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Effect of Gaza Seawater on Concrete Strength for Different Exposures

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ملخص لقد بدأت الدراسات على تأثير مياه البحر على الخرسانة منذ العام 1840 ومن ذلك الوقت وحتى وقتنا هذا ازداد عدد هذه الدراسات بشكل كبير مما يدل على أهمية هذا الموضوع. وعلى الرغم من كثرة عدد هذه الدراسات إلا أن نتائجها مثيرة للجدل و غير قاطعة ولذا تم القيام بهذه البحث لدراسة تأثير مياه البحر قبالة شواطئ مدينة غزة على خصائص الخرسانة حيث تم إعداد ست خلطات خرسانية باستخدام نسب مختلفة من الماء إلى الإسمنت وباستخدام محتويات مختلفة من الإسمنت، وتم بعد ذلك اختبار العينات الخرسانية خلال فترة سبعة أشهر من حيث مقاومتها للضغط وذلك لثلاث حالات مختلفة من الظروف البحرية ، وفي نهاية البحث أدرجت عدة توصيات رئيسية لتوفير الحماية الأفضل للخرسانة.

المفردات الرئيسية: مقاومة الضغط – نسبة الماء إلى الإسمنت – محتوى الإسمنت

Abstract The effect of seawater on concrete was first discussed in 1840. Since then, the volume of literature has increased considerably, implying the importance of the topic, but the findings are controversial and inconclusive. Therefore, this study was carried out to explore the effect of Gaza seawater on concrete properties. Six concrete mixes were prepared using different water/cement ratios and cement contents. These samples were tested for a period of up to 7 months in terms of their compressive strength for three different exposures. The study provides key recommendations in regard to better protection of concrete.

Keywords: Compressive strength- water-cement ratio- cement content

List of abbreviations:

DOWP	Depth of Water Penetration
W/C	Water/Cement Ratio
Agg/C	Aggregate Cement Ratio
σ	Compressive Strength
CC	Cement Content
FM	Fineness Modulus

1- Introduction

Reinforced concrete is one of the most important structural materials used in construction. It has excellent structural and durability performance. Nevertheless there are examples of early deterioration when subjected to marine environments. The most common cause of deterioration is corrosion of the reinforcement, with subsequent spalling of the concrete. Long-term performance of marine concrete structures requires a careful procedure to be followed in both design and construction stages. Selection of materials, mix design, proper detailing of reinforcement, appropriate construction technique and a strict control program are the essential parameters to produce a durable marine concrete structure [4-7, 12, 13-14, 17-19].

Generally, seawater can be thought of as a solution containing a great number of elements in different proportions. Elements, on solutions, combine and precipitate as salts on evaporation of the water. Much of the deterioration of concrete can only occur in the presence of water since aggressive agents which are present in the environment react with the concrete only when it is dissolved in water.

J. Smeaton and L.J. Vicat discussed the problem of concrete deterioration by seawater as early as 1840. A series of papers under the general heading of 'what is the trouble with concrete in seawater', prepared by R.J Wig and L.R. Ferguson were published in Engineering News-record in 1917. These papers report on an examination, over a two-year period, of a large number of concrete structures in seawater in the Unite States, Canada, Cuba, and Panama. A summary of the conclusions of these papers was published by Tibbetts [4].

Since these early times, the volume of literature on the durability of concrete and reinforced concrete in marine environment has increased tremendously indicating the ever-growing importance of the topic [5].

The chemical deterioration of concrete in marine environment has been a topic of interest to concrete technologists in the last few decades. The findings have revealed some very important facts, but still it remains to be a dynamic subject for further study and research [1, 10, 13].

Long-term performance of concrete depends largely on condition of exposure. Wetting and drying cycles can increase the rate of corrosion in reinforced concrete structures as a result of irons concentration, such as chlorides. Concrete structures, subjected to cyclic wetting and drying of seawater, are more liable to deterioration compared to these permanently immersed in seawater [2, 7, 9, 11-12]. The splash zone is claimed to be the area most vulnerable to corrosion due to these wetting and drying cycles. Underwater, concrete has generally been found to be less permeable than concrete above water, probably as a result of blocking of the pores in the concrete by materials like brucite and aragonite formed from chemical reactions with seawater [8, 9].

