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Hydro Economic Analysis of Saline Water Concentration on the Compressive Strength of Concrete

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Abstract

This research was carried out to investigate the application of saline water suitability in the production of concrete. The concrete cube's dimensions, 150 mm by 150 mm by 150 mm were cast interchangeably introducing fresh water and saline water with a design mix ratio of 1:1.51:4.01, 1:1.61:4.03, and 1:1.66:4.24 respectively. The mix was prepared using different water-cement ratios (w/c) of 0.47, 0.50, and 0.55 by weight. Similarly, 180 concrete cubes were produced into two sections; one section of the cubes was produced with fresh water, and the other section used saline water, the curing was done for 7,21,28,60, and 90 days. The study revealed an impressive gain of compressive strength for the concrete specimens mixed and cured with saline water. The concrete cubes produced with fresh water and saline water with a design mix of M30 1:1.8:3.31 by weight of concrete and 0.45 water-cement ratio yielded a higher compressive strength. The overall result of the cumulative compressive strength of concrete produced with freshwater ranges from 27.12 - 39.12N/mm2 and saline water application, produced a strength of 28.45 – 41.34N/mm2.

Keywords: Compressive Strength; Concrete; Freshwater; Seawater; Suitability.

Introduction

The hydro-economic analysis typically includes a spatially and temporally distributed computer-aided mathematical model, which improves the economic performance of water systems. An important motivation for the introduction of the hydro-economic analysis is to improve the economic performance of water systems that need to adapt to climate change. In incorporating a hydro-economic analysis, the demands for water consumption and the provision of the availability of water are basically, enhanced economically, and hydrologically. The application of physical integration of hydrology and economic components is to encourage, policy design of economic realities, where the ecosystem, capital, and water services at the right quality, quantity, timing, location, price control, and cost are scarce, they exist a need to embraced hydro economic application to address this. However, concrete is the most globally used construction material in the world. It is difficult to find out an alternate material for a concrete replacement for construction works, [1]. More so, concrete has been used extensively in construction operations for several decades, especially on the shores of the Mediterranean Sea and they are still intact.

Accordingly, [2] stated that reinforced concrete has a combination of two (2) dissimilar but complementary materials, concrete strength, which is durable, and has good resistance to fire but appears little or no strength in tension but achieve higher strength in compression. However, steel has a very good tensile property, but is weak in resistance to fire (due to rapid decline in strength under high temperature) and is very good both in sheer and in compression. Thus, a combination of these materials results in good tensile and compressive strength, durability, and good resistance to sheer. Similarly, concrete on its own is a composite material of cement, sand, coarse aggregates (gravels), and water, its good workability allows it to be easily used in any shape ranging from, all types of foundations, bulky dam walls, including some thinning sheet roof, etc.

According to [3] and [4], maintained that seawater has a salinity of 3-5% however, about 78% of the dissolved solids comprise, NaCl, $MgCl_2$, and $MgSO_4$ and have slightly higher early strength but lower long-term strength. The seawater contained a solution of many salts including, suspended silt, disserted gases, and decaying organic materials. The ordinary chemical compositions of seawater are the ions of Chloride, Calcium, Sodium, Magnesium, and Potassium. The saline water has large quantities of chlorides which create surface efflorescence and dampness, therefore, this type of water should not be used where visibility is important, or where plaster finish is to be applied. More so, the pH values of seawater vary between 7.4 -8.4. Lastly, corrosion of the reinforcing steel occurs below a pH of 11.

Literature Review

Seawater attack on concrete

The Seawater attacks the concrete and steel of the structure and undergoes both physical and chemical reactions in the short and long span. The main effects on concrete exposed to seawater are susceptible to its corrosive effects. The effects are more pronounced above the tidal zone than when the concrete is permanently submerged. When Magnesium and Hydrogen are in a submerged zone, they combine ions to precipitate a layer of brucite, about 30 micrometers dense, and provide a slower concentration of calcium carbonate where aragonite occurs. These layers somehow protect the concrete from other processes, which include attacks by Magnesium, Chloride, Sulphate ions, and carbonation. Above the water surface, mechanical damage may set through erosion, and also waves or sand and gravel they carry, and through crystallization of salts from water penetrating into the concrete pores and then drying up.

