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Enhancing Concrete Performance in Marine Environments: Insights into Seawater Effects and Cement Optimization

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Abstract

This study investigates the effects of seawater on the compressive strength of concrete through experimental analysis. Experimental cement concrete cubes of 150mm x 150mm x 150mm were cast using different mixes of concrete mixed and cured in seawater in order to determine the compressive strength. All the mixes were prepared using various water cement ratios (w/c) ranging from 0.5 to 0.6 by weight. A total of 60 concrete cubes were made in twenty batches; the cubes were cast and cured in sea water. The curing was done for 21days, and then crushed using the Compressive Strength Test Apparatus at the prescribed age. The study shows an increase in the compressive strength of concrete for concrete specimens mixed with seawater during the early stages of curing, up to 14 days. However, after 28 days and beyond, the compressive strength of concrete mixed and cured with seawater begins to decrease.

Keywords: Concrete, Compressive Strength, curing, Seawater, Optimization.

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1. Introduction

About 80 percent of the surface of the earth are covered by oceans; therefore, a large number of structures are exposed to sea water with high salinity either directly, or indirectly when winds carry sea water spray up to a few miles inland from the coast. As a result, several coastal and offshore sea structures are exposed to the continuous action of physical and chemical deterioration processes. This challenge of building and maintaining durable concrete structures in coastal environs have long become a serious issue to the people living in this area and this provides an excellent opportunity to understand the complexity of concrete durability problems in these areas.

Concrete is one of the major building materials used in modern day construction. It is a composite construction material composed of cement and other cementations materials such as fly ash and slag cement, aggregate (generally a coarse aggregate made of gravels or crushed rocks such as limestone, or granite, plus a fine aggregate such as sand), water, and chemical admixtures (Akinkurolere *et al*, 2007; Neville and Brook, 2008; Matthias, 2010). Concrete is used for numerous purposes in construction such as construction of buildings, dams, foundations, highways, parking structures, pipes, poles among others (Matthias, 2010). Also, the use of concrete offshore drilling platforms and oil storage tanks is already on the increase. Concrete piers, decks, break-water, and retaining walls are widely used in the construction of harbors and docks. Floating offshore platforms made of concrete are also being considered for location of airports, power plants, and waste disposal facilities in order to relieve land from pressures of urban congestion and pollution (Gopal, 2010).

Seawater is water gotten from sea, which is salty in taste. Seawater can be said to have a solution containing a great number of elements in different proportions. Primarily seawater contains some chemical constituent such ions of chloride, magnesium, calcium and potassium (Akinkurolere *et al*, 2007; Gopal, 2010). Most seawater is fairly uniform in chemical composition, which is characterized by the presence of about 3.5 percent soluble salts by weight. The ionic concentrations of Na+ and Cl- are the highest, in Atlantic Ocean typically 11000 and 20000mg/liter respectively.

In the vast majority of development that has crept into the building industry, concrete and steel have found their ways so useful and very paramount in the building component. Oyenuga (2004) stated that reinforced concrete is a

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combination of two dissimilar but complementary materials, namely concrete and steel. Concrete has considerable crushing strength, is durable, has good resistance to fire but offers little or no strength in tension but fair in shear. On the other hand, steel has a very good tensile property, poor resistance to fire (due to rapid loss of strength under high temperature) and very good both in shear and in compression. Thus, a combination of these materials results in good tensile and compressive strength, durability and good resistance to fire and shear. Concrete on its own is a composite material of cement, sand, coarse aggregate (gravel or crushed stone) and water. Its strength depends on several factors overtime. Thus this study investigates the effects of seawater on the compressive strength of concrete.

2. Materials and Method

2.1 Materials

Cement: The cement used was Dangote Portland Cement. It was stored under dry condition, free of lumps and in conformity with BS 12 (Specification for Portland cement).

Water: Seawater was used. The water samples were clean and free from oil. The sea water used was gotten from Port Harcourt Tourist beach, Rivers State, Nigeria.

