International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

Durability of Reinforced Concrete in Red Sea Marine Structures

Salma Faith Elaleem

Teaching Assistant, Civil Engineering Department, Red Sea University, Portsudan-Sudan

Abstract: ***Reinforced-concrete structures in the marine environment often deteriorate in the early stages of their service life. The main cause is corrosion in reinforcement and concrete, which may interact adversely with each other. In this paper eighteen cubes and eight reinforced concrete beams were casted and investigated for durability in tidal and submerged zones. The effect of deterioration, which is influenced by various factors, such as the mix proportion of the concrete, the depth of cover and the environmental conditions, was observed and the results from physiochemical processes, such as ion transportation and carbonation are discussed. The results of cubes in tidal zone observed that fluctuating in weight and so in volume which lead to produce cracking, as expressed in the study, for the cubes in submerged zone, increased in weight and subsequently lead to expansion and the marine growth covered the surface; for beams prevent adequate visual examination of concrete .The penetration and diffusion of chloride ions at the early age of construction, forming a corrosion environment of the reinforcing steel, but without carbonation***

Keywords: Durability, Reinforced concrete, Red Sea structures

1. Introduction

Most Sea water are similar with respect to the types and amounts of dissolved salts; the typical salt content is 35% by weight (35 g/ liter or 35 parts per thousand parts) and the principal ions present are $Na^{+,}$ Mg^{+2},Cl^{-}, and $(So_4)^{2-}$. In addition to dissolved salts, the presence of certain gases near the surface of seawater or in Sea water also plays an important part in the chemical and electrochemical phenomena influencing concrete durability. For instance, oxygen (O_2) present in the atmospheric air and in Sea water, depending on local conditions, varying concentrations of dissolved carbon dioxide (CO_2) and hydrogen sulfide (H_2S) may be found in Sea water and may cause lowering of the pH from its normal value, 8.2 - 8.4, to 7 or even less. Acidic waters reduce the alkalinity and strength of concrete, and enhance the electrochemical corrosion of the embedded steel.

Marine growth involving barnacles and mollusks are frequently found on the surface of porous concrete whose alkalinity has been greatly reduced by leaching. Barnacles, sea urchins, and mollusks are known to secrete acids which can cause boreholes in concrete and pitting corrosion on the surface of embedded steel. Some mollusks produce ammonium carbonate, which is very damaging to concrete. H_2S generating anaerobic bacteria are found in sediments containing oil, known as, the obacillus concretivorous attack weak and permeable concrete, leading eventually to pitting corrosion of the embedded steel. The presence of aerobic or sulfur-oxidizing bacteria causes the conversion of H_2S to sulfuric acid, which is highly corrosive to both concrete and reinforcing steel. Marine growth may also be a problem because it can produce increased leg diameter and displace volume which would result in increased hydrodynamic loading. The additional surface roughness provided by marine growth will increase the drag coefficient and will enhance the hydrodynamic, thus influencing structural stability structures; marine growth also prevents adequate visual examination of concrete surfaces for other defects.

The Red Sea weather conditions are mostly fluctuating from high temperatures in summer to low temperatures in winter; with similar pattern of relative humidity. Hot weather can adversely affect the rate of cement hydration, and the initial setting very rapidly thus decreases the varies slump. Thermal cracking can occur with temperature throughout the day; plastic shrinkage cracking is typically associated with high concrete temperature, low relative humidity and water bodies**.** The hydrostatic pressure of Sea water on the submerged portion of a structure follows the simple relationship:

$$P=\rho\, h \qquad (1)$$

Where P is unit pressure, ρ is density of the fluid, and h is depth of water. The hydrostatic pressure acts as a driving force to push seawater through a permeable material. A marine structure is exposed in the tidal range (between low and high tide levels) to twice-a-day cycles of wetting and drying, heating and cooling (due to differences between air and seawater temperatures).

Waves are caused mainly by the action of wind on water; through friction the wind energy is transformed into wave energy. [1]

The main objective of this research is:

- To assess clearly the aggression of concrete in marine environment (chemical action).
- To study the effect of permeability and diffusivity on concrete durability in marine environment.
- To specify acceptable limits of environmental marine concrete mix parameters, particularly (w/c ratio, cement content and selected admixtures).

