IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 21, Issue 6 Ser. 1 (Nov. – Dec. 2024), PP 38-43
www.iosrjournals.org

Effects Of Seawater On The Compressive, Flexural And Split Tensile Strength Properties Of Reinforced Concrete

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Abstract:
Background: *Reinforced concrete is a heterogeneous mixture of cement, aggregates, potable water and steel used for various construction purposes, such as buildings, highways, bridges and water retaining structures. However, increase in subsea construction projects, especially in Nigerian coastal areas now warrant understanding the effects of seawater on reinforced concrete. Also, the increasing scarcity of freshwater in Nigerian coastal areas is now pushing construction workers to settle for saline water. Therefore, this study investigated the applicability of seawater as alternative to freshwater in concrete mixing and curing for construction, especially subsea construction activities, thereby addressing an existing research gap.*
Materials and Methods: *The impacts of seawater were examined on the compressive, flexural and split tensile strengths of fresh and hardened concrete. Seawater samples from Suntan Beach, Badagry, Lagos State, were characterized at Central Research Laboratory of Bells University of Technology. Preliminary tests on cement and aggregates were conducted at Structures and Materials Laboratory of the same university. Production and curing of concrete specimens using both freshwater and seawater were done in four phases such as Freshwater (FF), Freshwater/Seawater (FS), Seawater/Freshwater (SF) and Seawater/Seawater (SS), with strength measurements conducted at 7, 14, and 28 days of curing respectively.*
Results: *Seawater characterization results showed significant presence of salts and oxides. Slump test results showed seawater reduced workability of concrete compared with freshwater. Results of compressive and flexural tests at 28 days ranged between 19.26 and 20.74 Mpa (SS and SF), while split tensile values were 3.1 for FS and 5.1 Mpa SS respectively, at 28days.*
Conclusion: *The study concludes that seawater negatively affected compressive and flexural strengths, but positively affected flexural strength. Therefore, admixtures which will protect compressive and flexural strengths are recommended when using seawater for construction.*

Keywords: *Freshwater; Seawater; Concrete; Curing; Construction; Compressive strength; Flexural strength; Split tensile strength; Freshwater*

Date of Submission: 11-11-2024 Date of Acceptance: 21-11-2024

I. Introduction

Concrete is a widely used composite substance known for its durability and affordability, which is composed of cement, water, and particles. When reinforced with steel, it gains tensile strength and durability, making it suitable for various construction projects. The process of hydration involves combining water and cement to create a cement paste, which is crucial for the hardening and setting of concrete[1]. Concrete, resembling rock, is vulnerable to deterioration in marine environments due to chemical reactions with seawater, alkali-aggregate expansion, salt crystallization pressure, frost action, corrosion of steel reinforcement, and abrasion[2]. Furthermore, water plays a vital role in the production of concrete, but its quality is of utmost importance. Impurities in water can adversely affect the setting and strength of the concrete, as chemical elements in water can interfere with the hydration process[3].

Similarly, the compressive strength of concrete can be compromised by impurities both during the mixing and curing processes. In certain situations, when fresh water is unavailable or too expensive to transport, sea water may be used for plain concrete without embedded steel, necessitating the use of an appropriate cement system to minimize the risk of reduced compressive strength[3]. Fresh water is described as a purified body of water free from any form of impurities[4]. Therefore, using such clean water is essential to ensuring the optimal performance and durability of construction materials. Approximately 80% of the earth's surface is covered by ocean water, making structures exposed to high-salinity sea water or sea water spray carried inland by winds. Seawater has a consistent chemical composition, with chloride, sodium, magnesium, calcium, and potassium as its primary constituents. Sodium chloride (NaCl) is the predominant salt, and freshwater constitutes only a small fraction of the world's water bodies[5].