Nevertheless, chlorides, particularly calcium chloride have been introduced to shorten the setting time of concrete. Sulfates and sulfites are ubiquitous in the natural environment and are present from many sources, including gypsum (Calcium sulfate) often present as an additive in blended cement which includes fly ash and other sources of sulfate, most sulfates are slight to highly soluble in water, as reported by [5] and [4]. Furthermore, in acid rain, the sulfur dioxide in the air when shed in the dissolved rainfall produced sulfurous acid. In lightning storms, the dioxide is oxidized to trioxide making the residual sulfuric acid in rainfall even more highly acidic.

Effect of saline water on concrete strength

They are basically two form tests for saline water which includes, electrical, and total conductivity test that measures specifically, the total soluble salt, provides the types of the composition of salts that are present, and provides the precise assessment of the salt reaction mechanism and its durability requirements of concrete specimens that can be suitable for more effective salinity control strategies. Hence, saline water effects on concrete are usually physical, and chemical attacks, or corrosion reinforcement.

Physical attack

The penetration of soil moisture contents on the concrete slabs results in sudden crystallization, and dampness formations, and the compressive strength of the concrete, leads to disruption of the concrete at its surface layer, allowing the concrete to be softened and fret away, exposing a fresh surface to an attack.

Chemical attack

Further, the presence of chloride and ions that are found in saline groundwater locations are basically, Sulphates of Sodium, Calcium, Potassium, or Magnesium. At certain concentrations, these sulfates can attack the concrete chemically. The degree of the attack is the function of the types of sulfates that are present in the reaction, their anticipated concentrations, and their fluidity on the groundwater, pressure, temperature, and the pressure of other ions, and potential sources, the source includes; groundwater containing dissolved sulfate formed from oxidation of sulphide minerals in the ground.

Reinforcement corrosion

A densely alkaline environment has a pH of about 12 which provides the concrete reinforcement, and the needed protection by offering a resilient impermeable layer of oxide on its surface. This naturally protects the reinforcement from any corrosion. The top concrete reinforcement cover provides a physical barrier to the absorption of substances such as salts. However, as the severity of the exposure increases, hence the required quantity of concrete cover. The composition of saline water is depicted in (Table 1).

Table 1: *The composition of saline water.*

NaCl	78%
$MgCl_2$	10.50%
$MgSO_4$	5%
$CaSo_4$	3.90%
K_2SO_4	2.30%
KBr	0.30%

More so, Mori et al, [5], reported that the difference in strength between concrete mixed with seawater and freshwater is relatively small after 10 years of exposure tests. Additionally, the concrete mixed with seawater may show higher strength compared with freshwater mixing in an environment below 150C, [6].

Nevertheless, [7] discusses very extensively the deterioration of reinforced concrete structures in a seawater environment. They found the structure to be seriously deteriorated due to steel corrosion. He concluded that the deterioration was not a result of the chlorides (Cl) gained from the water mix ratio, but particularly as a result of the surrounding environment. Therefore, the water-cement mix ratio of the concrete was relatively high from 0.52 – 0.74, when using ordinary Portland cement.

Nevile [8], in his work, recommended that seawater is not suitable for concrete-reinforced steel bars due to the high risk of corrosion. Similarly, [9], conducted research to investigate the effect of saline water absorption, on the compressive strength of concrete using saltwater from Lagos Bar – Beach, in Nigeria. More so, [10], and [11], in their works, achieved a compressive strength of 114% at 28 days of curing the concrete with saline water.

Likewise, Islam et al., [12], studied the suitability of saline water for mixing and curing concrete. They enumerated the effect of saline water on the compressive strength of concrete when used for design mix and curing, for different water-cement ratios.

Meanwhile, [13 and [14], concluded that concrete specimens cured with seawater brought about a reduction in the compressive strength of the concrete of about 10% compared to fresh water mixed and cured concrete. However, their result depicts that the compressive strength is reduced with a marginal increase in the saline water concentrations and the nature of the variation of strength is not proportional, as shown in (Table 2).

Table 2: *Typical ion composition of saline water.*

Common name	Ions	(G)
Sodium	Na	10360
Magnesium	Mg^{++}	1.294
Calcium	Cl^{++}	0.413
Potassium	K^{+}	0.387
Strontium	Sr^{++}	0.008
Chloride	Cl^{-}	19.353
Sulphate	SO_4^{2-}	2.712
Bromide	Br^{-}	0.008
Boron	N_3B_3	0.001
Bicarbonate	HCO^{3-}	0.142
Fluoride	F	0.001

Source: Laboratory analysis (2019).