2. Related Work

2.1 Materials and Specimens Preparation

Two types of cement were used in this, namely ordinary Portland cement (C_3A>5) and sulphate resistant Portland cement (C_3A<5). The reinforcing steel used for exposure tests are mild steels, the yield strength, FY for the tension

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steel bar were (250) Y12. The W/C ratios of the concrete as test was 0.53BS, and another mixture of 0.46, 0.42 and 0.6 of W/C ratio were casted for comparison for durability under the marine environment. The materials use in mix one was shown in table (1) below:

Table 1: Beam description

No of beam	B1	B2	B31	B32	B4	B5	B6	B7	B8
Beam Type	OPC	SRPC	OPC	OPC	OPC	OPC	OPC	OPC	OPC
Cement (Kg)	445.65	445.65	445.65	445.65	488.95	410	445.65	445.65	341.67
W/C ratio	0.46	0.46	0.46	0.46	0.42	o.53	0.46	0.46	0.6
Admixture	done	Done	done	done	done	non	Done	done	non
Slump(mm)	75-100	75-100	75-100	75-100	75-100	75-100	75-100	75-100	75-100
Cover(mm)	40	40	40	40	40	40	30	25	40
Coating	done	Done	done	non	done	done	Done	done	done
Dimension(cm)	20 X25	20 X25	20 X25	20 X25	20 X25	20 X25	20 X25	20 X25	20 X25

2.2 Location

Specimens of this investigation were collected from Red Sea region at Port Sudan (Sudan), the natural environment of Port Sudan is located in middle of west bank of red sea 19.35˚of north latitude 37.13˚of east longitude.

The maximum temperature is 47˚ C, the minimum temperature 18˚ C and the maximum relative humidity is 85%, the minimum humidity 40%.The maximum wind speed is 25m/s ,the minimum wind speed 5m/s and the average 8~10 m/s .

The maximum sea current speed is 0.5m/s, the wave height is 1.25m the maximum tide rang is less than 1m. [2].

The chlorine ion content and sulphate content $(SO_4)^{-2}$ of Red Sea water as shown in table (2)

Table 2: Results of Chloride and Sulfate Contents Red Sea Water

Sample No.	Sample designation	Sulphate content (%)	Chloride content (%)
1	Red Sea water	2.43g/l	23.9g/l

The work carried out in this paper was done in two zones of marine environment:
Tidal zone: beams in this zone were exposed to splash, (wetting/drying, heating/cooling cycles).
Submerged zone: beams in this zone were set submerged in Red sea water.

2.3 Measurements

Cubes were put in tidal and submerged zones then cleaned with iron brush and weighted after 15days for 6 months repeatedly.
For beams two types of measurements were done: a non-destructive test done in the exposure field [7] and laboratory analysis of exposed beams [8] showing in table (3). The experiment was run after 6 months exposed to marine environment conditions

Table 3: Measurements for beams investigation

Measurements at exposure site	Visual inspection	Crack, discoloration, peeling of lining layer
	Non-destructive test	Schmidt Hammer test
	Carbonation test	Phenolphthalein method
Measurements in laboratory	Cl^- concentration	(chemical analysis)
	Sulphate content	(chemical analysis)

3. Results

3.1 Volume Change for Cubes

Weight of cubes measured every 15 days up to6 month for Portland cement as shown in tables (4)figure(1) For Sulfate resistant cement as shown in table(5) and figure(2)in tidal and submerged zones,

Table 4: Average weight of cubes (O.P.C)

Days	average wt.(kg) in tidal zone	Average wt.(kg) in submerged zone
15	8.71	8.63
30	8.55	8.6
45	8.65	8.61
60	8.67	8.64
75	8.65	8.62
90	8.94	8.65
105	8.85	8.67
120	8.92	9.12
135	8.65	8.95
150	8.97	8.96
165	8.96	9.04
180	8.92	9.01

