



Possibility of Usage of Seawater for Mixing and Curing of Concrete in Salty Water Localities

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Aims: This study examines the possibility of using seawater as an alternative to freshwater in concrete mixing and curing in areas prone to saltwater. The study was as a result of shortage and scarcity of Freshwater in some parts of the world; mostly in the coastal areas, where seawater is the only source of water.

Place and Duration of Study: Seawater was obtained from Port Harcourt Tourist beach, River State, Nigeria was used to mix and cure a set of concrete cubes (CSW). And freshwater obtained from our Civil Engineering laboratory was used to mix and cure another set of concrete cubes (CFW) that serves as a control. The maximum days of curing were 28days.

Methodology: Concrete cubes of 150x150x150mm³ were produced and cured with sea and freshwater respectively. The compressive strength of those cubes were determined using Compression Testing Machine. The studied variable was only water used for mixing and curing of the concrete cubes. Other constituents of the concrete: cement, fine aggregate, and coarse aggregate were kept constant.

Results: It was found that the compressive strengths of concrete cubes mixed and cured with seawater at 7, 14, 21 and 28days were within the acceptable limits and a bit higher than those of cubes mixed and cured with fresh water. The variation in compressive strength of CSW and CFW at the 28th day of curing was just 1.45%. Hence, the seawater didn't affect the compressive strength.

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Conclusion: With the little variation in compressive strength between the CSW and CFW at the 28th day of curing; it is recommended that seawater can possibly be used for concrete mixing and curing in areas where freshwater is not available; provided that the concrete is kept inherently dry to prevent corrosion. In addition, higher concrete covers can be provided when designing the concrete structures. Meanwhile, careful and adequate design, well-supervised construction, and curing should be ensured to improve the ingress resistance of the concrete structures. However, the long-term effect of the seawater on the properties of concrete and reinforcements were not investigated.

Keywords: Seawater; concrete; compressive strength; mixing; curing.

1. INTRODUCTION

Seawater is simply water that is salty in taste or water that contains a certain quantity of salt in it. It is considered the most abundant water on the earth's surface, covering about 80 percent of oceans and seas.

A substantial number of structures made with concrete such as dams, bridges, culverts, barrages, siphons, regulators and aqueducts have unswerving contact with seawater. In some cases, parts or whole of the concrete structures mentioned are embedded in soil contaminated with chlorides and sulphates. While in other circumstances are exposed to salty irrigation water or wind-blown seawater which spray up to a few miles inland from the water bodies to affect the structures. This phenomenon causes several coastal and offshore structures around sea areas to undergo a continuous action of chemical and physical deterioration processes [1]. In a recent development, there is a wider increase in the construction of concrete structures for offshore drilling boards, concrete piers, oil storage tanks, break-water, decks, retaining walls in the construction of harbours and docks. The scarcity of land or unavoidable necessities especially in urban areas has resulted in the construction of floating offshore boards made of concrete for the siting of an airport, power plants, waste disposal facilities, etc. which do have contact with seawater [2].

There is a great need to ensure that these important and costly structures met with the necessary standard with regards to safety, durability and serviceability. As a result, it has become a serious issue to build and maintain durable concrete structures in areas prone to seawater and its environment and therefore the need to provide an excellent opportunity to unravel the intricacies and complexity of concrete durability problem in these areas.

1.1 Concrete and Its Components

The major component of most of the structures constructed in seawater areas is concrete; Concrete is one of the most common construction materials that is known for its durability and wide usage. It comprises of cement, aggregate – fine and coarse, water and sometimes extra materials called admixtures. Concrete is used for numerous purposes in the construction industry such as the construction of buildings, foundations, parking structures, pipes, dams, poles, etc. [3].