Aggregates: The fine aggregate was gotten from the stream, a washed sand deposit, free from organic matter with specific gravity of 2.73. The coarse aggregate was granite a crushed rock of less than 1-inch (20mm) size and of high quality with specific gravity of 2.63. Both aggregates met the requirements of BS 882 (Specification for aggregates from natural sources for concrete). Table 1 presents concrete mixture proportions.

Table 1: Concrete mix proportions

	Mix Ratios			
Batch	Z_1	Z_2	Z_3	Z_4
B1	0.6	1	1.5	2
B2	0.5	1	1	2
B3	0.55	1	2	5
B4	0.65	1	3	6
B5	0.55	1	1.25	2
B6	0.575	1	1.75	3.5
B7	0.625	1	2.25	4
B8	0.525	1	1.5	3.5
B9	0.575	1	2	4
B10	0.6	1	2.5	5.5
B11	0.5625	1	1.5	2.75
B12	0.6	1	2.0	3.37
B13	0.55	1	1.75	3.75
B14	0.575	1	1.875	3.75
B15	0.575	1	1.375	2
B16	0.5875	1	1.625	2.75
B17	0.6125	1	1.875	3.0
B18	0.5125	1	1.25	2.75
B19	0.5375	1	1.5	3.0
B20	0.5850	1	2.25	5.25

LEGEND;
Z_1 = Water Cement Ratio, Z_2 = Cement, Z_3 = Fine Aggregate, Z_4 = Coarse Aggregate

2.2 Methods

2.2.1 Preliminary Test: Some preliminary tests were carried out on the samples. The mechanical and physical properties tests were performed on the aggregates with respect to BS 812 (Testing aggregates). Setting time of the cement and sieve analyses, commonly known as the gradation test were carried out as shown in figure 1 to determine the gradation (the distribution of aggregate particles, by size, within a given sample) in order to determine compliance with design, production control requirements, and verification specifications.

2.2.2 Mechanical Analysis (particle size analysis)

The sieves were shacked one over the other, with decreasing size from the top to the bottom. The selection of the required number of sieves was done to obtain a good particle size distribution curve. A lid (cover) was placed at the top of the largest sieve. A receiver, known as pan, which has no opening, was placed at the bottom of the smallest sieve.

2.2.3 Specimen Preparation and Casting of Concrete Cubes: Batching was done by weighing the materials for the concrete specimen using a Manual Weighing Balance. Varieties of concrete mix ratios by weight of concrete with different water-cement ratios were used. Mixing was done manually on a clean concrete floor and the materials were thoroughly mixed in the dry state twice, after which water was added gradually while thoroughly mixing the concrete. Mixing of the concrete specimen continued by turning the mixture of cement, water and aggregates until the concrete was uniform in color and consistency. The test cubes were cast inside steel mold of size 150x150x150(mm) with the mold and its base clamped together. The inside of the molds was smeared with oil so as to enhance easy removal of the set concrete. The fresh concrete mix for each batch was fully compacted by tamping rods, to remove trapped air, which can reduce the strength of the concrete. 60 concrete cubes of 150x150x150(mm) were cast and cured in twenty batches using seawater for 21days.

2.2.4 Slump Test

The test was developed in Britain in the late 1940s and has been standardized as British Standard 1881-103. The apparatus consists of a mold in the shape of the lateral surface of the frustum of a cone with a base diameter of 203mm (8 inches), a top diameter of 102mm (4 inches), and a height of 305mm (12 inches). The mold was filled with concrete in three layers of equal volume. Each layer was compacted with 25 strokes of a tamping rod to remove voids. The tamping rod used was a round, straight steel rod 16mm [$^5/_8$in.] in diameter and approximately 600mm [24 in.] in length, having the tamping end. The slump cone mold was lifted vertically upward and the change in height of the concrete was measured. Part of the concrete sheared from the mass, the test was repeated with a different sample of concrete until the concrete remained intact and retained a symmetric shape referred to as the “true” slump, The entire test was completed from the start of the filling through removal of the mold without interruption and was completed within an elapsed time of $2^1/_2$ minutes. The final slump measurement was recorded no later than 60 seconds after the slump cone was removed by determining the vertical difference between the top of the mold and the displaced original center of the top surface of the specimen.