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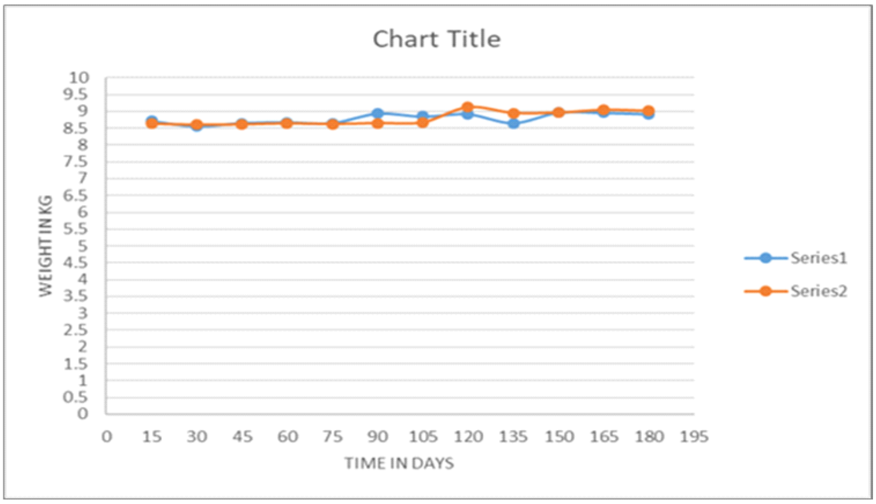

Figure 1: average wt. of cubes for OPC

Table 4: Average weight of cubes (S.R.P.C)

Days	average wt.(kg) in tidal zone	average wt.(kg) in submerged zone
15	8.77	8.84
30	8.7	8.72
45	8.79	8.71
60	8.81	8.75
75	8.77	8.72
90	8.79	8.75
105	8.79	8.77
120	8.81	8.87
135	8.77	8.79
150	8.67	8.8
165	8.66	8.85
180	8.77	8.7

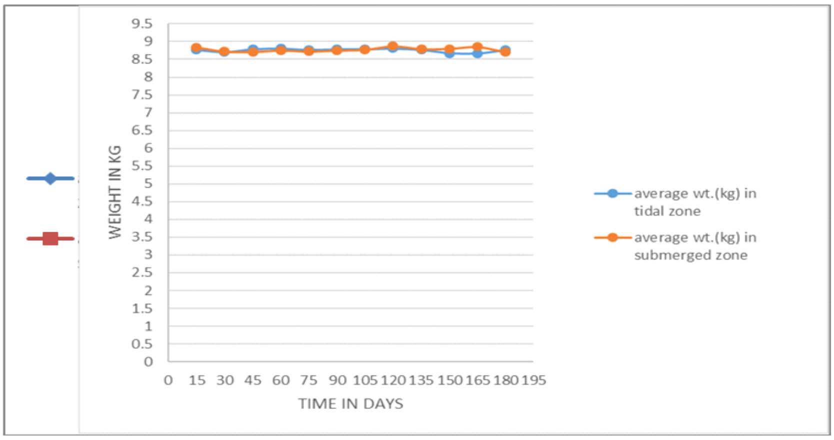

Figure 2: Average wt. of cubes S.R.P.C.

3.2 Results of measurements of beams in site

Visual Assessment

General observations were carried out below:

Beams in tidal zone observed no apparent effect has been detected except in $B3_1$, B5, B7 and B8.as shown in table (6)

Table 6: General observations

Beam type	General observations
$B3_1$	the colour changed to brown with some spots
B5	some brown spots appeared
B7	some traces of salt were found at the surface
B8	the colour changed to brown with some spots

Beams submerged in Sea water marine growth were observed covering the surface roughness of the beams and this led to the leg diameter increase of the beams as shown in table (7) and photo(1)and (2) .

Table 7: Diameter of submerged beams

No. of beam	Diameter(cm)
B1	22×29
B2	22×27
B5	23×27
B6	24×27
B7	21×27
B8	22×28
B4	22×27

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The marine growth was cut and weighted in laboratory, the results as shown in table (8).

Table 8: Weight of marine growth

No. of beam	weight (g)
B1	1131.2
B2	873.8
B5	1045
B6	1463
B7	1452.6
B8	1137.8
B4	921.8

Photo 1: Submerged beam Photo(2) Submerged beam after 6 months

Schmidt hammer test

Schmidt hammer was carried out to determine the strength in beams and test run after 6 months the results shown in tables (9), (10), (11) and (12) figures (3) and(4).