The effect of marine environment on concrete was found out to decrease its compressive strength and this reduction in strength increases with period of exposure [1]. Contrary to what is known, some concrete mixes of low water-cement ratios showed more reduction in compressive strength compared to mixes of higher water-cement ratios, when subject to marine environment [3].

A report by the Portland Cement Association provides the following conclusions concerning the durability of reinforced concrete piles made with different Portland cements after an exposure to seawater in four locations in the United States for 20 years:

Low water-cement ratio concrete mixtures (0.40 to 0.45 by weight) of low slump and high cement contents are necessary for durable concrete. A mix of 400 kg/m^3 represents the minimum cement content that can be used for severe exposure [6].

This study was carried out to explore the effect of Gaza seawater on concrete properties, since no other relevant results are available on the subject. Furthermore, the construction of Gaza Harbour has not yet started. The findings of this study are to be made available for the Palestinian Port Authority due to its importance.

Six concrete mixes were prepared using three different water-cement ratios and two cement contents for each of these ratios. The specimens were tested for a period of up to 7 months in terms of their compressive strength in three marine exposures; beach, tidal, and permanent immersion.

2- Experimental Program

Goals

* Study the effect of seawater exposure on concrete compressive strength.

* Determine the optimum concrete mixes to be used in Gaza seawater environment.

Description of Exposure Zones

Three zones of marine environment have been specified for placing the specimens before they are tested for compressive strength, chloride ion penetration, and water permeability.

Zone A (beach): the specimens are directly laid on the beach sand 40m away from the Gaza coastline. This zone combines the adverse effects of chloride attack and carbonation on concrete.

Zone B (tidal): exposure at mean tide level with specimens frequently submerged in tidal waters, thus subject to alternate wetting and drying cycles that cause deterioration of the concrete. The specimens were put into plastic crates, the crates were tied with ropes and fixed to the sides of the tetra-pods of the Gaza marina at a distance of 30 meters from the coastline. The depth of seawater from seabed to mean sea level was measured at 4 meters.

Zone C (Permanent immersion):

exposure at a depth of about 5.3 meters in seawater, 80 meters away from the coastline. The specimens are subjected to forces generated by weight of the water body and by water-borne sediments.

Materials

The materials used in preparing all of the concrete specimens were as follows:

Cement: ordinary Portland cement, manufactured by the Israeli company, Nesher with fly ash of up to 10 % of cement weight, and conforms to ASTM C150. It is the only cement type available in Gaza market. Table 1 shows the mechanical properties of the used cement.

Coarse Aggregates: crushed limestone, angular in shape and rough in texture, obtained from the West Bank quarries which is the only aggregate source available in Gaza market. A chemical analysis was carried out and showed their chloride content was 240 ppm, while their sulphate content was 100 ppm. (see Table 2 for sieve analysis)

Sand: Gaza dune sand. (see Table 2 for sieve analysis and fineness modulus "FM")

Mixing Water: drinking water from the piped water supply system in IUG was used in preparing all of the concrete mixes. Chemical analyses of this water along with Gaza seawater are shown in Table 3.

Workability Aids: no workability aids or admixtures were used throughout the study.

Table 1 Mechanical properties of cement

Test		Result
Compressive strength	3-day	200
	7-day	250
Normal consistency (%)		25.6
Initial setting time		135 min
Final setting time		280 min
Fineness		3550 cm^2/gr
Soundness		1.5 mm

Table 2-a Sieve analysis of coarse aggregates

Sieve mm	25	19	12.5	9.5	4.75	FM
% passing	100	85.6	43.4	16.0	0	5.98

Table 2-b Sieve analysis of fine aggregates

Sieve mm	4.75	2.36	1.18	0.60	0.30	0.15	0.075	0.00	FM
% passing	100	76.6	64.7	62.5	24.7	3.1	2.48	0	2.68