While seawater does not significantly impair the compressive strength of concrete, it may cause reinforcement to corrode under certain circumstances. Research suggests that seawater can be used in mass concrete or unreinforced concrete and it even accelerates early strength development. However, the 28-day strength of concrete may decrease by 10 to 15% when using seawater, which can be compensated for by adjusting the mix[6,7,8]. High chloride concentrations in seawater may lead to surface efflorescence and persistent wetness, making it unsuitable for aesthetic-sensitive areas or plaster finishes. Also a study investigated the impact of freshwater and saltwater on concrete strength by exploring four different water-based design conditions for concrete mixing and curing. Saltwater-cured concrete exhibited stronger bonds than freshwater-cured concrete, showing higher compressive, split tensile and flexural strengths during all curing periods[9].

Furthermore, a study investigated seawater's effect on concrete compressive strength by producing two sets of 140 cubes and testing them at various ages (7, 14, 21, 28, and 90 days), after curing in both freshwater and seawater. Concrete cubes cured in seawater showed gradually increasing compressive strength throughout the curing period[10]. Similarly, in another study which used saltwater to produce concrete. Three mixing proportions were considered with different target cube strengths, cementitious material content, fine aggregate content, coarse aggregate content and water to cement ratios. The concrete cube size adopted for the study was 150*150*150mm. The results showed a reduction in the concrete compressive strength by about 8% and the reduction was caused by the presence of chlorides and sulfates in the water[11].

Also, a similar comparative study was conducted to determine the effects of salt water and freshwater on concrete. Concrete cubes, beams and cylinders were produced using both freshwater and seawater, with the results indicating strength changes after different curing periods. The study found that seawater concrete showed marginally higher strength compared to freshwater concrete[12]. Another study examined the influence of sea and freshwater on concrete using a specific mix. The compressive strength, split tensile strength and flexural strength of the concrete specimens cured in salt water were slightly higher than those cured in fresh water[13]. Furthermore, a research investigated the effects of potable water and salt water on the compressive and flexural strength, as well as the durability of concrete and cement mortar. The use of salt water increased the strength but decreased the durability of the samples[14].

Similarly, a study investigated the impacts of seawater and freshwater on concrete strength. Specimens were cured using both water types for different durations. Saltwater-cured specimens showed slightly higher compressive, split tensile, and flexural strengths compared to freshwater-cured ones, but the difference was negligible[15]. Also, a study examined salt attacks on concrete from internal and external sources, including soil, water and nearby surface areas. The research focused on sulphate assault, which is increasingly impacting concrete structures. Different salt percentages and curing times were used to understand the effects on various concrete qualities and the results revealed that salt attacks weakened the binding property of the cement used and ultimately, the concrete compressive strength[16].

Based on the foregoing, especially given the continued depletion of freshwater in Nigerian coastal areas caused by climate change, this study therefore investigated the effects of sea water on the compressive, flexural and split tensile strengths of concrete. This was done through the production of four different Grade 15 concrete mixes (Freshwater, Freshwater/Seawater, Seawater/Freshwater and Seawater/Seawater), including 3/4-inch coarse aggregates, fine aggregates and Y16-size reinforcement.

II. Materials And Methods

Materials Sampling: For this study, seawater samples from Suntan Beach, Badagry, Lagos State, Nigeria were collected into three clean 25 liters kegs and taken to the Central Research Laboratory, Bells University of Technology, Ota, Ogun State, Nigeria. Furthermore, cement and aggregates samples were obtained from a local construction materials market in Ota as well.

Materials Characterization: The seawater samples were analyzed for their physical and chemical parameters, while the cement and aggregates samples were subjected to preliminary tests as well. The seawater samples were characterized in the Central Research Laboratory, Bells University of Technology for their physical and chemical parameters while the cement and aggregates samples were equally characterized in the Structures and Materials Laboratory of the same university.

Production of Concrete Specimens and Curing: Four sets of concrete specimens were produced using freshwater and seawater respectively (concrete specimens produced with and cured in freshwater; concrete specimens produced in freshwater and cured in seawater; concrete specimens produced in seawater and cured in freshwater; and concrete specimens produced in seawater and cured in seawater). Also, the same mix proportions and curing media were used for all four sets of concrete specimens.