Table 9: Schmidt Hammer Test Result - effect of w/c

Beam	W/C	Average strength (N/mm^2) in tidal zone	Average strength (N/mm^2) in tidal zone
B8	0.6	32.24	34.58
B5	0.53	34.56	35.32
B1	0.46	36.08	39.51
B4	0.42	40.03	42.13

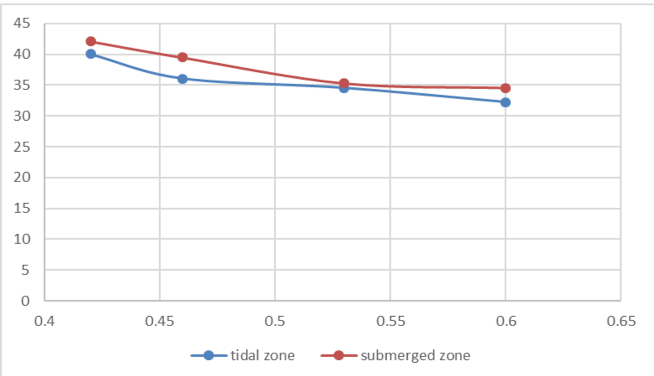

Figure 3: Effect of (w/c) on strength at tidal beams and submerged beams

Table 10: Schmidt Hammer Test Result - effect of cover

Beam	cover(mm)	Average strength (N/mm^2) in tidal zone	Average strength (N/mm^2)	in submerged zone
B7	25	33	35.16	
B6	30	34.89	35.36	
B1	40	36.09	39.51	

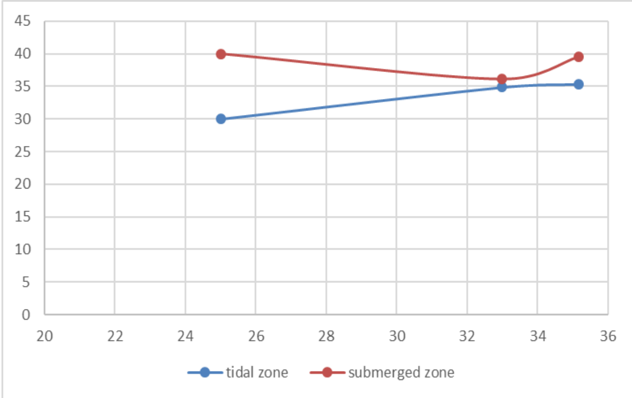

Figure 2: Effect of cover on strength at tidal beams and submerged beams

Table 11: Schmidt Hammer Test Result - effect of curing in tidal zone

Beam	Curing)	Average strength (N/mm^2)
$B3_2$	Good	39.59
$B3_1$	Poor	34.26

Table 12: Schmidt Hammer Test Result - effect of type cement

Beam	Cement	Average strength (N/mm^2) in tidal zone	Average strength (N/mm^2) in submerged zone
B1	O.P.C	36.09	38.92
B2	S.R.O.P	35.08	36. 88

Carbonation depth

The results of carbonation depth of beams submerged zone is zero for all beams, but for beams in tidal zone are shown in table (13).

Table 13: Carbonation Depth

No. of beam in tidal zone	carbonation depth(mm)
B1	Zero
B2	Zero
B5	5
B6	Zero
B7	Zero
B8	7
B4	Zero
$B3_1$	|zero
$B3_2$	8

4. Results of Measurement in Laboratory

Chloride and Sulphate Contents

The experiment of chloride and sulphate were carried out after 6month exposed to Sea water in tidal zone and in submerged zone and made from different level to represent content according to BS1377. [8] The effect of water cement ratio (w/c) on chloride and sulphate contents in tidal and submerged zones are shown in figures (5) and (6), and the effect of concrete cover for different levels are shown in figures (7) and (8) the effect of cement type are shown in figures (9) and (10) , finally the effect of curing is shown in figure (11)

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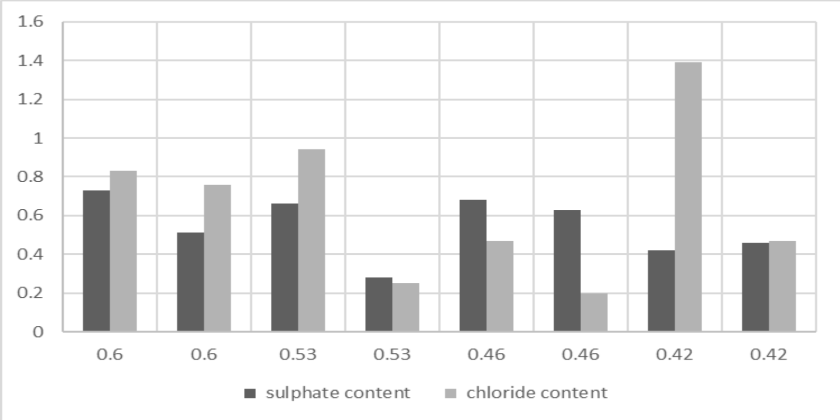