Materials and methodology

The seawater was collected from Ukpemeke in Ibeno Local Government Area of Akwa Ibom State in containers of about four hundred litres (400 litres). The seawater was collected for both mixing and for the curing of concrete specimens; the quantity collected was transported to a company yard at Bulletin construction in Mbak Itu Local Government Area. The pH value of the seawater is known to be 8 which is the average globally.

Collection of Fresh/Tap Water Samples

The fresh/tap water was collected from a borehole tap in the company yard, it was free of organic matter and oil, and was suitable for mixing and curing the cubes. The desired quantities of water were measured by a graduated jar and added to the concrete. The other materials for the concrete mix were by weight batching, and the pH value was 6.

Collection of Fine Aggregate

The river sand was collected/brought from the beach in Mbak, and Stock pilled in the yard. The river sand used was completely free of clay and organic impurities; the various aggregates were tested for their physical requirements including, fineness modulus, gradation, specific gravity, and bulk module with respect to British Standard.

Collection of Coarse Aggregate

The coarse aggregates were collected from stock-filled materials in the company yard, it was brought from RCC Quarry site Akpabuyo town, Cross River State. The crushed rocks are of nominal sizes of 20 mm.

Method/Procedure

We weighed the individual sieve and the respective weight was recorded, 500 g of fine aggregate was also weighed, and the standard sieve was arranged in order of increasing its diameter size from the bottom to the top. A tray was coupled to the bottom, and the 50 g of fine aggregate was poured into the sieve at the top and covered with the lid, and the sieve was mounted on the sieve shaker for a duration of 15 minutes. At the end of the time interval, the sieve arrangement was decoupled from the sieve shaker and individual sieves were separated and weighed with their retained materials. Hence, the percentage of the individual sieve sizes was calculated.

Grading of fine aggregate

We weighed the individual sieve and their weight was recorded, 5kg mass of coarse aggregate was weighed. The sieve was arranged in order of their increasing diameter size from the bottom to the top. A tray was attached to the bottom, and the 5kg mass of coarse aggregate was gently poured into the sieve at the top and covered with the lid. The whole arrangement was mounted on the sieve shaker and timed for 15 minutes. At the elapsed of this time interval, the sieve was removed from the sieve shaker; and the individual sieve was separated with their respective retained materials and weighed and recorded. Hence, the percentage passing of the individual sieve was calculated.

Placing the fresh concrete in the moulds

A 150 x 150-inch concrete cube was used, and freshwater and seawater were used to batch the concrete by weight. Three mixtures were tested. The first mixture had a water-cement ratio of 0 points 47 and was intended to have a target cube strength of 43 N/mm2. It contained 340 kg/m3 of cementitious material, 1387 kg/m3 of fine aggregate, 310 N/mm2, and 310 kg/m3 of coarse aggregate.

The second design mix had a water-cement ratio of 0:55, 310 N/mm3 of cementitious material, 498 kg/m3 of fine aggregate, and 1250 kg/m3 of coarse aggregate. The third mixture was estimated to have a strength of 36 N/mm2, a cement content of 290 kg/m3, 480 kg/m3 of fine aggregates, 123 kg/m3 of coarse aggregates, and a cement content of 0 point 50. This study makes use of saltwater from Ibeno Beach in Akwa Ibom State and fresh water from a borehole tap, both of which have specific gravities of 6 points 62 and bulk densities of 1533 kg/m3, while the aggregates adhere to BS 877 of 1967 (pg. 3) and BS 3797 of 1964, and the cement to BS 12 of 1978. From UNICEM, cement was purchased. After being thoroughly lubricated with points to reduce friction, the concrete cubes were properly mixed with the freshwater and seawater. Next, the cubes were filled to one-third of their height and compacted 35 times. After that, they were pilled to two-thirds of the mold's height and compacted 35 times. Finally, the excess concrete level was removed from the top of the mould by screening.

Curing of Concrete Cubes

The cubes were demoulded after 24 hours, and the ones made with saline water were cured separately in wells containing seawater (SS), while those made with fresh water were cured in containers made with fresh water but were also cured with seawater for "7, 21, 28, 60, and 90 days," respectively, and for a specified period of hydration.

- Casting and curing of concrete cubes using seawater (SS)
- Casting and curing of concrete cubes using freshwater (FF)
- Casting with seawater and curing of concrete cubes using freshwater (SF)
- Casting with fresh water and curing concrete cubes using seawater (FS)

A total number of 90 concrete cubes were cast, forty-five cubes using seawater and forty-five (45) cubes using fresh water.