Laboratory Analyses of the Concrete Specimens: Furthermore, both the fresh and hardened properties of the concrete specimens produced were tested in the Structures and Materials Laboratory, Bells University of Technology, Ota, as well. The concrete's strength development was evaluated through compressive, flexural and split tensile testing at different curing durations of 7, 14, and 28 days. Suffice to mention that except otherwise stated, all testing procedures adopted in this study for examining water required for concrete production, aggregates required for concrete production and the strength properties of concrete respectively were in accordance with established standards respectively[17,18,19].

III. Result

Physical and Chemical Analyses of Seawater: The physical and chemical analyses of seawater included measurements of various parameters such as Temperature, Total Solids, Total Suspended Particles, Electrical Conductivity, pH, Nitrite, Calcium Hardness, Magnesium Hardness, Sodium, Total Chloride, Dissolved Oxygen, Sulphate, Nitrate, Phenolphthalein Alkalinity, Methyl Orange Alkalinity and Total Alkalinity. The results obtained as shown in Table 1 showed that the seawater has relatively high concentrations of heavy metals, salts, oxides and hydroxides which are typical for water samples obtained in such highly saline conditions.

Table 1: Results of physical and chemical analyses of seawater

S/N	Parameters	Values
1	Temperature	25 °C
2	Odour	Odourless
3	Total Solids	7,959 mg/l
4	Total Suspended Particles	23.6 mg/l
5	Electrical Conductivity	>10,000 us/cm
6	Ph	9.8
7	Nitrite	3.65 mg/l
8	Calcium	69.5 mg/l
9	Magnesium	71.5 mg/l
10	Sodium	44.8 mg/l
11	Total Chloride	8254 mg/l
12	Dissolved Oxygen	5.93 mg/l
13	Sulphate	123.7 mg/l
14	Nitrate	4483 mg/l
15	Phenolphthalein Alkalinity	2315 mg/l
16	Methyl Orange Alkalinity	19.2 mg/l
17	Total Alkalinity	19.55 mg/l

Tests on Aggregates: The study evaluated the properties of fine and coarse aggregates used in concrete production. The fine aggregate values as shown in Table 2 had a high moisture content of 4.3%, while the coarse aggregates had 0% moisture. Specific gravity values were 2.5 for fine aggregates and 2.44 for coarse aggregates, indicating denser aggregates for better concrete performance. The water absorption ratio for coarse aggregate was 34%, potentially affecting workability and compressive strength. The particle size distribution analyses of fine aggregates as shown in Table 3 showed non-uniform gradation, which could impact its suitability for specific construction applications. Adjusting the water-cement ratio and considering water absorption are crucial for achieving optimal concrete performance. American Standard for Testing and Materials guidelines should be followed to ensure compatibility with construction requirements.

Table 2: Results of aggregates test

	Fine Aggregates	Coarse Aggregates
Moisture Content	4.3%	0%
Specific Gravity	2.5	2.44
Water Absorption Ratio	-	34%
Sieve Analyses	Cu= 4.3, Cc= 0.73	

Table 3: Results of particle size distribution analyses

Sieve Sizes (mm)	Weight of Sieve (g)	Mass of Sieve+ Soil	Mass Retained	% Retained	% Passing	%Cumulative Retained	Cumulative Retained
13.2	595	610	15	3	97	3	15
9.5	545	552	7	1.4	95.6	4.4	22
6.3	605	623	18	3.6	92	8	40
4.47	575	586	11	2.2	89.8	10.2	51
2	540	602	62	12.4	77.4	22.6	113
0.85	455	605	150	30	47.4	52.6	263
0.6	470	542	72	14.4	33	67	335
0.212	425	579	154	30.8	2.2	97.8	489
0.15	395	400	5	1	1.2	98.8	494
Pan	410	416	6	1.2	0	100	500
Total			500	100			

Tests on Cement: The results as shown in Table 4 provided consistency information for standard cement paste (OPC-42.5N) at different water percentages, indicating a softer consistency as water content increases. The water quantity required for setting time is approximately 86.7ml, obtained from consistency measurements. The initial setting time is 90 minutes, and the final setting time is 440 minutes, meeting EN 197-1:2011 standards, ensuring suitable workability and hardening characteristics for construction applications.