Figure 5: Chloride and sulphate content in tidal zone as effect of (w/c)

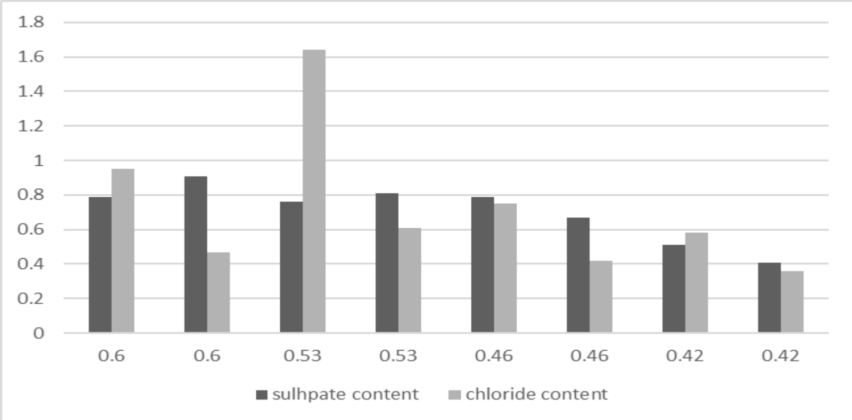

Figure 6: Chloride and sulphate content in submerged zone as effect of (w/c)

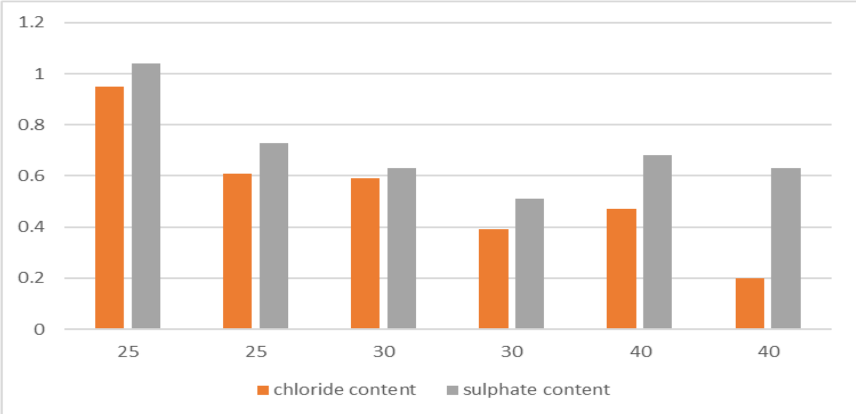

Figure 7: Chloride and sulphate content in submerged zone as effect of (cover)

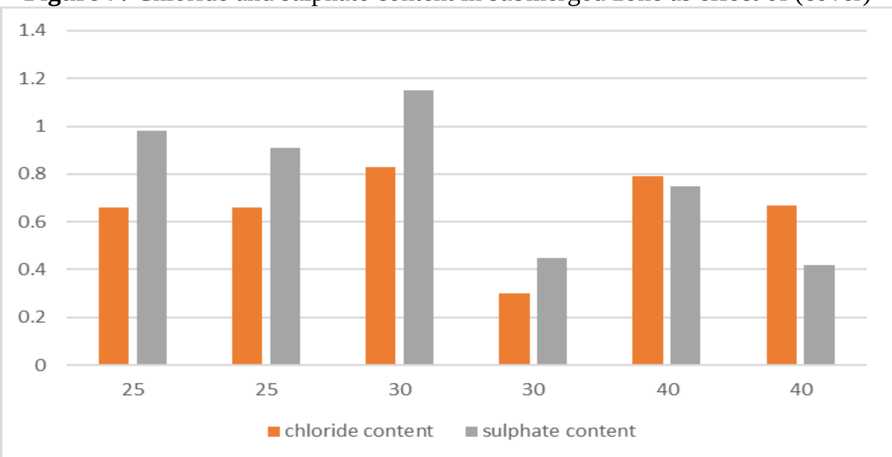

Figure 8: Chloride and sulphate content in submerged zone as effect of (cover)