Table 3 Chemical analyses of mixing water and seawater

Test	Mixing	Seawater
Turbidit	< 5 ntu	0.90 ntu
PH	7.0	8.13
E.C*	1053 micro Moh/cm	57.60 micro Moh/cm
T.D.S**	1490	43300 ppm
Nitrite	- ppm	0.40 ppm
Nitrate	22 ppm	- ppm
Ammon	- ppm	- ppm
Chlorid	220 ppm	22500 ppm
Sulfate	110 ppm	1475 ppm
Hardnes	246 ppm	- ppm
Calcium	62 ppm	210.6 ppm
Magnesi	28 ppm	1341 ppm
Fluoride	0.90 ppm	- ppm
Potassiu	- ppm	477 ppm
Iron	- ppm	0.10 ppm
Bicarbo	- ppm	168 ppm
Suspend	- ppm	164 ppm
Barium	- ppm	< 0.10 ppm
Strontiu	- ppm	0.50 ppm
Sodium	- ppm	11720 ppm

* Electrical conductivity
**Total dissolved solids

Mix Proportions and specimen preparation

Usually, in marine environment, relatively richer mixes with low water/cement ratios are used. This aspect was kept in mind in planning the experimental program. Six concrete mixes were used as shown in Table 4 using water/cement ratios of 0.40, 0.45, and 0.50 and two cement contents of 400 kg/m^3 and 500 kg/m^3 for each of the three ratios.

Specimens

For compressive strength evaluation, cubic samples of 10 cm were used.

Curing

For the lab environment, specimens were cured 24 hours after preparation and demoulding by placing them in a curing tank at a temperature of 25° for 28 days. For the beach environment, specimens were placed 24 hours after preparation on the beach sand a way from seawater and cured by sprinkling the specimens periodically for a period of 10 days. For tidal and permanent immersion specimens, curing is done 24 hours after preparation and after demoulding in a plastic tank full of seawater for a period of 7 days before moving them to their designated locations.

Table 4 Details of concrete mixes

Mix	cement content (kg)	W/c ratio	Mixing water (kg)	Aggregate		density Kg/m^3
				Type	Content (kg)	
1	400	0.40	178.41	I	480	2488
				II	282	
				III	381	
				IV	768	
2	400	0.45	197.90	I	466	2454
				II	274	
				III	370	
				IV	746	
3	400	0.50	217.38	I	453	2420
				II	266	
				III	359	
				IV	724	
4	500	0.40	216.56	I	432	2434
				II	254	
				III	342	
				IV	690	
5	500	0.45	240.91	I	415	2391
				II	244	
				III	329	
				IV	663	
6	500	0.50	265.27	I	398	2348
				II	234	
				III	316	
				IV	636	

Testing Compressive Strength

For lab, beach, and tidal zones, the specimens were tested after 1, 3, 6, and 7 months. For continuous immersion, the specimens were tested at 1, and 3 months due to the loss of a large number of specimens occurred during the Israeli rocket attack on Gaza beach. The loading rate was kept at 2.5 KN/sec during all compressive strength tests. The tests were carried out according to BS 1881: Part 3.

3- Methodology of Analysis:

To obtain an accurate analysis of the effect of seawater environment, the following factors have been specified:

A. Seawater main factors (for analytical consideration)

Test parameters	Description
Variable	Exposures : Beach (A) exposure, Tidal (B) exposure, permanent Immersion (C) exposure. Also humidity
Variable	Duration
Assumed Fixed	Hydrodynamic forces: Currents, waves, and tidal effect
Fixed	Chemical characteristics of seawater

B. Concrete materials factors:

Variable	Water/Cement (W/C) Ratio
Variable	Aggregate /Cement (Agg./C) Ratio
Variable	Cement Contents
Fixed	Chemical composition of cement, aggregate and mixing water
Fixed	Cement type
Fixed	Compaction

4- Characteristics of Exposure Zones:

The beach zone is characterised by the following:

- Intermittent curing (by sprinkling seawater) to imitate field conditions
- Intermittent dry and wet action
- Variations in temperature and ambient salty humidity

* No hydrodynamic forces

The tidal zone is characterised by the following:

- Intermittent curing (by tidal effect and splash)
- Continuous dry and wet action
- Variations in temperature and ambient salty environment
- Continuos hydrodynamic forces (waves and currents and intermittent hydrostatic pressure)

The permanent immersion zone is characterised by the following:

- Continuous immersion under seawater
- No wet & Dry effect
- No thermal variations
- No hydrodynamic forces except hydrostatic pressure

Full set of results for permanent immersion zone was impossible to get as the site of immersion zone samples was bombed by the Israelis during their air raids on Gaza Fishery port in 2000.