Table 4: Results of cement analyses

Parameters Tested	Result	Code Specification Bs En 197-1:2011
Consistency	34%	25 – 35%
Initial Setting Time	90mins	<45 mins
Final Setting Time	440mins	<600mins

Concrete Production: The study compared as shown in Table 5 the slump values of concrete prepared with freshwater and seawater using a mix ratio of 1:2:4 and a water-cement ratio of 50%. The slump value for freshwater was 75 mm, while for seawater, it was slightly lower at 60 mm, indicating reduced workability due to seawater impurities. The study followed the BS 1881-105 standard test method.

Table 5: Slump test values

Slump Designation	Values
Slump for concrete mixed with freshwater	75mm
Slump for concrete mixed with seawater	60mm

Physical Examination of Cubes: The study examined two sets of concrete cubes: freshwater-cured (FF and SF) and seawater-cured (FS and SS) as shown in Figure 1. Freshwater cubes were normal, while seawater-cured cubes showed efflorescence and higher moisture content.

Variation of Compressive Strength: The study results as shown in Table 6 and Figure 2 revealed that using freshwater in the mixing process generally results in higher concrete strength compared with seawater. Curing with freshwater also leads to higher strength values than seawater curing.

Split Tensile Strength: The research analyzed split tensile strength results of concrete designations FF, FS, SF and SS at 28 days as shown in Figure 3 and Table 7. SS cured with seawater displayed the highest split tensile strength (5.1 MPa), while FS, also cured with seawater had the lowest strength (3.1 MPa). Mix design and material selection significantly influenced concrete's tensile strength. SS mixed and cured with seawater, showed potential for applications requiring high tensile strength.

Figure 1: Hardened concrete specimens showing FF, FS, SF and SS

Table 6: Compressive strength of concrete cubes

	Average Compressive Strength		
Concrete Designation	7 Days	14 Days	21 Days
FF	15	20	19.56
FS	12.6	16.74	19.82
SF	16	20.15	20.74
SS	14.7	19.70	19.26

Flexural Strength: The study compared different concrete mixes based on mixing and curing with freshwater and seawater as shown in Figure 3 and Table 8. Freshwater-cured mixes (FF and SF) showed higher compressive strength values after 28 days, with FF being the strongest (1.9 MPa). Seawater-cured mixes (FS and SS) had lower strength, with SS being the best among seawater-cured mixes (0.7 MPa). Overall, using freshwater for both mixing and curing resulted in consistently higher concrete strength values, making it advisable for projects requiring optimal strength properties.