2.2.5 Vicat Test

To determine the initial and final setting times of cement, 400g of cement was placed in the enameled tray. About 25% water by weight of dry cement was thoroughly mixed to get a cement paste. Total time ttaken to obtain thoroughly mixed water cement paste i.e. "Gauging time" was 5 minutes. The vicat mold was filled, rested upon a glass plate, with this cement paste. After filling the mold completely, the surface of the paste was smoothened, made level with top of the mold. The whole assembly was placed (i.e. mold + cement paste + glass plate) under the rod bearing plunger. The plunger was lowered gently so as to touch the surface of the test block and quickly released the plunger allowing it to sink into the paste. The depth of penetration was measured and recorded. Trial pastes were prepared with varying percentages of water content and following the steps as described above, until the depth of penetration became 33 to 35 mm.

2.2.6 Initial Setting Time

The test block was immediately placed with the non-porous resting plate, under the rod bearing the initial setting needle. The needle was lowered and quickly released allowing it to penetrate in to the mold. In the beginning the needle completely pierced the mold. This procedure was repeated until the needle failed to pierce the mold for 5.5mm. The period elapsed between the times of adding water to the cement to the time when needle failed to pierce the mold by 5.5mm was recorded as the initial setting time

2.2.7 Final Setting Time

The needle of the vicat apparatus was replaced by the needle with an annular ring. Lowered the needle and quickly released. The process was repeated until the annular ring made an impression on the mold. The period elapsed between the times of adding water to the cement to the time when the annular ring failed to make the impression on the mold was recorded as the final setting time.

Table 2 presents mix design of M20-grade concrete

Table 2: Mix design of M20-grade concrete

Material	Batch Quantity /m^3
Cement (kg)	100
Water (Liter)	286
Coarse Aggregate (kg)	400
Fine Aggregate (kg)	200

2.4 Method of curing used

The cast cubes were totally immersed in saltwater throughout the curing period; the curing water was maintained at an average laboratory temperature of 28°C (82.4°F) to prevent thermal stresses that could result in cracking. The specimens were cured in the curing tank in conformity with BS 1881:1997- (Method of curing used for the test specimens was "Ponding").

Tables 3 & 4 presents the ion and chemical composition of seawater.

Table 3: Major ion composition of Seawater

Common name	Ions	(g)
Sodium	Na	10.360
Magnesium	Mg^{++}	1.294
Calcium	Ca^{++}	0.413
Potassium	K^{+}	0.387
Strontium	Sr^{++}	0.008
Chloride	Cl^{-}	18.379
Sulphate	SO_4^{2-}	0.099
Bromide	Br^{-}	0.008
Boron	N_3B_3	0.001
Bicarbonate	HCO_3^{-}	0.142
Fluoride	F^{-}	0.001

Source: Laboratory analysis (2009).

2.5 Los Angeles Abrasion Test

This is a very popular test for measuring the abrasion resistance of aggregates. A material which is highly abrasion resistant has a long life. The test has been standardized in BS 812 (Testing aggregates).

The machine consists of a circular drum of internal diameter 700mm and length 500mm mounted on a horizontal axis enabling it to be rotated. An abrasion charge consisting of the cast iron spherical balls of 48mm dia and weight 390-445gm was placed in the cylinder along with the aggregates. The quantity of aggregates used was 7kg due to the gradation (20mm). The cylinder was rotated at a speed of 30-33revolution per minute (with regards to the material). After the specified revolutions, the material passing through 1.7mm size sieve was separated. The weight of this material (fines) expressed as a percentage of the total weight of the sample is known as the Los Angeles Abrasion Value.

