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Effects of Seawater on Setting Time and Compressive Strength of Concretes with Different Richness

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Abstract

Water is one of the main constituents of concrete. Although many types of water exist, fresh water is the mostly used in concrete industry. Fresh water is expected to be in a great shortage by 2050 according to UN world water development report. Incorporating seawater in concrete mixture can help in the expected problem of scarcity of fresh water. Also, in many cases seawater may be the only available water especially in coastal regions. Many reports mention various possibilities of using seawater in concrete without detrimental effect on concrete properties. In this study another beneficial effect of seawater over tap water was concluded. Setting tests of cement paste mixed with seawater was determined using Vicat apparatus and compared to tap water. Compressive strength tests at the age of 28 days of Portland cement concretes with varied quantity of cement i.e. 300, 350, 400, 450, and 500 kg, and mixed with seawater was also performed and compared to tap water. The results show that seawater affects standard consistency of cement paste and two percent increase was required in order to attain the same consistency as tap water. It shows also seawater slightly accelerates initial setting of cement but the effect is not so pronounced so as to cause a trouble in concrete and final setting time almost remains unaltered. Compressive strength tests show an increase in concrete strength mixed with seawater for all tested mixtures and depending on quantity of cement. It also shows a beneficial effect of seawater on compressive strength of rich concrete with quantity of cement 450 and 500 kg over tap water.

Keywords: Seawater; Setting Time; Compressive Strength; Rich Mixture.

1. Introduction

According to UN world water development report [1], 40% of the world's population is projected to live under water severe stress by 2050, Middle East and North Africa are included. Concrete industry consumes huge amount of fresh water annually, and saving these quantities by seeking for suitable alternative sources of water for concrete industry can help in the expected problem of scarcity of fresh water. On the other hand, in many cases seawater may be the only available water especially in coastal regions. Therefore, the necessity of utilizing seawater for mixing and curing of concrete arises.

Seawater contains 3.5 percent of dissolved salts, about 78 percent of the salt content is sodium chloride and 15 percent is chloride and sulfate of magnesium [2]. A broad variation in salinities may also be found [3]. Due to the high content of dissolved solids, seawater may affect setting of cement, strength of concrete, volume stability of concrete

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mass, and durability of concrete structures especially chloride-induced corrosion of reinforcement. Therefore, the effects of seawater when used for mixing and curing and long-term durability of concrete structures should be carefully investigated.

2. Literature Review

The effects of seawater on setting time of cement, strength of concrete, and long-term durability based on literature searches can be summarized as follows:

Seawater and synthetic seawater were somewhat more quick-setting in the Vicat test [4]. Steinour mentioned a significant acceleration but is not so pronounced as to cause serious trouble [2]. Kaushik and Islam found seawater significantly reduced the setting time of cement by 30 to 75% for concentrations tested and recommended the use of suitable retarding admixture. Initial setting time was more affected than final setting time [5]. Ghorab et al. concluded, seawater accelerates the setting time but found it to depend on the type of cement i.e. two cement types were approximately much less affected by the water type [6]. Seawater accelerating effect on setting time was also concluded in reference [7].

Seawater shows conflicting results regarding strength of concrete, but the majority of reports mention that seawater improves early strength development of concrete. Abrams found concrete mixed with seawater and cured in moist room gave higher strengths than fresh water at ages of 3 and 7 days; at 28 days and over, the strength-ratios for seawater ranged from 80 to 88 percent. Air cured concrete mixed with seawater was lower in strength than similar fresh water concrete at 3 mo., but showed a recovery in strength at later ages and gave strengths equal to fresh water [4]. Steinour also asserted the same conclusion [2].

Ghorab et al. concluded compressive strength of concrete is insensitive to the water type and that the early acceleration of strength due to chloride ions in seawater and the delay in late strength mentioned in literature is not detected [6]. Otsuki et al. also mentioned seawater stimulated the development of strength in the early ages, and stagnated strength development in late stages. But using BFS in the mixture also increases strength development in late stages. Using FA in the mixture has the same effect but smaller compared to BFS. The increase in strength was more apparent as the substitution rate was larger. They also mention that NaCL in seawater is mainly responsible [8].

Sikora et al. observed, using of seawater has a noticeable effect on early strength development. After 28 days, the specimens mixed with artificial seawater and demineralized water exhibited strengths of 50.8 and 56 MPa respectively [9]. Younis et al. concluded using seawater in concrete resulted in an initial slight increase in the compressive strength and tensile strength at 7 days. Then, a reduction of around 7-10% was observed in the compressive and tensile strengths after 28 days [7]. Regarding long-term compressive strength, Otsuki et al., after 20 years exposure to tidal environment, found that the kind of mixing water has little influence on the strength [10]. The same effect on long-term compressive strength of specimens exposed to marine environment was mentioned by JCI technical committee [8]. The same observation was also reported by Mohammed et al. [11].