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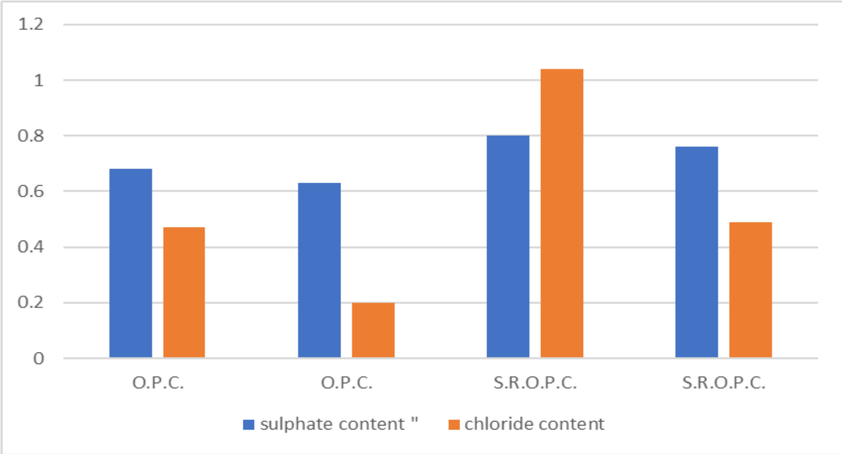

Figure 9: Chloride and sulphate content in tidal zone as effect of (types of cement)

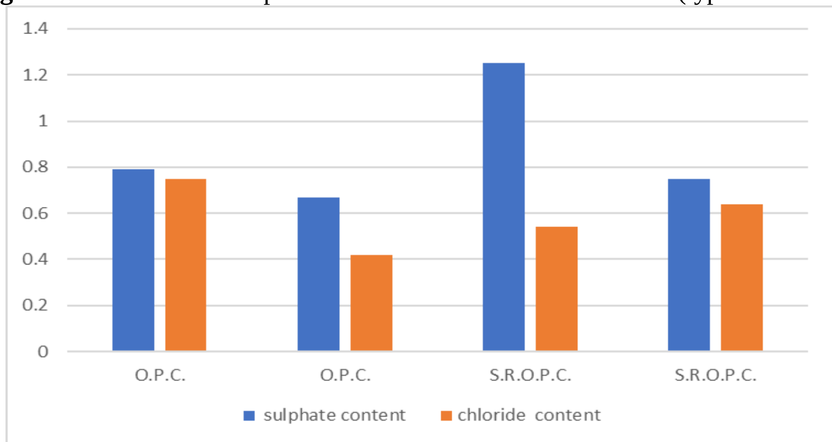

Figure 10: Chloride and sulphate content in submerged zone as effect of (types of cement)

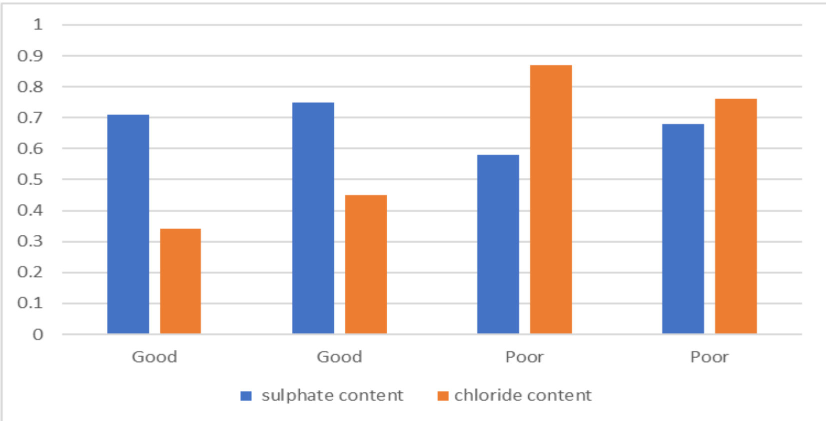

Figure 11: Chloride and sulphate content in tidal zone due to curing

5. Analysis and Discussion Results

Volume changes for cubes

Cube weight and dimensions are measured every 15 days for 180 days some volume change was found in cubes as shown in tables (4) and (5), figures (1) and (2)

Schmidt hammer

Test was carried out for different cubes and the influence of water/cement ratio was viewed as in table (9) and figures (3) the suitable w/c for compressive strength the tidal zone is was found to be 0.42 and the submerged zone was 0.46. The depth of the cover effect on strength, was shown in tables (10)and figure(4).Larger increasing cover depth is forming a wide electric field that facilitated the glow of a corrosive current after chloride ions had penetrated to a certain degree. From table (11) the curing effect it proveded good curing result in higher strength.