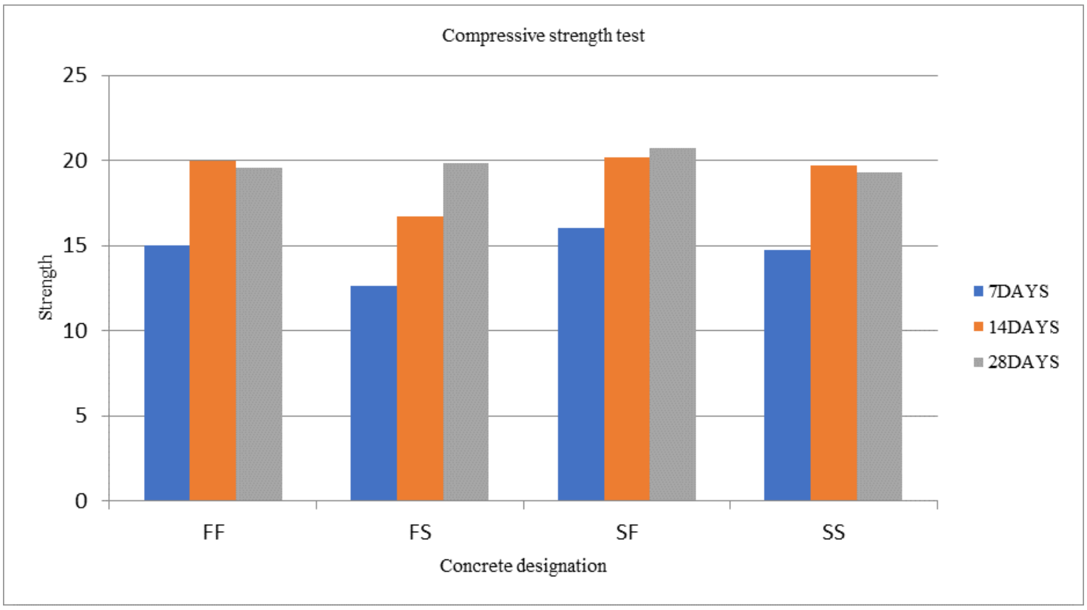

Figure 2: Compressive strength of concrete cubes at 7, 14 and 28 days

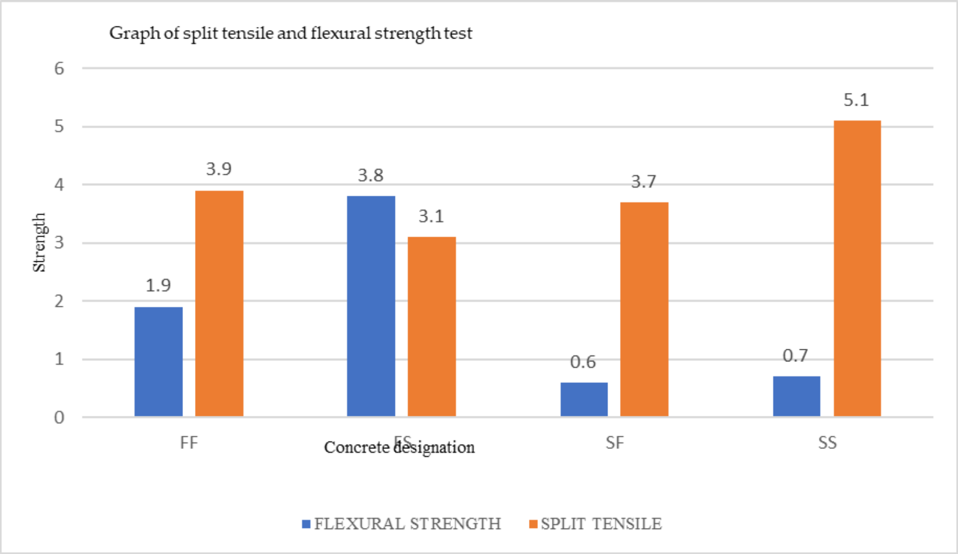

Figure 3: Split tensile and flexural strength test at 28 days

Table 7: Split tensile strength values

Concrete Designation	Age (Day)	Grade	Force (KN)	Strength (Mpa)
FF	28	15	61.60	3.9
FS	28	15	48.69	3.1
SF	28	15	58.44	3.7
SS	28	15	79.74	5.1

Table 8: Flexural strength test results

Concrete Designation	Age (Day)	Grade	Force (KN)	Strength (Mpa)
FF	28	15	38.07	1.9
FS	28	15	29.77	0.6
SF	28	15	36.30	1.8
SS	28	15	33.78	0.7

IV. Conclusion

This study compared the compressive, flexural and split tensile strength values of four concrete mixtures under different curing conditions: FF (freshwater mixing and curing), FS (freshwater mixing and seawater curing), SF (seawater mixing and freshwater curing), and SS (seawater mixing and curing). The highest compressive strength was observed in SF at 28 days (20.74 MPa), while FS had the highest flexural strength (3.8 MPa) and SS had the highest split tensile strength (5.1 MPa). The findings suggest that seawater curing positively impacted flexural and split tensile strength, while freshwater curing resulted in higher compressive strength. These results have implications for concrete mix design both in subsea and freshwater construction projects. However, this study recommends that further investigation is needed to assess the impacts of seawater on the durability of concrete (especially under different curing conditions), before finally considering it for construction purposes.

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