Both EN 1008 and ASTM C1602 put limits on the maximum chloride content of mixing water i.e. 1000 ppm for concrete with reinforcement or embedded metals and 500 ppm for prestressed concrete, which prohibited the use of seawater in concrete mixture [12, 13], because of the risk of corrosion of reinforcement due to high amount of chloride ions in the vicinity of steel bars. Regarding to chloride-induced corrosion, the aspects, remedies and counter measures based on literature can be summarized as follows:

It was mentioned in JCI technical report for concrete under water, even mixed with seawater, steel suffered almost no corrosion after 27 years exposure to a tidal environment. Steinour also mentioned the same conclusion and found, for other conditions, the type of concrete and the cover depth are important factors [2]. Another important factor regarding chloride-induced corrosion of reinforcement was studied by Mohammed et al., who tested concrete with embedded steel under accelerated marine exposure condition and compared it also with long-term exposure tests and found the presence of gaps or voids at the steel-concrete interface is crucial. The steel bars lost passivity locally at the region near void or gap and a significant amount of macrocell and microcell corrosion creates a localized pit. They mentioned gaps are formed under the horizontal steel bars oriented perpendicular to the casting direction but should not be neglected for the steel bars oriented along the casting direction due to poor compaction [14]. The importance of good steel-concrete interface was also mentioned in many other reports [11, 15-18]. It was also mentioned, in case of seawater mixed concrete, a deeper corrosion pits are formed which may start immediately after casting concrete compared to tap water.

Otsuki et al., after 20 years exposure to tidal environment, found the kind of mixing water has little influence on corrosion. The specimens with BFS is far better than with OPC, HSC, and moderate cement notwithstanding the kind of mixing water [16], similar conclusion can be found in [13, 14] where a detrimental effect of alumina cement was also observed. So, in tidal zone there is a possibility to use seawater as mixing water considering the kind of cement.

The effectiveness of slag cement regarding to corrosion of reinforcement in marine environment was also confirmed by Mohammed et al. who concluded, after 15 years exposure in tidal environment of uncracked and pre-cracked concrete specimens mixed with tap water, that chloride ingress and corrosion of steel bars can be ordered as OPC is the highest then fly ash cement, slag cement type A, type B then slag cement type C for uncracked and cracked concrete with small cracks, width≤ 0.5 mm, and that small cracks undergo healing irrespective of cement type and advised to control the crack width for long-term durability in marine environment [19].

Nitrate corrosion inhibitor was confirmed to be safely used in concrete mixed with seawater, but the long-term elution of nitrate ions in a marine environment should be considered. Also, concrete mixed with seawater can be used with stainless steel reinforcing bars or corrosion resistant steel bars [8, 10]. Now it can be deduced that seawater can safely be used in concrete mixture. Other positive opinions can be found in references [20, 21].

3. Experimental Procedure

The experimental work is illustrated in the following paragraphs and the flow chart of the research methodology is shown in Figure 1.

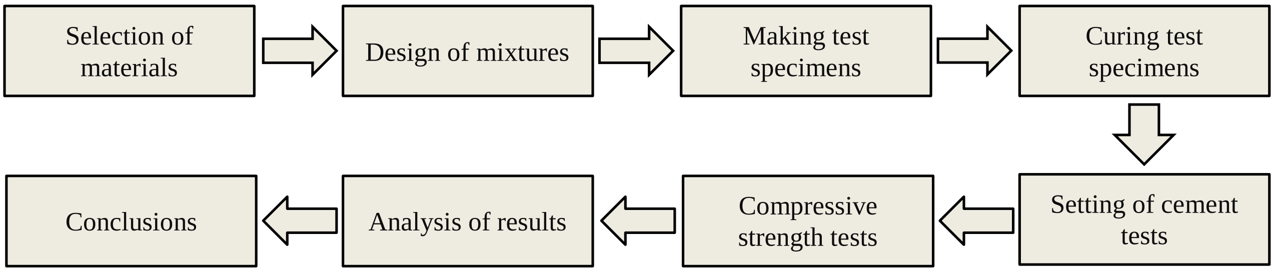

Figure 1. The flow chart of the research methodology

3.1. Materials

Aggregates were crushed dolomitic stone coarse aggregate and natural river sand. Coarse aggregate has a nominal size of 10 mm and fineness modulus of 6.1. Fine aggregate has fineness modulus of 2.4, both conforms to BS 882. The physical properties, made in accordance with BS 812- part2, are shown in Table 1 also the grading of coarse aggregate and fine aggregate, made in accordance with BS 812-103.1, are shown in Figures 2 and 3. The uncompacted bulk density test was performed in oven dry basis, while grading of aggregate was performed using washing and sieving method. Mixing water was natural seawater and tap water for control, the chemical analyses of seawater is given in Table 2. Cement, CEM I 42.5 N manufactured by Suez Cement Co. and conformed to BS EN 197-1, was used.

