the permeability coefficient of the concrete change over time. Therefore, the time variations should be taken into account when modeling the permeation of chloride ion.

Eq. (4) was used in most modeling procedures to take into account the variations of chloride ion diffusion over time [35, 50, 51].

$$D_a(t) = D_{ref}\left(\frac{t_{ref}}{t}\right)^m \tag{4}$$

In this relationship, D_{ref} is the diffusion coefficient for the chloride ion obtained from the NT Build 443 test, t_{ref} is the time corresponding to the diffusion coefficient D_{ref} (equal to 28 days), t is the age of concrete, and m is the age factor of concrete.

The results from published researches show that the long-term results should also be used to determine the age factor of concrete. Based on the permeability coefficient values obtained for SCC and NC under laboratory conditions at the age of 28 days as well as the field results, the age factor (m) was assumed to be 0.2 in the modeling process in the Life365 software [52]. Assuming this value for age factor, Eq. (4) can be used to almost accurately predict the permeability values in Table 7 based on the results of the NT Build 443 test.

Various relationships have been proposed to take into account the variations in the concentration of surface chloride ion [35, 50, 52]. In Life365 software [52], the concentration of surface chloride ion is considered to vary linearly with time. However, the results reported by Wu et al. [50] and Kim et al. [35] suggest that Eq. (5) is more consistent with the results measured from specimens exposed to submerged, tidal, and atmospheric conditions.

$$C(t) = C_0 t^n \tag{5}$$

In this relation, $C(t)$ is the weight percentage of chloride ion with respect to concrete, t is the duration of exposure to chloride, and constants C_0 and n are obtained by fitting the curve on the measured concentration of surface chloride ion at different times. Therefore, the parameters C_0 and n were determined by curve fitting Eq. (5) using the results from the measurement of concentration of surface chloride ion. The results were presented in Table 8 for each of the atmospheric, submerged, and tidal conditions.

Table 7 Apparent chloride diffusion coefficient and surface chloride concentration in field exposure

	D_c ($\times 10^{-12}$) (m^2/s)						C_s (% wt. of concrete)					
Days	28		90		150		28		90		150	
Concrete type	NC	SCC	NC	SCC	NC	SCC	NC	SCC	NC	SCC	NC	SCC
Atmosphere	21.70	17.83	9.36	7.73	7.21	6.55	0.054	0.048	0.072	0.062	0.08	0.071
Submerge	17.52	16.42	7.57	7.59	6.79	6.24	0.146	0.124	0.213	0.179	0.245	0.196
Tidal	20.71	16.05	9.24	7.30	7.21	6.40	0.298	0.248	0.361	0.337	0.398	0.357

Table 8 Parameters of C_0 and n

Storage condition	C_0		n	
	NC	SCC	NC	SCC
Atmosphere	0.0267	0.0248	0.2149	0.2113
Submerge	0.0676	0.0644	0.2532	0.2829
Tidal	0.1874	0.1386	0.1564	0.2028

By applying the finite difference method and based on Eqs. (2), (4) and (5), and the use of concrete permeability and concentration of surface chloride ion obtained from NT Build 443 standard test, chloride ion penetration profile was modeled. Then, the beginning of the rebar corrosion process at a depth of 5 cm in SCC and NC specimens was investigated. Fig. 11 compares the results obtained from the model and the experimental results, indicating good consistency between them.

Note that the corrosion process is started when the concentration of the chloride ion reaches the critical concentration level [35, 50, 52, 53]. Time to corrosion initiation results is presented in Table 9. Note that the critical chloride ion concentration was considered to be 0.05 wt% of concrete [53].

The corrosion initiation time obtained from the modeling is compared with the outputs of the Life365 software in Table 9. The corrosion in the model of NC under submerged and tidal conditions started sooner compared to Life365, which is due to assuming an identical age factor related to the difference in the variations of concentration of surface chloride ion. Note that in Life365 software, the finite difference method is used to solve the diffusion equation. However, the corrosion occurs sooner for the NC under atmospheric conditions in the Life365 software compared to the prepared model in this study. The reason for this can be attributed to the difference in variations of concentration of surface chloride ion over time. Investigating of the corrosion initiation time indicates that NC experiences corrosion sooner than SCC. The corrosion initiation time in SCC under tidal, submerged, and atmospheric conditions is longer than NC by a factor of 1.65, 1.45, and 2.03, respectively. For the same water-to-cement ratio in both SCC and NC, these differences can be attributed to the application of mineral powder in SCC species which reduces the concrete permeability. The decrease in permeability is due to the filling of the concrete porosities by mineral powder, which are shown by Sawicz and Heng [54], Ghafoori et al. [55], and Ramezanianpour et al. [56].