Table 4: Chemical Analysis of Seawater

TEST	SEAWATER
PH	7.8
Total suspended solid	_
Total dissolve solid	31200 mg/l
Chloride	6000 mg/l
Nitrate	_
Hardness	_
Calcium	210.6 mg/l
Magnesium	1644 mg/l
Acidity	_
Alkalinity	1644 mg/l
Iron	0.14 mg/l
Sulphate	1400 mg/l
Potassium	475 mg/l
Chromium	0.03 mg/l
Phosphate	1.10 mg/l
Salinity	32. 6 g/l
Total solid	_
Odour	Unobjectionable
Colour	Blue
Temperature	32.6 ^{O}C

Source: Laboratory analysis (2009).

Methodological Summary

The experimental study and report were carried out on the effects of salt in saline water (seawater on mass concrete structures in the coastal regions). The primary data for the research work comprises review of researches conducted on concrete while the secondary data includes the relevant past laboratory record (Published and unpublished), In addition a laboratory experiment was conducted to determine saline water effects on compressive strength of concrete. The approach used is:

- Casting and curing of the concrete cubes samples using seawater labeled (CSW)

Concrete cube samples were cast and immersed in an isolated concrete tank filled and reticulated with seawater. The cast concrete element comprises 150mm x 150mm x 150mm concrete cubes cast and cured with seawater. Dimension of the cube specimens were measured with the measuring tape. The mixes were prepared in the laboratory in different ratios of cement, sand and coarse aggregates. The control mix (CSW) as described above were prepared to ascertain the effect of seawater on the compressive strength of concrete. These specimens were observed for 21 days to allow for compressive strength development before crushing with compressive crushing machine. All the cubes were cured by total submersion in water.

Characterization of aggregates, mixing and preparation of concretes and compressive strength test were performed in accordance with British standards. Different water cement ratios were used in all mixes. This approach was adopted to provide basis for qualitative comparison of how different types of water affect compressive strength of concrete when they are used for casting and curing of concrete. The striking of the molds used for various concrete specimens were done immediately after 24hrs (twenty-four hours) of casting and the various samples were placed into the various water and the environment of curing.

3. Results and discussion

The results obtained from preliminary tests carried out on concrete and water are presented and discussed here as:

3.1 Effect of Seawater on the Setting Time of Cement Paste

From Table 5, it can be seen that the value of the setting times of Ordinary Portland cement paste of standard consistency decreases with seawater. It is observed that the initial and final setting times of ordinary Portland cement paste decreases with seawater. This was due to the crystallization that takes place at the point of evaporation of water which has a substantial reduction in the initial and final setting time of cement paste.

Shetty, also reported that sulphate attack denotes an increase in the volume of cement paste in mortar due to the chemical action between the products of hydration of cement and solution containing sulphates.

Table 5: Mechanical Properties of Fresh Concrete

TEST	CSW
Slump (mm)	78
Initial Setting Time (mins)	35
Final Setting Time (mins)	280

The test results for the setting time of cement and slump value are shown in Table 5 above.

CSW – Concrete mixed with salt water

Table 5 shows increase value of setting time, which implies that concrete mix with sea water is not susceptible to the problem of flash and false set. Also, the value reveals that it falls into the normal range of concrete (Table 6).

Table 6: Concrete Cubes Test Result

S/N		Batch 9		
1	Mix Ratio	1:2:4		
2	Water/Cement Ratio	0.575		
3	Slump (mm)	7.8		
4	Date of Manufacture	14-05-2017		
5	Date of Test	05-06-2017		
6	Age at time of test (days)	21		
7	Dimensions (mm)	150x150x150		
8	Weight (gms)	9000	9070	9100
9	Volume (cm^3)	3375	3375	3375
10	Density (gm/cm^3)	2.67	2.69	2.70
11	Cross-sectional Area (mm^2) x 10^{-3}	22.5	22.5	22.5
12	Maximum Load (KN)	437	448	455
13	Compressive Strength (N/mm^2)	19.40	19.91	20.22
14	Average Strength (N/mm^2)	19.85		

3.2 Sieve Analysis Test Results

Gradation analysis of both fine and coarse aggregates was carried out by sieving, using standard set of sieves (Tables 7 & 8). BS 812 (Testing aggregates) defines the required procedure. Dry sieve analysis is generally suitable for the testing of graded coarse aggregates.

