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Suitability of sea water on curing and compressive strength of structural concrete

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Abstract

Construction officials in coastal areas have long been facing the challenge of building and maintaining durable concrete structures in a saltwater environment. Gradual penetration of sea salts and the subsequent formation of expansive and leachable compounds lead to disintegration of structural concrete. As a part of durability study, this paper describes the effect of sea water on compressive strength of concrete when used as mixing and curing water. Concrete specimens were cast from four different grades and plain water as well as sea water was used as mixing water in making the test specimens. Test specimens were cured under sea water as well as plain water upto 180 days. Test results indicate that sea water is not suitable for mixing as well as curing of concrete. Concrete specimen made and cured with sea water exhibits compressive strength loss of about 10% compared to plain water mixed and cured concrete.

Keywords: Fertilizer, nutrient load, rice cultivation, agricultural return flow, nonpoint-source pollution

1. Introduction

The successful performance of a marine structure depends to a great extend on its durability against the aggressive marine environment. Disintegration of concretes in marine environments is mostly caused by chemical deterioration such as sulfate attack, chloride attack and leaching. Physical deterioration from crystallization of soluble hydrated salts in pores of the concrete, erosion and abrasion promotes further disintegration. The overall results of these attacks on concrete are softening, cracking and partial removal of cover concrete. This in turn exposes a fresh surface for further attack (Shetty, M. S. 2002).

Coastal and offshore sea structures are exposed to the simultaneous action of a number of physical and chemical deterioration processes, which provide an excellent opportunity of understand the complexity of concrete durability problems in practice. Second, oceans make up 80 percent of the surface of the earth, there fore, a large number of structures are exposed to seawater either directly or indirectly as winds can carry seawater spray up to a few miles inland from the coast. Most sea waters are fairly uniform in chemical composition, which is characterized by the presence of about 3.5% soluble salts by weight. The ionic concentration of Na^+ and Cl^- are highest typically 11,000 and 20,000 mg/liter, respectively. However, from the standpoint of aggressive action to cement hydration products, sufficient amount of Mg^{2+} and SO_4 are present, typically 1400 and 2700 mg/liter, respectively. The pH of seawater varies between 7.5 and 8.4., the average value in equilibrium with the atmospheric CO_2 being 8.2. Under exceptional conditions, pH value lower than 7.5 may be encountered. These are usually due to a higher concentration of dissolved CO_2, which would make the seawater more aggressive to Portland cement concrete (Mehta, P. K. 1985).

An understanding of the aggressive elements of the environment and the mechanism of their attack on concrete structures is essential to develop the right course of action in providing structures to best withstand the aggression. However, most of the problems regarding concrete durability can be eliminated if appropriate measures are taken in the selection of materials, mix design, reinforcement detailing, construction techniques and quality control methods. As an ingredient material, the quality of mixing and curing water has an important role in making the concrete durable.

Divergent options exist on the effect of sea water as mixing water in concrete. As sea water contains various types/amounts of dissolved salts that can react with reactive aggregates, sea water should not be used even for plain concrete if the aggregates are known to be potentially alkali reactive. It is reported that the use of sea water for mixing concrete does not appreciably reduce the strength of concrete although it may lead to corrosion of reinforcement in concrete in certain cases. Sea water slightly accelerates the early strength of concrete but it reduces the 28 days strength by about 10 to 15 percent. Since the factors controlling the rebar corrosion including permeability, lack of concrete cover etc, cannot be adequately taken care of always at the site, it may be wise that sea water be avoided for making reinforced concrete. It is pertinent at this point to consider the suitability of water for curing. Water that contains impurities which causes staining is objectionable for curing concrete members. The most common cause of staining is usually high concentration of iron or organic matter in the water. Water that contains more than 0.08 ppm of iron may be avoided for curing if the appearance of concrete is important and hence the use of sea water may also be avoided in such cases. In other cases, the water, normally fit for mixing can also be used for curing.