Cement is one of the structural materials in concrete that its production is energy-intensive. It serves as a binder when mixed with water. The reaction of water with cement enables it to set, hardens and adheres to aggregates and other materials, binding them together. Water is highly needed for a chemical action of cement to be activated. The quality of water plays an important role in the preparation of concrete [4]. Impurities in water may interfere with the setting and hardening of the cement and may adversely affect the strength and durability of the concrete as well. Concrete mixed with freshwater has been reported to have compressive and flexural strengths greater than those mixed with saltwater [5].

1.2 Seawater Reactions with Concrete

The major chemical constituents of seawater are the chloride ion, sodium ion, magnesium ion, calcium ion and potassium ion. It has been analysed that seawater contains 78% NaCl, 7.86% MgCl₂, 3.74% MgSO₄, 2.34% CaSO₄, 1.8% K₂SO₄, 0.22% CaCO₃, 0.2% MgBr₂. NaCl and MgCl₂ have the highest concentration in comparison to other salts [6,7].

The high percentage of sodium chloride in seawater helps to accelerate the attack on other compounds/components of concrete. Chloride ions enter into the concrete through a solution diffusion process and got melted in pre-existing

pore water. The contaminated pore-water reaction plays a major role in reinforcing steel corrosion through the following effects [8]:

1. Gradual reduction of alkalinity of concrete
2. Increase in the electrical conductivity of concrete and
3. Depassivation of the steel surface even at the high alkaline environment.

When steel corrodes, the resulting rust occupies a greater volume than the steel. The expanded steel results in tensile stresses in the concrete which can ultimately cause cracking, delamination and spalling sulphates attack on concrete by reacting with hydrated compounds in the hardened cement [9]. These reactions can induce the cement paste, resulting in loss of cohesion and strength. It has been stated that in reinforced concrete that all common forms of serious weakening are as a result of water ingress. And therefore, if concrete could be kept inherently dry, most corrosion and deterioration issues would disappear. However, it is important to understand the mechanisms by which water penetrates through the concrete [1,9].

Many researchers have attributed that the high permeability of water is absorptive nature of concrete and that the speed of absorption is rapid. In contrary Ravindrarajah and Moses [8] opined that the predominant mechanism of water movement through concrete is by simple capillary absorption. Calculation of the water penetration depth done by Butler [10] during his capillary absorption test of concrete showed that the speed of capillary absorption is of the order of a million times faster than permeability. Research done by Costa and Appleton [11] has shown that the durability of concrete structures exposed to the marine environment depends on the ability of concrete to resist chloride ingress.

On the aspect of cement content, work done by Zaher and Samir [12] shows that cement content is not a factor in terms of protecting concrete against saltwater effects. Also, an investigation carried out by the Portland Cement Association (PCA) in a long time study of the performance of cement in concrete (LTs) program offers key insights into the behaviour of concrete in seawater. The results of their 37 years study revealed that seawater had no damaging effect on submerged concrete specimens, regardless of the composition of the cement; however, concrete positioned above high tide experienced more corrosion damage than concrete located at the mean tide level [13].

Mehta [14] opined that concrete in the marine environment suffers deterioration. He attributed it to the effects of chemical reaction of seawater constituents with cement hydration products, an alkali-aggregate expansion (which occurs when reactive aggregates are present), crystallization pressure of salts (within the concrete when one face of the structure is subjected to wetting and others to drying conditions), frost action in cold climates, corrosion of embedded steel in reinforced or prestressed members, and physical erosion due to wave action and floating objects. Shetty [15] was of the view that the failure of concrete structures that are in contact with seawater could be attributed to the alkali-aggregate reaction. He maintained that certain types of aggregates are reactive in the presence of salt more than others. The more reactive aggregates are, the more they promote the alkali-aggregate reaction. Some of the rocks that give rise to reactive aggregate include andesite, rhyolites, siliceous limestone and certain types of sandstone. The reactive constituents may be in the form of opals, cherts, chalcopyrite, volcanic glass and zeolites.

Since the major problem associated with the use of saltwater in concrete structures is the ingress or diffusion of the chloride ion [2,14].