Table 7: Sieve Analysis of Fine Aggregate

Sieve size (mm)	Percentage passing (%)
10	100
3.35	96
2.36	95
1.70	81
0.212	2.5
0.125	0.8
0.063	0.2
Receiver	_

Table 8: Sieve Analysis of Coarse Aggregate

Sieve size (mm)	Percentage passing (%)
30.0	100
26.5	78
25.0	47
20.0	16
14.0	2.9
10.0	0.2
3.35	0
Receiver	_

The test results for the particle size distribution of aggregates are shown in Tables 3.3 & 3.4 above.

3.3 Compressive Strength Test Results

Cubes of concrete mixes (Batch1-Batch20) were tested for compression, and the average ultimate compressive strengths were determined in order to study the effect of Seawater on compressive strength. The obtained values of average compressive strengths are given in Table 8

Table 8: Compressive Strength test results for Concrete Cast and cured with Seawater

Water-Cement Ratio	Fine Aggregate	Coarse Aggregate	Maximum Crushing Load (KN)	Average Strength (N/mm^2)
0.6	1.5	2	224.55	9.98
0.5	1	2	225.95	10.04
0.55	2	5	263.40	11.71
0.65	3	6	470.00	20.89
0.55	1.25	2	380.90	16.92
0.575	1.75	3.5	438.90	19.51
0.625	2.25	4	273.90	17.10
0.525	1.5	3.5	393.55	17.49
0.575	2	4	446.67	19.85
0.6	2.5	5.5	278.20	12.30
0.5625	1.5	2.75	226.00	10.04
0.6	2.0	3.37	322.05	14.31
0.55	1.75	3.75	235.20	10.45
0.575	1.875	3.75	218.35	9.70
0.575	1.375	2	220.00	9.77
0.5875	1.625	2.75	230.40	10.24
0.6125	1.875	3.0	230.00	10.22
0.5125	1.25	2.75	225.00	10.00
0.5375	1.5	3.0	229.90	10.22
0.5850	2.25	5.25	260.00	11.50

The test results for cubes cast and cured with seawater are shown in Table 8.

The test results for cubes cast and cured with Fresh water are shown in Table 9.

Table 9: Compressive Strength test results for Concrete Cast and cured with Fresh Water

Water-Cement Ratio	Fine Aggregate	Coarse Aggregate	Maximum Crushing Load (KN)	Average Strength (N/mm^2)
0.6	1.5	2	675	30
0.5	1	2	720	32
0.55	2	5	427.5	19
0.65	3	6	270	12
0.55	1.25	2	713.25	31.7
0.575	1.75	3.5	546.75	24.3
0.625	2.25	4	441	19.6
0.525	1.5	3.5	558	24.8
0.575	2	4	450	20
0.6	2.5	5.5	416.25	18.5
0.5625	1.5	2.75	630	28
0.6	2.0	3.37	506.25	22.5
0.55	1.75	3.75	524.25	23.3
0.575	1.875	3.75	515.25	22.9
0.575	1.375	2	693	30.8
0.5875	1.625	2.75	621	27.6
0.6125	1.875	3.0	551.25	24.5
0.5125	1.25	2.75	630	28
0.5375	1.5	3.0	569.25	25.3
0.5850	2.25	5.25	436.5	19.4

Figures 1-4 presents particle size distribution of fine aggregates, particle size distribution of coarse aggregates, Water-cement ratio and compressive strength relationship for SS and FF.