The need to use sea water for construction arises in such situations where no other source of fresh water is available or costly to transport. Such conditions have occurred along the sea coast construction. The result of several investigations as well as the recommendations of different codes of practice regarding the use of salt/sea water for mixing and curing are summarized in Table 1. Although the existing literature and codes of practice reveal the effect of mixing and curing of sea water on durability of concrete, it still remains an area requiring further study and research particularly of the use of structural concrete in marine environment. The primary objective of the study is to investigate the strength behavior of concrete made with plain as well as sea water and also to be exposed in marine condition.

2. Research Significance

Now-a-days, as a progress of development, lots of engineering construction including high rise building, embankment walls, bridge etc is going on along the coastal belt of the country. In coastal areas, there has always been a deficiency of plain water as the available water is affected by sea salts. So it is difficult to arrange plain water for construction works in such location. Also it is economical to use sea water that is available near the construction site instead of plain water to be transported from other areas/sources. But sea water contains large amounts of sea salts, which may have adverse effect on the properties of concrete. So it is required to investigate the effect of sea salts on strength properties of different types of concrete while using sea water for casting and curing of concrete.

Table 1
Past observations / recommendations of various researchers / Codes regarding effect of sea water (SW) on concrete

Salt/Sea water	Observations / Recommendations	Reference
SW (Mixing)	Water cured: Higher strength at 3 and 7 days but lower strength after 28 days in comparison to fresh water concrete (80-88%). Air cured: Lower strength at 3 months and then showed recovery after 1 year.	Abram, D.A. (1924)
SW (Mixing)	Increase of strength by 17% during first month. After 3 months, a constant strength of 6% lower than the identical mix made with PW.	Narver, D.L. (1964)
SW (Mixing)	Gain in early strength but later strength has been observed to fall by 8% to 15%.	Steinour, H. H. (1960)
SW (Mixing+curing)	No sign of harm to the reinforced concrete up to ten years exposure.	Chen, B. et al (1983)
SW (Mixing+curing)	Reduction of initial and final setting time of cement by 25% over PW. Compressive strength of concrete was unaffected up to 17 months.	Ghorab (1989)
SW (Mixing)	Approximately 3 years study on plain concrete revealed that the degree of deterioration under the action of SW was greatest with SW as mixing water in comparison to PW.	Nishibayashi, S. et al. (1980)
SW (Mixing+curing)	Mixing or curing of concrete with sea water is not recommended. Under unavoidable circumstances, it may be used for plain concrete or concrete structures which are permanently submerged.	IS: 456-1978
SW (Mixing)	Mixing water shall be potable and free from salts. Gives no specific reference to SW. Mortar test cubes made with non potable mixing water shall have 7 day and 28 day strength equal to at least 90% of strength of similar specimen made with potable water.	ACI: 318-83 (1985)
SW (Mixing)	Not recommended for use in reinforced, pre-stressed or other structural concrete.	FIP (1985)

3. Experimental Program

The experimental program was planned to investigate the effect of sea water for mixing, curing and on the gain in strength of different grades of concrete. This study includes determination of compressive strength (upto 180 days) of concrete made and cured by using plain water as well as sea water.

3.1 Materials used

(a) *Cement*: ASTM Type-I Portland cement conforming to ASTM C-150 was used as binding materials. Its physical properties are given in Table 2.

Table 2
Physical properties and chemical analysis of Portland cement

Sl. No	Characteristics	Value obtained	Value specified as
1.	Fineness (#200 Sieve) %	95%	>90%
2.	Blain specific surface (cm^2/gm)	3400	>2800
3.	Normal consistency (%)	24%	22%-30%
4.	Setting times-Vicat test (minutes)		
	Initial	130	> 45
	Final	185	< 375
5.	Specific gravity		
6.	Compressive strength (MPa)		
	3 days	16.8	> 12.4
	7 days	20.4	> 19.3
	28 days	31.3	> 27.6

(b) *Aggregates*: The coarse aggregate used was crushed stone with a maximum nominal size of 12.5 mm; the fine aggregate was river sand. The coarse and fine aggregate was separated into different size fractions. The grading of the aggregates and its physical properties are shown in Table-3.