Table 1. Physical properties of aggregates

Parameter	Gravel	Sand
Density (oven dry basis kg/m^3)	2590	2620
Density (saturated and surface dry basis kg/m^3)	2660	2640
Apparent density (kg/m^3)	2770	2760
Absorption %	2.44	0.82
Un compacted bulk density (dry basis kg/m^3)	1400	1667

Table 2. Chemical analysis of seawater

PH	Cond. (μs/cm)	T.D.S (ppm)	T.S.S (ppm)	Alkalinity (ppm)	Chlorides (ppm)	Sulphates (ppm)	Density (gm/cm^3)
8.23	59160	35500	28	160	19496	1946	1.021

Concrete mixtures of different richness with quantity of cement 300, 350, 400, 450, and 500 kg were used in the investigation. Almost all of the tested mixtures are used for reinforced concrete structures. The quantity of aggregate was the same in all mixtures and the coarse to fine aggregate ratio was 2:1 by volume i.e. 0.8 m^3 for coarse aggregate and 0.4 m^3 for sand. In order to convert the volumes into weight basis the uncompacted bulk density (see Table 1) was used. Both of coarse and fine aggregates were in dry condition before preparing strength specimens and the quantity of water was adjusted to take into account the absorption of the aggregate (numbers in brackets). The moisture contents, made in accordance with BS 812-109, were 0.29 and 0.41 percent for coarse and fine aggregate respectively. The difference between absorption (see Table 1) and the moisture content was calculated and added to the quantity of water. The composition of each mixture is given in Table 3.