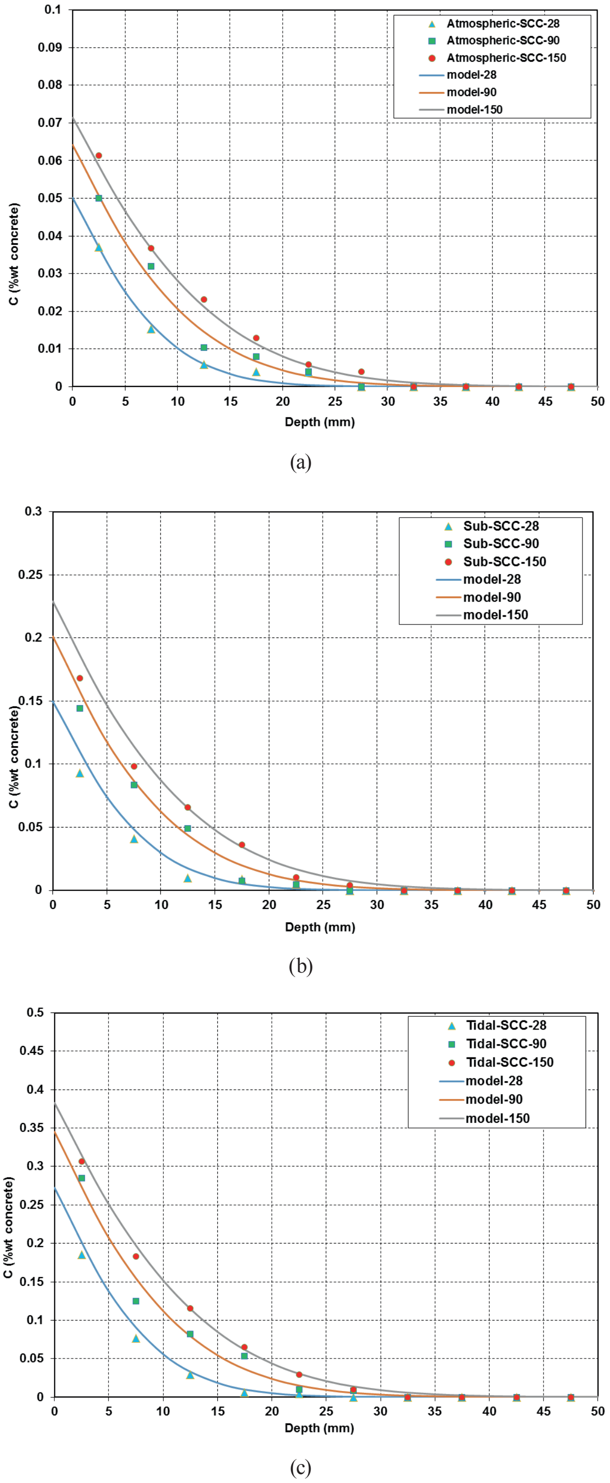


Fig. 11 Comparison of experimental results with model predictions for self-compacting concrete under different exposure conditions: (a) atmospheric; (b) submersion; (c) tidal

The results indicate that the time to corrosion initial in tidal conditions is shorter than in atmospheric and submerged conditions. The corrosion beginning time for NC species under atmospheric and submerged conditions

Table 9 Predicted time to reach critical chloride concentration (C_{cr}) at 50 mm depth in each exposure zone

Storage condition	Time to reach C_{cr} (year) based on the model		Time to reach C_{cr} (year)
	NC	SCC	Life-365
Atmosphere	12.0	17.1	10.1
Submerge	3.4	5.1	3.6
Tidal	2.7	3.7	3.1

was longer than it in tidal conditions by 4.4 and 1.3 times, respectively. Similarly, these factors were 4.6 and 1.4 times for SCC. The results obtained in this study are consistent with those reported by Kim et al. [35].

4 Conclusions

By analyzing three aggressive environments in the Oman Sea and their effects on the penetration of chloride ion into concrete, the following results were obtained in this research:

According to the test results, tidal is the most aggressive zone in terms of penetration of chloride ion into normal and SCC specimens.

Analysis of profiles of chloride ion reflects the satisfactory performance of SCC as compared to normal concrete in the Oman Sea.

The values of surface chloride and diffusion coefficient in submersion conditions also showed better performance on SCC. The diffusion coefficient of SCC on 28 days and 150 days were 10 % and 15 % lower than that of normal concrete, respectively. In the same conditions, the surface chloride concentration of self-compacting concrete on 28 days and 150 days were 18 % and 52 % lower than that of normal concrete, respectively.

The proposed equations to determine the amount of surface chlorine and the chloride diffusion factor of concrete are more accurate than the Life 365 software in normal and self-compacting concrete. By comparing experimental results with proposed models, the accuracy of each model is high and acceptable in different environments.

Investigating the initiation time of corrosion indicates that the time of corrosion of self-compacting concrete is longer than normal concrete. The time to corrosion in the tidal, submerged and atmospheric conditions of self-compacting concrete are 1.65, 1.45 and 2.03 times higher than normal concrete, respectively. In general, the results show that the use of self-compacting concrete in marine structures located in the Chabahar zone reduces permeability and improves the durability of chloride ion penetration.

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