Table 3
Grading and physical properties aggregate

Properties	Coarse Aggregate	Fine Aggregate
Grading of Aggregates		
Sieve Size (mm)	Cumulative % Passing	
25.0	100	--
12.5	100	--
9.5	45	--
4.75	0	100.0
2.36	--	94.0
1.18	--	78.5
0.6	--	55.5
0.3	--	13.0
0.15	--	2.5
Physical Properties of Aggregates		
Specific Gravity	2.67	2.59
Unit Weight	1635 kg/m^3	1540 kg/m^3
Fineness Modulus	6.45	2.57
Absorption Capacity	0.8 %	1.2 %

(c) *Sea water*: Sea water was collected form the Bay of Bengal at the Potentga point of Chittagong, Bangladesh. The surface salinity of Bay sea water oscillates from 32 to 34.5 parts per thousand.

3.2 Variables studied

(a) *Concrete quality*: Four different grades of concrete, namely concrete A, B, C and D were used. Relevant information of the concrete mixes is given in Table 4. Both plain water (PW) and sea water (SW) were used for mixing and curing water. Plain water means fresh water or tap water.

(b) *Exposure period*: Test specimens were tested periodically after the specified curing periods of 7, 28, 90 and 180 days in plain water as well as sea water.

(c) *Size of specimens*: Cylinder specimens of size 150 mm diameter and 300 mm high were cast and the compressive strength of the concrete was determined according to ASTM C39.

(d) *Curing environment*: A total of 192 concrete cylinder specimens were cast in the laboratory. At the end of casting, the specimens were kept at 27ºC temperature and 90% relative humidity for 24 hours. After demoulding, all the specimens were made and cured as per program schedule indicate in Table 4. After a specific period of exposure, the specimens were taken out form curing tank for compressive strength test. Visual examinations of the specimens were carried out before compressive strength tests to observe the physical changes including color changes, cracks formation, surface erosion etc.

Table 4
Detailed experimental program

Concrete Mix	Mix Proportions	w/c Ratio	Specimen No.	Mixing Water	Curing Water	Exposure Periods (Days)
A	1 : 1.5 : 3	0.40	12	PW	PW	7
			12	PW	SW	28
			12	SW	PW	90
			12	SW	SW	180
B	1 : 1.5 : 3	0.45	12	PW	PW	7
			12	PW	SW	28
			12	SW	PW	90
			12	SW	SW	180
C	1 : 2 : 4	0.40	12	PW	PW	7
			12	PW	SW	28
			12	SW	PW	90
			12	SW	SW	180
D	1 : 2 : 4	0.45	12	PW	PW	7
			12	PW	SW	28
			12	SW	PW	90
			12	SW	SW	180
Total No. of Specimen			192			

4. Results and Discussion

Concrete specimens of different grades are taken out for compressive strength test as well as visual examination after specific period of exposure in different curing environment.

4.1 Visual examination

Surfaces of the specimens were washed carefully with plain water for the visual examination of outer surfaces of all the specimens. Concrete specimens made by using both plain and sea water as mixing water showed change in color from dark gray to whitish gray when exposed to sea water. On the other hand specimens kept in plain water showed almost no color change.

Changes in color may primary be due to salt deposition on the surfaces of the specimens exposed to sea water action.

However the interior part of the specimens made by using sea water or plain water retained their original color. It indicates that the specimens are mostly affected at the outer side by the action of sea water. For longer period of curing, the specimen prepared by mixing sea water exhibits the presence of expansive product named frields salt and ettringtite.

4.2 Compressive strength

The compressive strength of different grades of concrete cast and cured with plain water and sea water with different exposure period have been presented in Figures 1 to 4. From the figures it is seen that, the strength increases with the increase of exposure period for all the concretes. Almost all the concrete specimens exposed to sea water environment showed rapid increase in early strength as compared to plain water cured concrete. 28 days and 7 days strength ratios for concrete A are 1.30 (PW mixed & cured), 1.33 (PW mixed & SW cured), 1.35 (SW mixed & PW cured) and 1.37 (SW mixed & cured). Whereas 180 days and 7 days strength ratios for concrete C are 1.72 (PW mixed & cured), 1.67 (PW mixed & SW cured), 1.69 (SW mixed & PW cured) and 1.65 (SW mixed & cured). The early increases in strength are basically due to blocking of the pores by products of hydration. But ultimately strength decreases with time due to leaching out of the soft hydration product.