1.3 Control of Seawater Penetration in Concrete

Many researchers have tried to find a solution on how to bring to the nearest minimum the penetration of water in concrete. Research done by Otsuki et al. [16] has shown that the use of some environmental by-product such as fly ash, slag or silica fume as an admixture or for partial replacement of Portland cement has resulted in the production of concrete with high compressive strength, low permeability and good resistance to freeze the cycling. Other researchers have argued that special cement such as Blast-furnace slag cement (BFS) can be used as against OPC for the reduction of water permeability in concrete. Meanwhile, the use of corrosion-resistant reinforcement and inhibitors can equally take care of problems arising from the use of seawater in concrete works [17-21]. That notwithstanding, carefulness in design, construction and curing of concrete in marine areas can as well improve the ingress resistance of concrete structures. This can only be achieved through the selection of suitable materials, good mix design, proper detailing of reinforcement,

ensuring appropriate construction techniques and enforcement of strict control programs.

Apparently, there is a shortage and scarcity of freshwater in some parts of the world especially in the coastal areas, where seawater is the only source of water. In reality, it is practically impossible to produce and cure concrete without seawater in those areas, necessity has given rise to the need to find a means to use seawater as an alternative to freshwater in casting and curing of concrete in those areas. Hence the need for this work.

2. EXPERIMENTAL STUDY

2.1 Materials Used

2.1.1 Cement

The cement used was Ordinary Portland Cement (OPC), Dangote brand. It was stored under dry condition, free of lumps and in conformity with BS 12:1996 (specification for Portland cement)

2.1.2 Aggregates

The fine aggregate was a washed sand deposit gotten from a stream, free from organic matter with a specific gravity of 2.73 and was passing through 10mm sieve. The coarse aggregate was a granite crush rock of not more than 1 inch (25mm) size and high quality with a specific gravity of 2.63. The aggregate met the requirements of BS 882:1992 (specification for aggregate from natural sources for concrete).

2.1.3 Water

The freshwater used was clean portable water from the school laboratory, it was free from suspended particles and chemicals. The seawater used was gotten from Port Harcourt Tourist beach, River State, Nigeria. The water sample was clean and free from oil.

2.2 Experimental Procedure

Batching was done by weight method using a Manual Weighing Balance. The adopted concrete mix ratio was 1:2:4 for the cement, fine and coarse aggregate. A Water-cement ratio of 0.45 was used. The materials were thoroughly mixed manually on a clean concrete floor in the dry state until the mixture becomes uniform in colour. The batched mix was then divided into two equal portions, after which fresh and seawater were added gradually to the two different mixes. The mixture of cement,

aggregate and the two different water samples were further mixed to achieve the concrete specimens. The test cubes were cast inside a steel mould of 150x150x150(mm³) in size that was already spread with oil to enhance the easy removal of the set concrete cubes. Adequate compaction was done on the fresh concrete by the use of tamping rods, to ensure that voids were eliminated and improve the water ingress resistance of the cubes.

Twenty-four concrete cubes were cast for the study, twelve cubes were mixed and cured in freshwater (CFW) and twelve other cubes were mixed and cured in seawater (CSW). The concrete cubes were tested at the ages of 7, 14, 21, and 28 days for compressive strength. The specimens were cured at room temperature in the curing tanks.

The studied variable was only water used for casting and curing of concrete. Other constituents of the concrete: cement, fine aggregate and coarse aggregate were kept constant.

At the end of each curing days of 7, 14, 21, and 28days; the cubes were removed from the curing tanks, cleaned, dried, and subjected to a compressive strength test. Each cube was placed in between the compressive plates in a manner that it is parallel to the surface and then compressed at a uniform rate until failure occurred. The maximum load at failure of each cube was read through the screen of the compression testing machine and recorded. Thereafter, the compressive strengths were calculated by dividing the recorded maximum load by the area of the cubes.