5- Compressive Strength Tests Results:

Marine exposures are the decisive factors in predicting concrete behaviour and accordingly the compressive strength has a direct relation to concrete durability.

Table 5 shows the results obtained from the compressive strength test.

Table 5 Compressive Strength Test Results

Mix #	w / c	cement content (kg)	Exposure	compressive strength (σ Kg/cm̂2			
				1 (month)	3 (months)	6 (months)	7 (months)
1	0.4	4	Lab	442.6	485.2	497.25	5 9.6
2	.45			397.75	479.25	487.3	49 .75
3	.5			379.5	476.4	485.47	488.5
4	.4	5	Lab	473.3	56 .5	575.	584.5
5	.45			4 5.9	489.	499.9	5 6.25
6	.5			34	4 5.2	446.8	45
	.4	4	Exposure (A) (Beach)	5 2.9	43 .6	42 .3	426.75
2	.45			42 .2	366.43	359.4	355.33
3	.5			365.4	34 .5	368.	392.9
4	.4	5	Exposure (A) (Beach)	4 8.	426.8	43 .6	43 .9
5	.45			395.	362.55	366.7	35 .55
6	.5			326.5	374.65	362.65	355.8
	.4	4	Exposure (B) (Tidal)	468.	38 . 5	39 . 5	328.9
2	.45			389.6	383.9	466.7	446.65
3	.5			4 6.	437.7	494.6	5 4.4
4	.4	5	Exposure (B) (Tidal)	379.5	539.6	568.8	532.8
5	.45			382.	46 .5	42 .	382.3
6	.5			286.5	362.85	4 5.4	369.7
	.4	4	Exposure (C) (Immersion)	433.5	454.2	N/A (*)	N/A
2	.45			385.2	448.5	N/A	N/A
3	.5			378.4	428.3	N/A	N/A
4	.4	5	Exposure (C) (Immersion)	447.45	48 .3	N/A	N/A
5	.45			435.	47	N/A	N/A
6	.5			336.75	348.9	N/A	N/A

N/A means not available

Many trends may be plotted from Table 5. Examples of these trends for the compressive strength are shown in Figures 1 through 6.

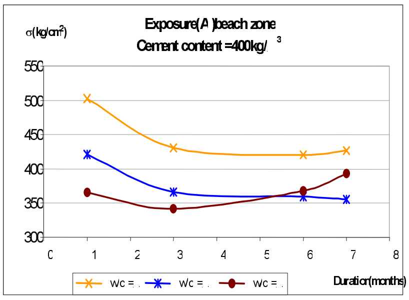


Fig 1 Compressive Strength Vs. Duration for e

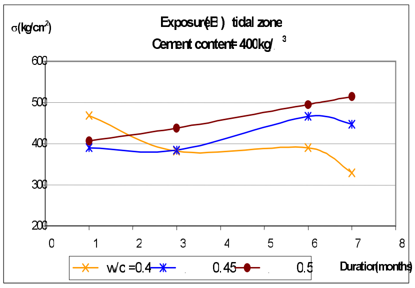
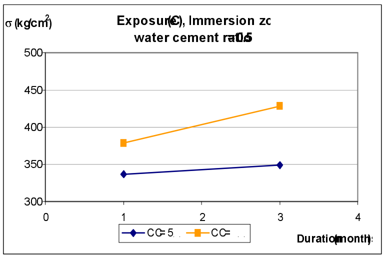


Fig 2 Compressive Strength Vs. Duration for exposure (B),



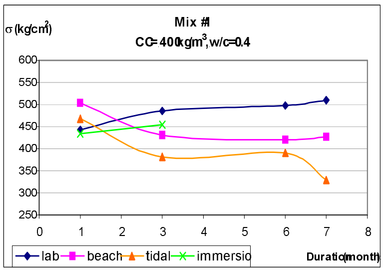


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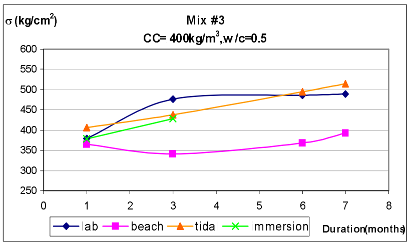
Fig 4 Compressive Strength Vs. Duration for w/c=0.4 and CC=400kg/m^3