Figure 1: *Samples of Concrete cubes cast.*

Results and discussion

According to the laboratory analysis, the cube was cast in fresh water and cured in a saline water container, so the early 7 days' strength had no effect. Instead, the compressive strength, tensile strength, and flexural strength decreased over time for 28 and 90 days. Evidently, the strength increases for a few days after the concrete is cast and is cured with salt water, but it then gradually decreases over time. Similar to salt water, it undergoes changes in normality over many years, and these changes in normality are largely responsible for the effects observed.

However, it is important to investigate how seawater affects the curing of high-strength concrete. Therefore, the innate factors that negate the strength of concrete in marine water are basically the corrosion of metallic bars by chloride ions, leading to the deformation of the cement paste caused by sulfate attack, and creating swelling disruption of concrete. Table 3 shows the findings of the chemical and physical examination of freshwater and saltwater.

Table 3: *The result of the physical and chemical analysis of fresh water and saline water.*

S/N	Parameter	Standard distilled and deionized H_2O	Sample of Borehole water	Sample of freshwater
1	PH	7	6.4	7.5
2	Colour	0		Blue
3	Odour	Unobjectionable	Unobjectionable	Unobjectionable
4	Taste	Insipid	Not detected	Not detected
5	Temperature (°C)	28	20^0C	32^0C
6	Conductivity	0	0.24	410
7	Salinity (mg/l)	0	0	875
8	Total dissolved solids (mg/l)	0	21	1300
9	Total suspended solids (mg/l)	0	0.04	59

10	Turbidity	0	0.08	46.7
11	Dissolved oxygen (mg/l)	0	0.06	4.5
12	Total hardness $CaCO_3$ (mg/l)	0	5.2	20.9
13	Alkalinity (ppm)	0	1.04	4.01
14	Chemical oxygen demand (mg/l)	0	0	2.02
15	Total hydrocarbon content (mg/l)	0	0	1.5
16	Total petroleum hydrocarbon (mg/l)	0	0	1.5
17	Biochemical oxygen demand (mg/l)	0	2.2	14
18	Nitrate ion (NO_3^2) (mg/l)	0	0.002	0.186
19	Phosphate (mg/l)	0	0.08	0.2
20	Phenols (mg/l)	0	0	0.51
21	Sulphate (mg/l)	0	6.7	180
22	Lead (mg/l)	0	i0.02	i 0.01
23	Iron (mg/l)	0	0.04	0.42
24	Copper	0	0.34	0.61
25	Nickel	0	i0.002	0.9
26	Vanadium (mg/l)	0	0.96	i0.002
27	Zinc (mg/l)	0	i0.001	0.03
28	Cadmium	0	0	i0.001

Similar to this, Table 4 and Figure 2 show the concrete design and its compressive strength at a water-to-cement ratio of 0:47, with fresh water curing increasing strength at 90 days, saline water curing increasing strength to 42:34 N/mm2, and freshwater curing increasing strength to 38:81 N/mm2.

Table 4: *Water cement ratio (0.47) 1:2:4.*

Concrete Designation	Curing Days	Average Crushing Load (KN)	Compressive Strength (N/mm^2)
FF	7	336.31	14.95
	21	388.67	17.27
	28	454.67	20.21
	60	542.67	24.12
	90	620.67	27.58
FS	7	371.21	16.5
	21	441.13	19.61
	28	511.15	22.71
	60	547.09	25.5
	90	629.17	28
SF	7	568.11	25.24
	21	654.02	29.08
	28	753.12	33.47
	60	846.33	37.61
	90	873.33	38.81
SS	7	615.12	27.35
	21	703.33	31.26
	28	803.33	35.7
	60	896.67	39.85
	90	952.67	42.34

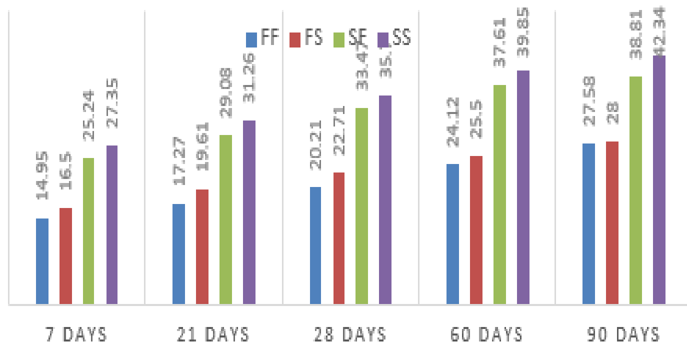

Figure 2: *Average compressive strength of concrete cubes at 7, 21, 28, 60, and 90 days, cast and cured with fresh water and saltwater using a water-cement ratio of 0.47.*

The results for the water-cement ratio of 0.50 as depicted in Table 5 and Figure 4, show a strength of 39.13 N/mm2, for concrete cured with fresh water, and higher strength of 41.0 N/mm2, for concrete cured with seawater.