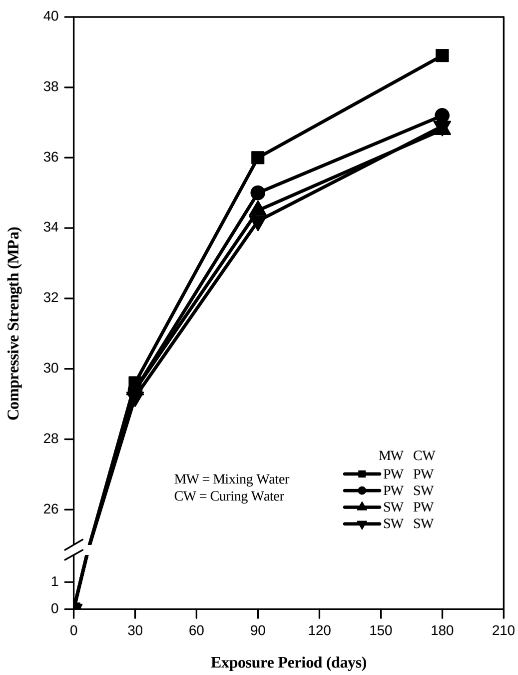

Fig.1: Compressive Strength - Exposure Time Relation for Concrete A

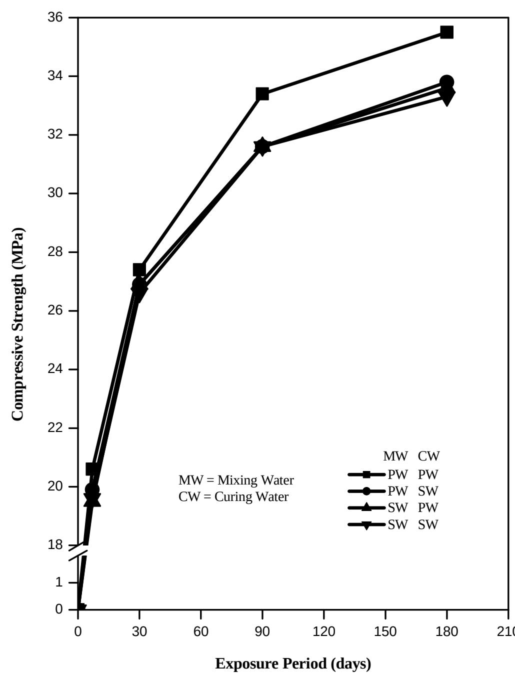

Fig.2: Compressive Strength - Exposure Time Relation for Concrete B

Careful study of the curves indicates that the sea water has significant effect on the gain of concrete strength with curing age. The concrete specimens made by mixing sea water and cured in plain/sea water shows higher strength deterioration compared to plain water made and cured concrete for relatively longer period of curing. The rate of gain in strength of sea water mixed and cured concrete is observed to be less than that of plain water mixed and cured concrete. For concrete D, the ratio of compressive strength for 180 days and 7 days is equal to 1.87 for concrete made and cured with plain water whereas this value is 1.83 for plain water mixed and sea water cured concrete, 1.81 for sea water mixed and plain water cured concrete and 1.78 for sea water mixed and sea water cured concrete.