3. TEST RESULTS AND DISCUSSIONS

The sieve analysis for the fine and coarse aggregate presented in Tables 1 and 2 showed the particle size distribution of the aggregates respectively. The table reveals that the aggregates are well graded. Figs. 1 and 2 showed that the grading of fine and coarse aggregates were well distributed and met with the requirements of BS 882:1992.

The selected aggregate samples as can be seen in Figs. 1 and 2 contain proportional sizes of aggregate particles that are required for elimination of voids in concrete. This is necessary to prevent the ingress of salt ions through void which will eventually corrode/weaken the concrete structure.

The results obtained from the workability test carried out on the two sets of concrete pastes are presented in Table 3. From the table, the results indicate that all the mixes were workable with the concrete made with saltwater having a higher slump value when compared with that of freshwater. This result shows that workability can be affected by the salt constituent in seawater.

The results of setting time for the two concrete pastes are presented in Table 4. From the result, it can be seen that the presence of salt in seawater decreases the setting time of the concrete. This was proved by the lower values of both the initial and final setting time of the seawater paste.

The result on Table 5 shows that there is a significant increase in the strength of cubes mixed and cured with seawater (CSW) when compared with that of concrete cubes mixed and cured with freshwater (CFW). The result of 7 days of curing which was 22.85N/mm² shows that concrete made with seawater gains rapid strength in the early days of curing. The strength gains in freshwater concrete at 7 days of curing which was 20.24N/mm² was equally appreciable when compared with that of seawater. At 14th

day of curing, the increase in strength of CSW was a bit higher when compared with that of CFW. CSW increased by 35.89% while CFW increased by 34.89%. There was a slight increase in the 21 days compressive strength for the CFW which had a strength of 30.85N/mm² when compared with its 14th day compressive strength which was 27.30 N/mm², but the strength gain in CSW from 14 days to 28 days was minimum when compared with other days result. Fig. 3 equally showed that the CSW had a slight increase in strength at 28 days by 0.34% when compared with 21 days result but CFW had an appreciable increase in strength. On average, the concrete mixed and cured with seawater produced a compressive strength of comparable values to that mixed and cured with fresh water as shown in Fig. 3.

Additionally, a comparison of the result in Table 5 and Figs. 3 and 4 provides an indication that the presence of salt in seawater doesn't affect the compressive strength per say. But the actual problem is the effect of the absorbed seawater after the construction of the concrete structures. If the ingress and absorption of seawater can be controlled, there is a possibility of usage of seawater for concrete mixing and curing.

Table 1. Sieve analysis for fine aggregates

Sieve size BS 410-1:2000	Weight retained (g)	% retained	Cumulative % Retained	% passing	Cumulative % Passing
9.50mm	1.5	0.3	0.3	99.7	99.7
6.30mm	8.5	1.7	2.0	98.3	98
2.36mm	14.0	2.8	4.8	97.2	95.2
1.18mm	22.1	4.42	9.22	95.58	90.78
600µm	167.9	33.58	42.80	66.42	57.20
355 µm	125.8	25.16	67.96	74.84	32.04
150 µm	120.5	24.10	92.06	75.90	7.94
75 µm	31.0	6.2	98.26	93.80	1.74
Receiver pan	8.3	1.66	99.92	98.34	0.08

Table 2. Sieve analysis for coarse aggregate

Sieve size BS 410-1:2000	Weight retained	% retained	Cumulative % Retained	% passing	Cumulative % Retained
25.00mm	25.5	5.1	5.1	94.9	94.90
22.40mm	54.3	10.86	15.96	89.14	84.04
19.00mm	102.5	20.5	36.46	79.5	63.54
16.00mm	96.8	19.36	55.82	80.64	44.18
13.20mm	130.5	26.10	81.92	73.90	18.08
12.50mm	81.0	16.20	98.12	83.8	1.88
11.20mm	8.5	1.70	99.82	98.3	0.17
Receiver pan	0	0	100	0	0