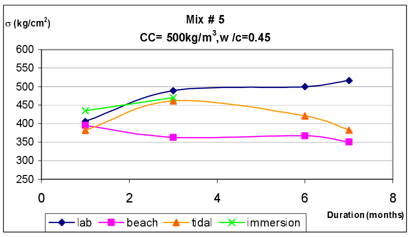


Fig 5 Compressive Strength Vs. Duration for w/c=0.5 a

Fig 6 Compressive Strength Vs. Duration for w/c=0.45 and CC=500kg/m^3

6- Discussion of Results

Compressive Strength

In the beach zone, the specimens were placed on beach sand and sprinkled periodically with water for 10 days simulating what is done in practice. This curing regime which is not adequate for activating full hydration process may explain strength losses and non-uniformity of strength gain with time. It has been established that beach environment contributes severely to decreasing the compressive strength, i.e. decreasing the bond strength between aggregates and cement paste. It is noticed that cement content does not seem to have much of an effect on concrete compressive strength in this zone of exposure where less than 7 % differences are obtained for all cases. So using lower cement content mixes for concrete structures at this zone is economically better, as higher cement content mixes give the same performance. The overall trend for different cement contents is that strength decreases with time.

The strength gain, at the beach environment, is faster than that of the lab environment for short periods (1 and 3 months). After that, other factors, such as crystallisation and thermal variations started to affect the strength gain.

In the tidal zone, concrete has no certain trend for its strength development. It is worthy noticing that as w/c increases, low cc mixes give higher strength than the high cc mixes do.

In the permanent immersion zone, the effect is almost the same as in the lab environment. Under continuous immersion strength increases with time. The factor of chloride penetration is very severe on the compressive strength if reinforcement exists because concrete, at this zone, will be saturated with seawater, which is considered as a good electrolyte. Then, it can depassivate the concrete around it giving very suitable conditions to the electrical cell, which stimulates steel corrosion.

Effect of Cement Content and Water-Cement Ratio

In the beach zone, high cement content can mitigate the aggressive effect of low water cement ratio giving more workability to the mix as well as enhancing the bond strength among concrete components. At high cement contents, the action of micro cracking works together with the action of crystallisation resulting in strength loss occurrence at earlier stages than it is supposed to happen if the crystallisation action is the only governing factor. Higher cement content concrete has higher pore volume than low cement content concrete, thus more vulnerable to cracking.

In the tidal zone, higher cement content means more cement matrix exposed to salts. Accordingly, the strength loss will be retarded for a while. Higher cement content means higher microcracking as it provides higher amount of binder. Then, no certain trend can be pointed out here, one of the factors accelerates the harmful effect while other factor retards it for some time, either of the two factors could dominate. It should be pointed out that higher cc gives higher strength at w/c of 0.4 and 0.45 while lower cc gives higher strength at w/c of 0.5. Obviously, this can be referred to the amount of binder, which is correspondent to the amount of pores.

In the permanent immersion zone, for the short period shown, the effect of cc is almost the same as that for the lab environment but at slower rate.

Effect of Thermal Variation and Moduli of Elasticity

When concrete is located near sea (on the beach), its compressive strength is badly affected due to several factors, e.g. differentiation in temperature and ambient humidity. These factors are aggravated in the state of a composite material such as concrete where incompatibility in moduli of elasticity exists, leading to damage and disintegration of the concrete microstructure, including the bond between aggregate and cement matrix. This effect is related to the concrete ingredients' proportions as shown in Figure 7.

On average, after one to two months, the compressive strength will depreciate due to cracks developed by thermal expansion.