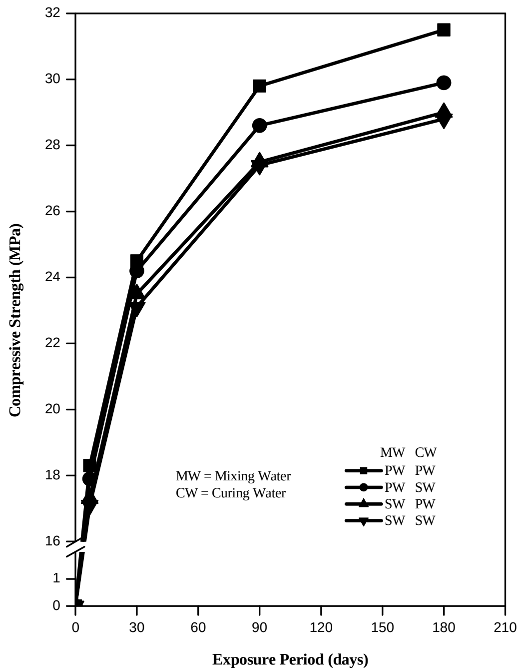

Fig.3: Compressive Strength - Exposure Time Relation for Concrete C

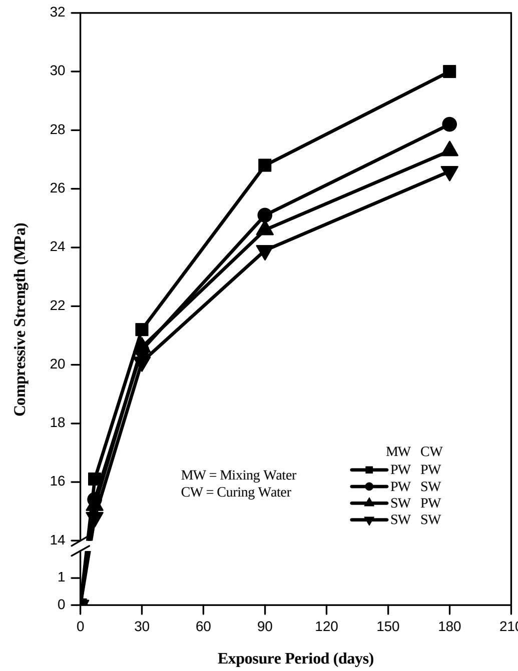

Fig.4: Compressive Strength - Exposure Time Relation for Concrete D

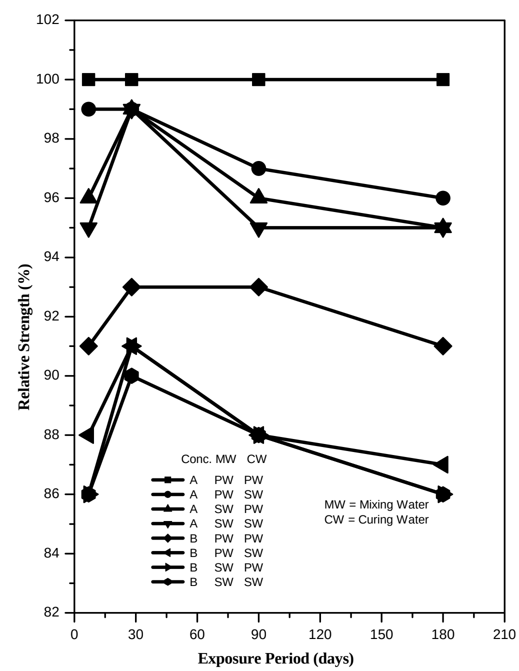

Fig.5: Relative Strength-Exposure Time Relation for Concrete A & B

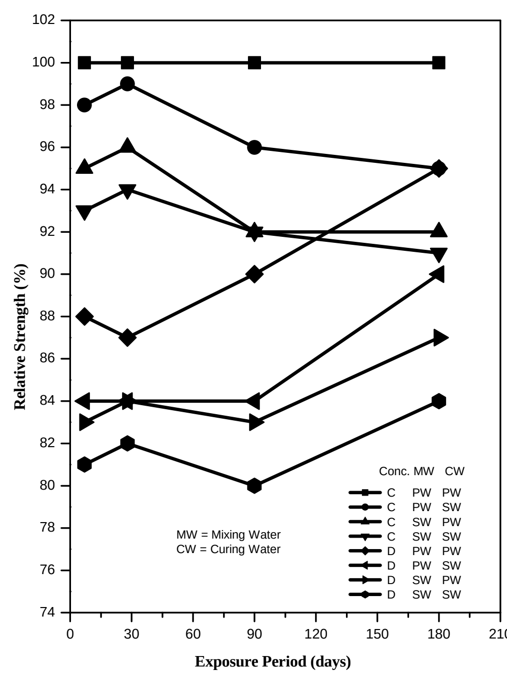

Fig.6: Relative Strength-Exposure Time Relation for Concrete C & D

Effect of seawater on the compressive strength of different grades concrete has also been explained in terms of relative strength. For a better understanding of the rate of strength deterioration and also for the ease of comparison, the relative compressive strengths are plotted in Figures 5 and 6. The concrete strengths at different ages are compared with plain water mixed and cured concrete specimens for identical conditions to get the relative strength. Strength deterioration of concrete is observed to vary with the grade of concrete. The reduction of strength is seen to be higher for the lower grade concrete. Among all the concretes studied, concrete D is seen to be mostly affected by sea water. The possible cause for strength deterioration may be due to dissolution of the compounds rich in lime and the formation of expansive compounds as a result of chloride and sulfate attack of sea water. At the end of 28 days curing period, the overall loss of strength is observed to 1% for grade A, 3% for grade B, 4% for grade C and 5% for grade D concrete. However at the end of 180 days, the losses are observed 4% for grade A, 6% for grade B, 9% for grade C and 10% for grade D concrete. So it can be concluded that relatively higher strength concrete showed better resistance against strength deterioration as compared to lower strength concrete. In contrast, sea water made concrete shows around 9% higher strength deterioration as compared to plain water made concrete. Strength deterioration rate is lower for plain water made concrete as compared to sea water made concrete. Many researchers have tried to explain the causes of strength deterioration of concrete exposed to marine environment. The aggressive salt ions penetrate into the interior portion of the concrete mass and change the hydration mechanism with the formation of some expansive products such as ettringtie or frields salt and also some leachable/soft compounds. As a result, micro cracks develop within the concrete mass together with leaching action of the newly formed compounds lead to the deterioration of concrete strength in sea water environment. On the other hand, the rapid gain in the early strength of sea water made concrete in sea water may