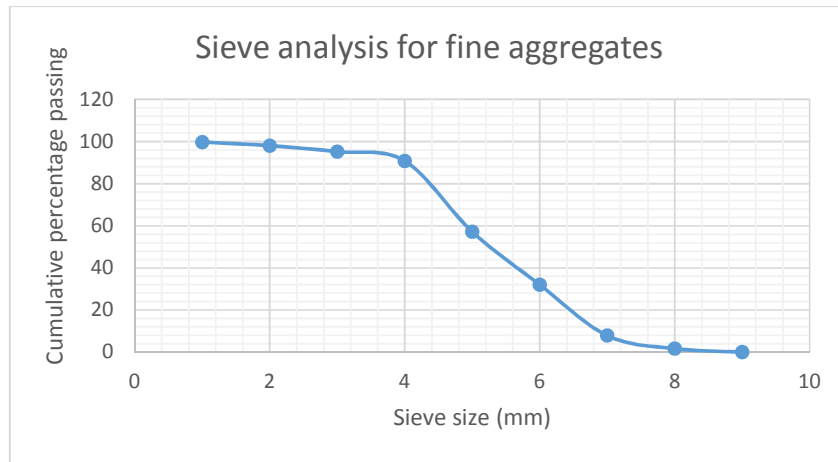


Fig. 1. A graph of sieve analysis for fine aggregate

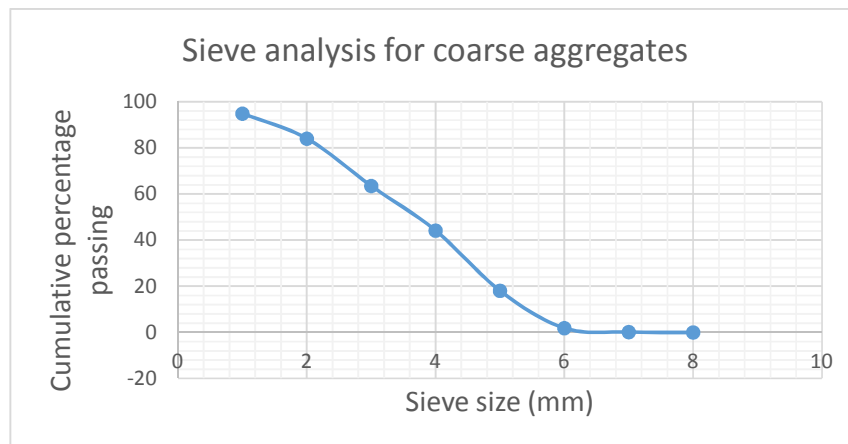


Fig. 2. A graph of sieve analysis for coarse aggregate

Table 3. Workability of concrete

Type of mix water	Slump mean value	Standard Deviation
Portable water concrete	75	3.559
Sea water concrete	80	2.160

Table 4. Result of cement setting time

Water sample used for concrete cast	Mean Setting time (min.)		Standard Deviation	
	Initial	Final	Initial	Final
Fresh water	130	198	1.633	2.449
Seawater	120	185	0.816	1.633

Table 5. Average test result for concrete compressive strength

Cube identification	Concrete cube Mean crushing strength (N/mm ²)				Standard Deviation			
	7 days	14 days	21 days	28 days	7days	14days	21days	28days
CSW	22.85	31.05	32.66	32.76	0.682	0.348	0.480	0.399
CFW	20.24	27.30	30.85	32.30	0.531	0.460	0.510	0.502