Table 5: *Water cement ratio (0.50) 1:2:4.*

Concrete designation	Curing days	Average crushing load (kN)	Compressive strength (N/mm^2)
FF	7	555.33	24.68
	21	601.7	26.68
	28	706.1	31.38
	60	767.4	34.08
	90	881.33	39.13
FS	7	368.33	16.37
	21	355.6	15.76
	28	460.3	20.45
	60	526.7	23.41
	90	625.7	27.81
SF	7	353.33	15.7
	21	420	18.67
	28	465.7	21
	60	566	25.15
	90	705	31.33
SS	7	613.33	27.26
	21	668	29.67
	28	717.33	32
	60	785.7	35
	90	918	41

Figure 3: *Average compressive strength of concrete cubes at 7, 21, 28, 60, and 90 days, cast and cured with fresh water and saltwater using a water-cement ratio of 0.50.*

As shown in Table 6 and Figure 4, the water-cement ratio of 0.55, achieved a strength of 36.03 N/mm2 of concrete cured with fresh water, and a significant increase of about two percent of strength cured with seawater respectively.

Table 6: *Water cement ratio (0.55) 1:2:4.*

Concrete designation	Curing days	Average crushing land (kN)	Compressive strength (N/mm^2)
FF	7	530.33	23.58
	21	597.33	26.56
	28	724.67	32.22
	60	785.67	33.44
	90	810.3	36.03
FS	7	347.67	15.44
	21	412	18.31
	28	472	21
	60	505	22.44
	90	540	24
SF	7	350	16
	21	377	17.05
	28	510.33	22.68
	60	524.33	25.02
	90	555.67	26.09
SS	7	563.33	25.05
	21	624.33	29.24
	28	745.33	33.14
	60	788.33	34
	90	854.67	38.13

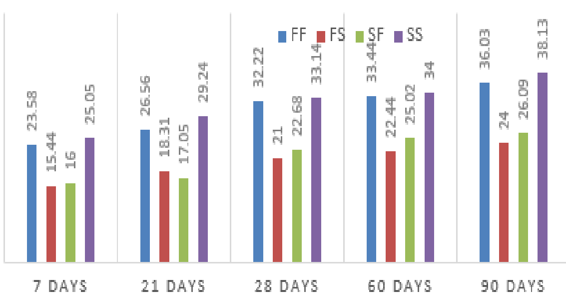

Figure 4: *Average compressive strength of concrete cubes at 7, 21, 28, 60, and 90 days, cast and cured with fresh water and saltwater using a water-cement ratio of 0.55.*

Conclusion and Recommendation

Conclusion

According to the laboratory findings, adding salt water to the concrete during casting and curing has no negative effect on the concrete's compressive strength; on the contrary, it actually increases strength. However, without reducing its compressive strength properties, this type of concrete will be appropriate for large-scale concreting projects. More specifically, the concrete is damaged when it is exposed to seawater because of a solution of magnesium sulfate and sodium chloride salts. The aforementioned incidents happen more frequently as a result of poor concrete production practices, which also result in wetting, drying, freezing, and thawing, rather than just the effects of seawater.

The components of hardened Portland cement paste, such as magnesium sulfate, chlorides, and alkalis that are produced during alkali-aggregate reactions, typically attack the surface of the concrete. Finally, the cement that can guard against damage and provide a high level of resistance to aluminate content with a maximum nonreactive aggregate should be used to bind concrete that will be exposed to salt water. This cement will also provide protection for concrete with a low capacity for absorption.

Recommendations

- The provision of anti-chloride admixtures should be incorporated for concrete production to protect the saline water reaction on concrete.
- Further work should be carried out to investigate higher strength concrete of M40, and M50.
- The introduction of outer surface coverage of unplasticized polyvinyl chloride (uPVC) tubes should be adopted to safeguard concrete columns.

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