be due to the accelerating effects of some of the sea salts originally introduced during the mixing of concrete. Sea water containing salts like NaCl, K_2SO_4 which was used in making concrete, cause a more rapid dissolution of compounds of cement particularly tricalcium silicate in water and hence facilitates more rapid hydration of concrete. At the later stages, the reaction products of sea salts with hydrated cement matrix being expansive and leachable in nature, cause progressive strength deterioration of concrete. From the figure it is noticed that for longer curing period relative strength of sea water made concrete gradually decreases. Strength exposure time relation curves clearly indicate their decreasing trends at higher exposure periods. Also much more strength deterioration of sea water made concrete as compared to plain water made concrete is noticed. Thus from the study it is clear that such investigation should be carried out over a longer exposure period to get clear idea about strength deterioration of sea water mixed concrete.

5. Conclusion

Test results of the investigation carried out on four different grades of concrete made with plain and sea water, exposed to plain as well as sea water over a period of 180 days has been critically studied and analyzed. Based on limited number of variable studied and test conducted, the following conclusions are drawn:

(1) Concrete specimens made by using both plain and sea water as mixing water and exposed to sea water environment showed some change in color from dark grey to light grey.

(2) Sea water affects the gain in strength of concrete when used for mixing and curing. It increases the early strength gaining but ultimately the strength decreases.

(3) Sea water affects the rate of gain in strength of concrete when used for mixing. The strength of concrete made by using sea water is observed to be decreased by about 10% at 180 days.

(4) Concrete specimens made with plain water and cured in sea water showed a loss in strength of around 6% whereas concrete specimens made with sea water and cured in sea water environment showed loss in strength of around 10% as compared to the similar concrete specimens made and cured with plain water.

(5) Among the four grades of concrete studied the higher grade concrete A showed around 9% lowers strength deterioration as compared to the other grades of concrete B, C and D.

Based on this study, it is recommended that sea water should not be used as mixed water. A long term study is required to assess the amount and extent of strength deterioration of concrete in sea water environment.

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