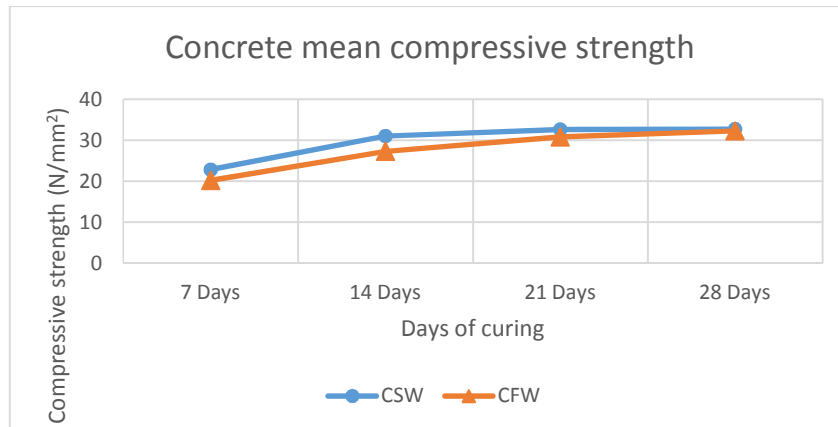


Fig. 3. A graph of concrete compressive strength for CSW and CFW

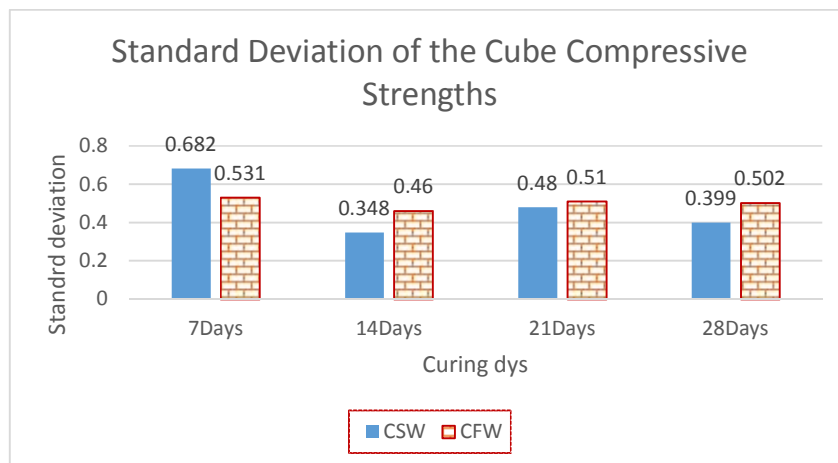


Fig. 4. Standard deviation for CSW and CFW

4. CONCLUSION

The abundance of seawater around us has led to the experimental evaluation of its impact on the compressive strength of concrete. To know if it can be economically used as an alternative to freshwater for concrete mixing and curing in construction works. It was observed that concrete mixed and cured with seawater (CSW) have rapid strength gain at early ages than that of that mixed and cured with freshwater (CFW). But on the 28th day of curing, the outcome of the result shows a variation in compressive strength of 1.45% between CSW and CFW samples; which is acceptable and recommendable. The effect of seawater on the workability of concrete produced with it was quite workable as seen in the slump result. Furthermore, it was observed that the initial and final setting time of concrete prepared with seawater was a little bit lower

when compared with that of fresh concrete. From the findings, we can conclude that there is no reduction in the strength of the concrete mixed and cured with seawater. Therefore seawater can be used for concrete works in regions and localities where they abound provided that the concrete is kept inherently dry to prevent corrosion. In addition, higher concrete cover can be provided when designing the concrete structures [3,22].

5. RECOMMENDATION

This research was limited only to 28days of curing, for an understanding of the long-term effect of seawater on compressible strength of concrete, further research is advised in this area especially on its effect on long years. However, based on the findings from this research, the following recommendations are made:

1. The use of seawater for mixing and curing of concrete produced using Ordinary Portland Cement should not be discouraged in areas where freshwater is not available especially in coastal areas.
2. They should be adequate care in the design and construction of concrete with seawater to ensure that void and air bubbles are avoided to minimize water ingress.
3. Long term effect of seawater on other properties of concrete such as durability, splitting strength, creep, etc. need to be investigated.

Further studies should be made on the durability of reinforcements in a reinforced concrete cast and cured with seawater.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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