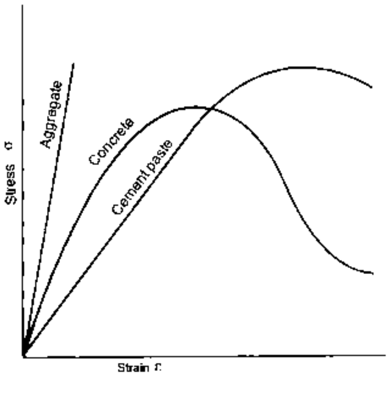


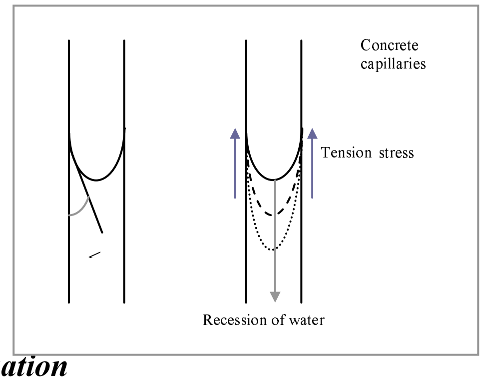
Figure 7 Typical non-linear stress-strain curves for aggregate, hardened cement paste, and concrete [19]

Since the bond strength is less than the strength of the binder matrix, which, in turn, is generally less than the strength of the aggregate, the interfacial region is the weakest link in the structure and cracks tend to start forming in this region.

The previous discussion explains why there is a loss in strength for different w/c ratios, but this loss depends on the mix, w/c ratio, cement content, i.e., it depends on the pore volume.

Effect of Water Penetration

As water dries out, water surface recedes inside the concrete, hence creating internal stresses due to surface tension, which induces micro-cracks. As pores inside the concrete media have capillary tube action, the angle between the water surface and the wall of this capillary is acute, i.e., causing the surface of the concrete to be wet. As the process of recession is repeated, cracks increase in size and new micro-cracks are created. With the depravation of water, the strength of concrete is not expected to improve a great deal. Figure 8 illustrates this effect.



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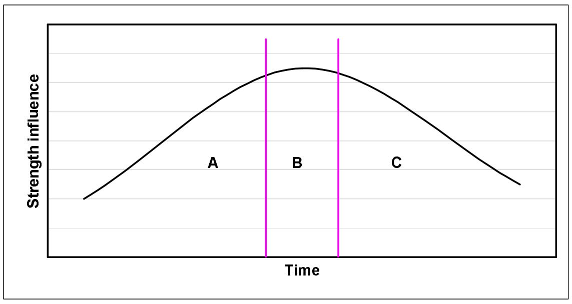
Effect of Crystallisation

In the beach exposure, the wet-dry state of concrete is of critical importance as well as crystallisation controlling the behaviour of the concrete subjected to tides. This factor is the micro-cracking of concrete matrix due to differences in coefficients of thermal expansion which makes each component of concrete resists variations in temperature in different manner and also due to recession of water in the pores of the concrete medium. The parameter of micro-cracking is very effective for low w/c concrete because hydration water in this concrete can be lost easily at early stages leaving some thin hydrated products shielding another unhydrated ones. The joint effect of micro cracking and crystallisation may result in high non-linear strength gain, which appears clearly at low water cement ratios.

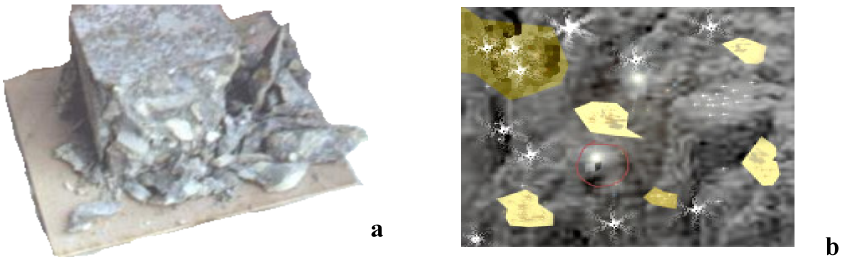
In tidal exposure, the most severe action is that of chloride salts crystallisation action. Intermittent wetting and drying is very suitable for crystals building-up within the pores of concrete. At the beginning, crystals start to form within concrete pores, thus increasing concrete tightness, which, in turn, increases concrete strength. This is valid to a certain point, which can be named as an inflection point, at which the crystal volume is equal to the pore volume. The crystal will continue increasing in volume to reach a volume larger than the pore volume producing internal stresses that harmfully weaken and may damage the microstructure of concrete. Hence the crystals building up will inversely affect the compressive strength of the concrete