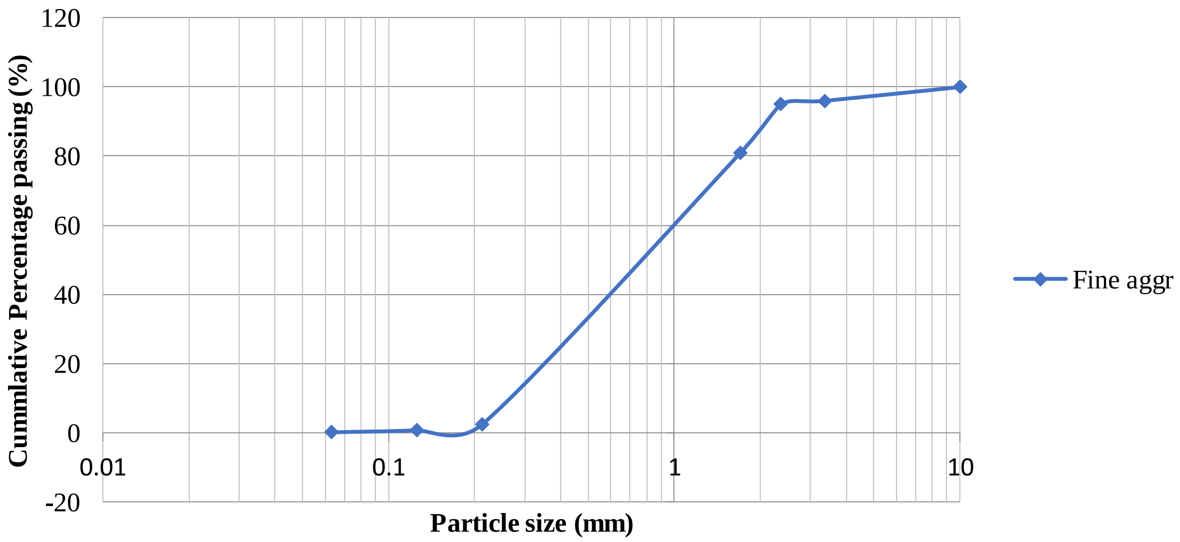

Figure 1: Particle size distribution of fine aggregates

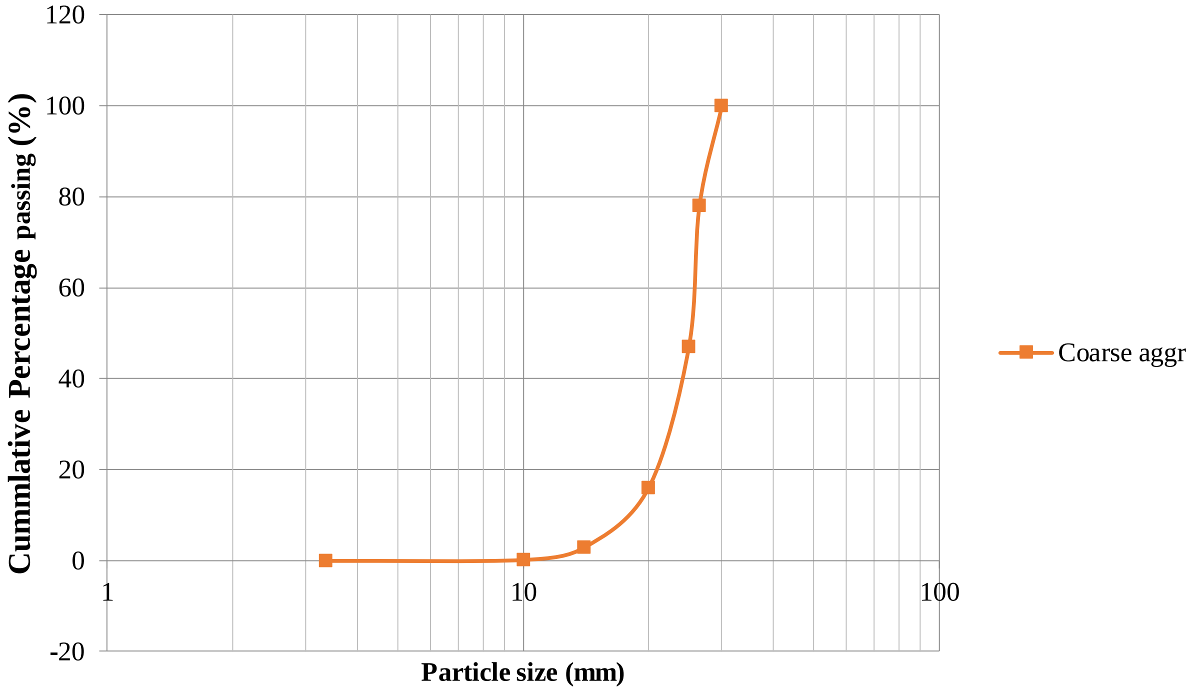

Figure 2: Particle size distribution of coarse aggregates

3.4 Dry Sieve Analysis

The soil sample was taken in suitable quantity (500g). The soil was taken air-dry and was pulverized. The soil did not contain any lump. The sample was placed in the top sieve and the set of sieves was kept on a mechanical shaker and the machine was started. 10minutes of shaking was sufficient for the soil. The mass of soil retained on sieve and on the pan was obtained. The mass of the retained soil was checked against the original mass.