Carbonation Test

Carbonation test was carried out after 180 days and reveal that, the depth of carbonation is less than depth of cover, so the result express that the corrosion is not occurring by carbonation in early time as shown in table(13).

Chloride and Sulphate Contents

Test was carried after 180 days the result of sulfate content from was shown in figures (5), (6), (7), (8), (9), (10) and (11). The influence of the W/C on the chloride content concrete in surface direction at tidal zone, as in figure (5),

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the Cl^- concentration at the depth of 0-20 mm (the surface) was higher in the case of W/C = 0.42 than W/C = 0.60, and at the depth of 20-35 mm (the interior) the Cl^- concentration decreased in the case of W/C = 0.42, while for W/C = 0.60, it is increased , and in submerged zone as in figure (6) the total Cl^- of each surface in the 0.42 W/C beams and 0.60 W/C beams were higher, so the transport of chlorides was dominant by capillary absorption in the outer layers of the specimens direction Figures (7) and (8), the influence of depth of cover was marked at the initial stage of exposure. However, the chloride content when the cover depth is 25mm is bigger than the cover depth 40mm in tidal and submerged zone figures (9) and (10) , showed the chloride content when using sulphate resistance cement is more than 0.2% refer to BS 8110 (table in appendix B) .So higher the chloride content means the greater risk of corrosion and that indicated the sulphate resistance cement must unused in marine environment. Figure (11) showed the good curing in initial stage of hardiness concrete has low chloride concentration.

6. Conclusions

Small change was found and those in tidal zone are high than those in submerged zone at the first 105 day but the volume in those in submerged zone increase after 105 days. The main reason of volume changes is chemical reaction between cement and water subsequent drying of concrete which produce cracking, resistance to the action of leaching, corrosion of reinforcement concrete, attack by sulphate and other chemicals.

Beams in tidal zone, have no longitudinal cracks along the reinforcing bars, but in the beams B8, $B3_1$, B7and B5some of salt spot present in the surface. Beams putting in submerged zone observed the algae and shales covered the surface, it is preventing adequate visual examination of concrete surface, it is present are able to oxidize sulfur to sulfate, with eventual formation of sulfuric acid which is highly corrosive to both steel and concrete, the hydrodynamic loading would result from the displaced volume of algae and shales which influencing structural stability.

The marine growth covered the surface, contributing in the defect of concrete because it is able to oxidize sulfur to sulfate, with eventual formation of sulfuric acid which is highly corrosive to both steel and concrete

The penetration and diffusion of chloride ions occur corrosive reaction starts in early time but without carbonation. Therefore, corrosion due to chloride ion seems to be the main corrosive factor in the marine environment.

Small cover made with poor quality concrete has a higher tendency to crack due to heat and moisture.

Curing should never be ignored or mismanaged especially during the first one week of place.

Selection of cement based on suitability for various concreting environment is important for durability consideration of structures, so Sulphate resistance cement must unused in marine environment

7. Recommendations

This paper does not cover the properties of aggregates and the workmanship in construction. These factors also significantly contribute to high quality concrete. Should be coved in future research. It is recommended to maintain the maximum water cement ratio in ordinary Portland cement concrete in the range of 0.4 to 0.5 for exposure according to their varying severity. This must be implemented provided workability of the mix is ensured. The severity of the Red Sea environment demands certain provisions for a design code that would need to a local code in concrete. It recommends for future studies in using new techniques in prevention of corrosion such as bar coating using different epoxy resins

References

[1] P. Kumar Mehta, 2003," Concrete in the Marine Environment", University of California at Berkeley, USA.
[2] Guangzhou Harbour Engineering Check Center ,1996,"Report of Examination and Valuation for Reinforced Concretes Structures of Berth 17|18, Port Sudan BS 8110, 1997, "Structural use of concrete", The British Standards institution, part 1: code practice for design and construction.
[3] BS 12, 1996, "Specification for Portland Cement", The British Standards institution.
[4] Product data sheet, Edition 10, 2004, "High Range Reducing Water and Retarding Concrete Admixtures", Sika Egypt
[5] BS812, 1988," Testing aggregates **",** The British Standards institution, Part 117. Method for determination of water-soluble chloride salts
[6] Industrial applications and chemistry section, 2002, "Guidebook on non-destructive testing of concrete structures", Vienna, Austria.
[7] BS 1377, 1990, "Methods of test for soil for civil engineering purposes", The British Standards institution, part 3: chemical and electro-chemical tests.

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