Apparently, strength losses do occur at different stages e.g. at w/c = 0.4 and cc = 400 kg/m^3, the adverse effect started between 3 to 6 months, whereas at w/c = 0.5 the effect didn't take place for the same period. Concrete pores represent a blank area that crystals can occupy and as much as they are larger and greater in number, their capacity to contain or to mould crystals will be greater and the time at which crystal will start its harmful effect will be longer. High pore volume corresponds to high water-cement-ratio concrete and vice versa. Figure 9 is a schematic sketch describes in a simple way that crystallisation badly affects the compressive strength of concrete.

Visual inspection of the crystals was performed in The Environmental Laboratory of the Islamic University of Gaza using a microscope of a magnification power of 1 to 1000 times. The results proved the theoretical analysis mentioned earlier as shown in Figure 10.



9 y l l , (A) y l' l l z ,
(B) y l' l q l z ,
(C) v l' l h z (A)



1 : ( ) - l l z
(b) S y l b by l , ( )

The successful performance of a marine concrete structure depends to a great extent on its durability against the aggressive marine environment. Most of the problems of deterioration of concrete structures could perhaps be eliminated if appropriate measures are taken into consideration as selection of materials, mix designs, reinforcement detailing, construction techniques and quality control.

A. Beach Zone

- Compressive strength varies according to the exposure condition. When concrete is located near the sea (on the beach), its compressive strength will be harmfully affected due to several factors, e.g. variations in temperature and ambient humidity. These factors are aggravated in the state of a composite material such as concrete where incompatibility in moduli of elasticity exists, leading to damage and disintegration of the concrete microstructure, including the bond between aggregate and cement matrix. This effect is related to concrete ingredients' proportions.

The strength gains at beach environment is faster than that of the lab for short periods (1 and 3 months). After that, other factors such as crystallisation and thermal variations start to affect concrete strength.

B. Tidal Zone

- The visual inspection supports the finding where severe action of tides brings into action salt crystallisation, where intermittent wetting and drying is convenient for crystals building-up in pores. In short time period, crystals settle within concrete pores, increasing concrete tightness. This, in turn, increases concrete strength to a point beyond which the crystals' volume is equal to the pore volume. After that, the crystal will continue to increase in volume as long as it is subjected to such environment, till it reaches a volume larger than the pore volume, producing internal stresses that harmfully weaken and may damage the microstructure of concrete.
- As w/c increases, low cc mixes give higher compressive values than the high cement content mixes do.
- Increasing the cement content by 25 % resulted in strength reduction differences of less than 7 % for mixes 5 and 6 compared with mixes 2 and 3. On the other hand, mix no. 4 aggravated the strength loss by 15.84 % compared with mix No. 1. This proves that cement content is not a major factor in this exposure environment.

C. Permanent Immersion zone:

Concrete strength increases with time but at a lower rate than at lab environment due to the nature of continuous curing and low temperature in this zone. After three months, compressive strength reductions ranged from 3.88 % to 14.46 % when compared with lab recorded values. Mix no. 3 was the best of all six mixes.

8- Recommendations:

Based on the experimental program conducted for Gaza seawater environment, and analysis of results, the following recommendations can be reached:

1. For beach exposure, mix no. 1 (w/c = 0.40, and cc= 400 kg/m^3) proved to be the best of the six mixes, as it showed least strength loss at 7 months compared with corresponding lab result. This clearly proves that cement content is not a factor in terms of protecting concrete. This mix is recommended for Gaza beach environment.
2. For tidal exposure, mix no. 3 (w/c = 0.50, and cc= 400 kg/m^3) was the best of all mixes in terms of 7-month compressive strength. So, this mix is recommended in this exposure zone.
3. In permanent immersion, mix no. 5 (w/c = 0.45, and cc= 500 kg/m^3) proved to be the best of all mixes. Therefore, this mix is recommended in this exposure zone.

The recommendations given above are valid for Gaza seawater environment. Extending these recommendations to other marine environments need to be verified through a testing programme.

9- Acknowledgement:

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