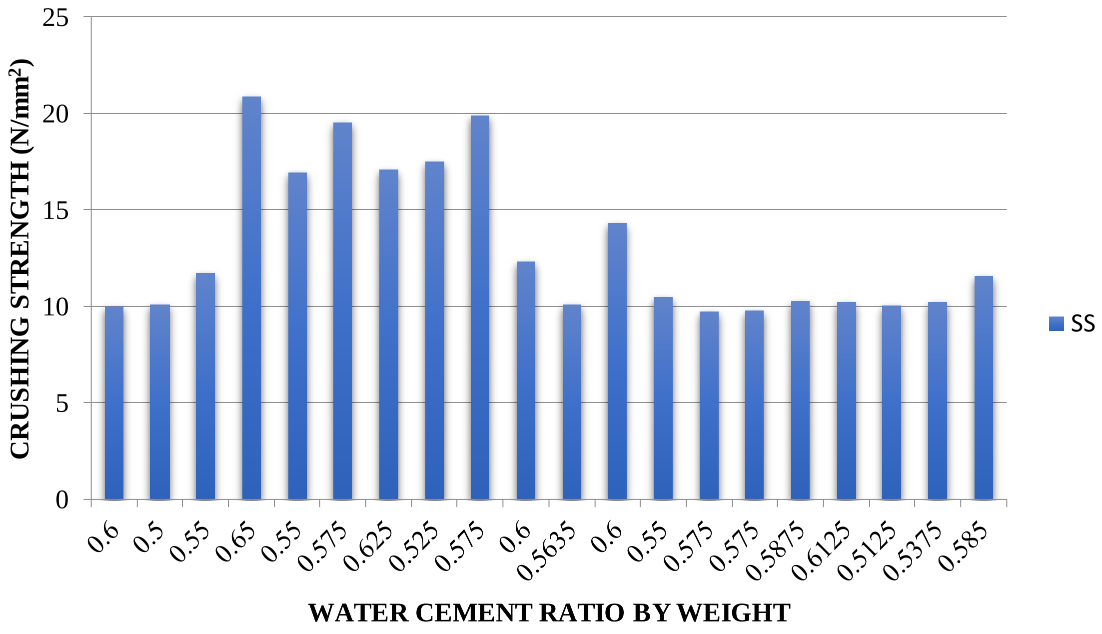

Figure 3: Water-cement ratio and compressive strength relationship for SS

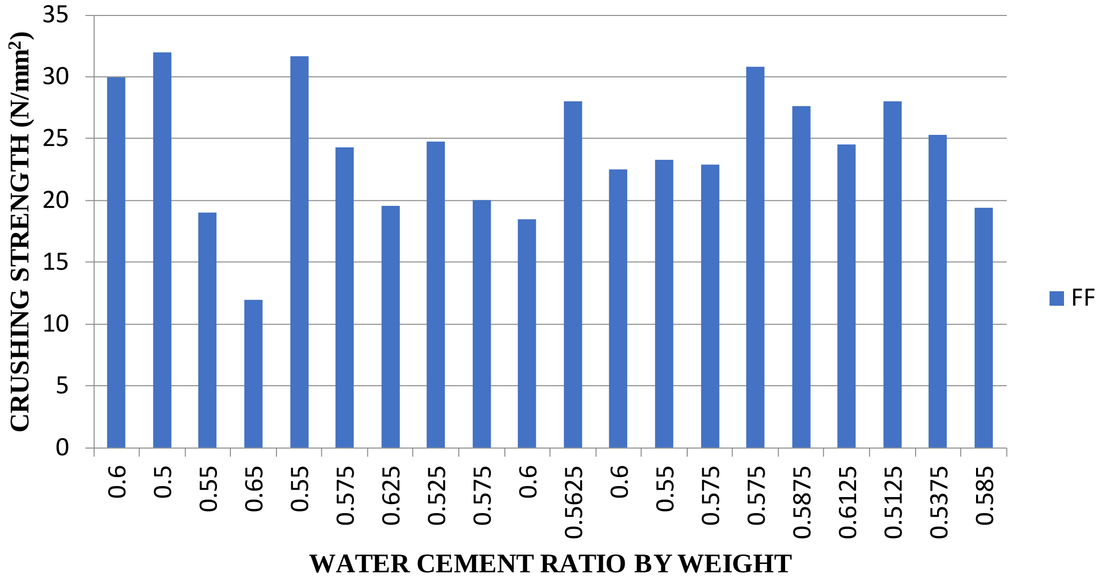

Figure 4: Water-cement ratio and compressive strength relationship for FF

Where;
SS – concrete cast and cured with Seawater
FF – concrete cast and cured with Fresh water

3.5 Testing Compressive Strength: The compressive strength test was performed on the concrete cubes, tested at the curing age of 21days using the compression testing machine. The cube was placed between the compressive plates parallel to the surface and then compressed at uniform rate (without shock) until failure occurred. The maxi load at failure and the compressive strength were read through of the screen at the top of the machine. The compressive strength was calculated by dividing the maximum load in Newtons (N) by the average cross-sectional area of the specimen in square millimeter (mm^2). The reported result is the average of three samples. The test was carried out according to BS 1881: part 3 (Testing Concrete). The representation is shown in Fig. 3.

3.6 Los Angeles Abrasion Value

In Table 10, a summary of the physical and mechanical properties of the aggregate were presented.

Table 10: Summary of Physical and Mechanical Properties of the Aggregate

Experiment	20mm Granite Sample
Specific Gravity (gm)	2.63
Los Angeles Abrasion Value (%)	30

The test sample consists of clean aggregate which was dried in an oven at 110°C to substantially constant weight. The test sample and the abrasive charge were placed in the Los Angeles abrasion testing machine and the machine rotated at a speed of 25rev/min. The machine was so driven and counter-balanced as to maintain a substantially uniform peripheral speed. At the completion of the test, the material was discharged from the machine and a preliminary separation of the sample was made on a sieve coarser than the 1.70 mm BS sieve. The material coarser than the 1.70 mm sieve was washed dried in an oven at 110°C to a substantially constant weight, and accurately weighed to the nearest gram.

4. Conclusion

Based on this experimental investigation the following conclusion can be drawn:

1. Concretes mixed and cured in seawater have higher compressive strengths than concretes mixed and cured in fresh water in the early ages at 14 and 21 days. The strengths after 21 days for concrete mixes mixed and cured in fresh water increase in a gradual manner.
2. Cement content in concrete mixes has a great effect on concrete strengths and durability. Higher cement content produces strength five times higher, especially for low water–cement ratios.
3. Strengths are also affected by the aggregate type and properties and cement type, age and curing conditions but with a lower rate than the effect of cement content.
4. The increase of cement content in concrete improve the resistance of concrete for deterioration against seawater and salty solutions.
5. Care should be taken in the manufacturing of concrete to produce impermeable dense concrete in order to resist the attack of seawater.
6. A meaningful test method is needed for evaluating the effect of seawater under continuous and alternating exposures.
7. Increase in concentration of seawater used in preparation of cement paste lowers the setting time i.e. initial and final setting time.

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