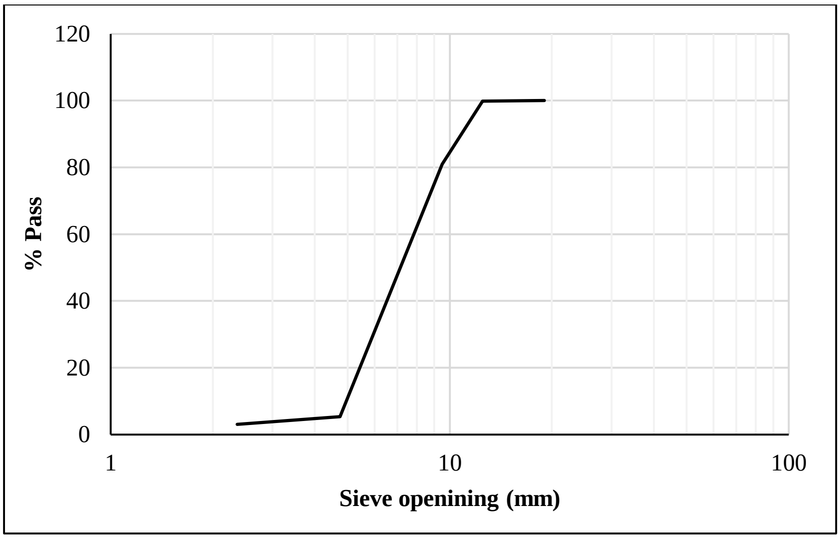

Figure 2. Grading curve of coarse aggregate

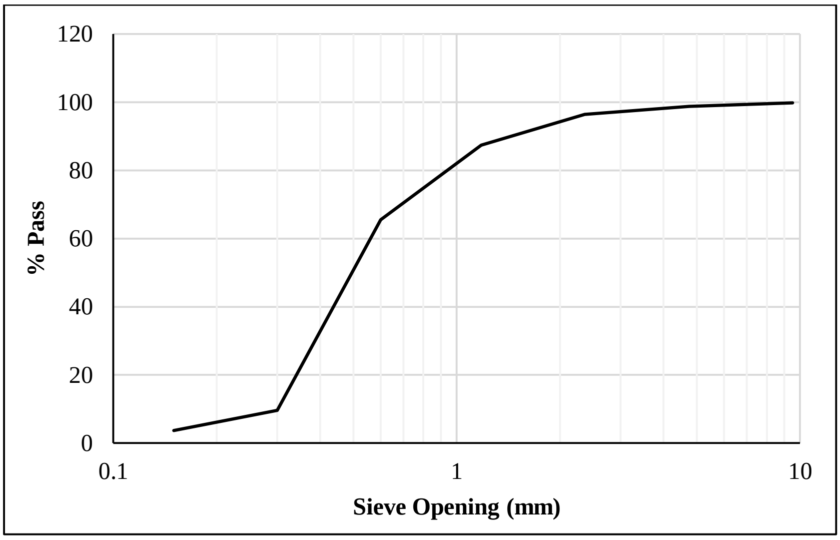

Figure 3. Grading curve of fine aggregate

Table 3. Concrete mixtures for compressive strength tests

Mixture	Gravel (kg)	Sand (kg)	Cement (kg)	Water (kg)	W/C
1	1120	667	300	140 (167)	0.47
2	1120	667	350	150 (177)	0.43
3	1120	667	400	160 (187)	0.4
4	1120	667	450	180 (207)	0.4
5	1120	667	500	200 (227)	0.4

3.2. Methods

Setting of cement tests were made in accordance with BS 4550-3-3.6. Five tests were made on pastes mixed with tap water and eight tests on pastes mixed with seawater.

Compressive strength tests of 15 cm cube specimens were performed in accordance with BS 1881-116 using each mixture. After the moulds were lightly coated with oil, the concrete casted in three layers and compacted with vibrating table, then the surface smoothed with a trowel. Specimens cured for 24 hr. under damp cloth covered with polyethylene sheet then cured under water and tested at the age of 28 days (see Figures 4 and 5). Every reported result is the average of three specimens. Tap water was used for control purpose.

Figure 4. Curing under damp cloth covered with polyethylene sheet for 24 hr

Figure 5. Curing under water for the remaining period and tested at the age of 28 days

Figure 6. The failure shape of the specimens

Figure 6 shows the failure shape which is classified as satisfactory failure according to BS 1881-116. All other specimens have the same failure shape.

4. Results and Discussion

The results of standard consistency are shown in Figure 7 also the results of initial and final setting times are shown in Figures 8 and 9. The average percentage of tap water required for standard consistency of cement paste is 27.5% by weight of cement. For seawater 29.5% was required i.e. 2 percent increase to attain normal consistency as compared with tap water.

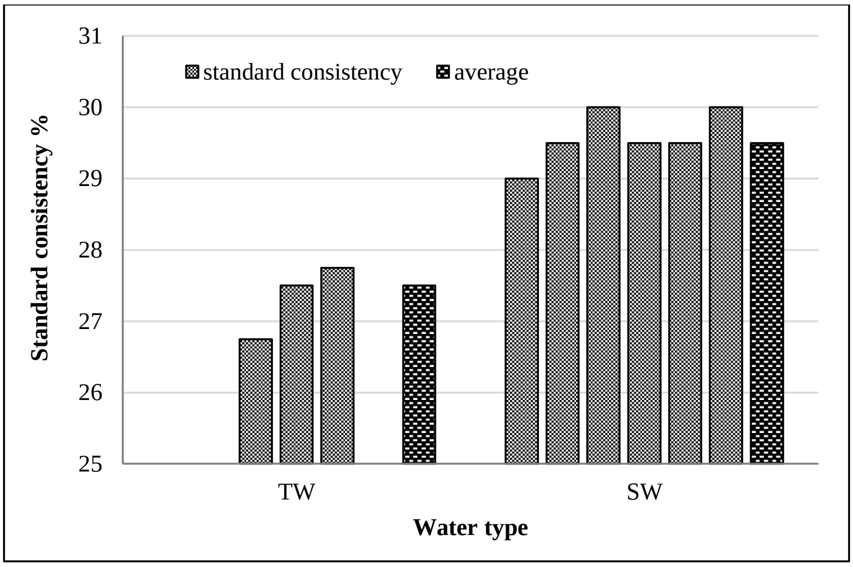

Figure 7. Standard consistency of cement pastes mixed with tap water and seawater

Seawater also slightly accelerates initial setting of cement but final setting almost remains unaltered. Setting times are 125 min. and 180 min. in average for cement pastes mixed with tap water, for seawater are 110 min. and 175 min. i.e. 15min. and 5min. difference in initial and final setting respectively. Seawater accelerating effect on setting time of cement was confirmed by many reports as mentioned before. The conclusion found by Kaushik and Islam was not detected. Ghorab et al. mention that seawater reduces initial and final setting times of ordinary Portland cement by 24 and 22% respectively over tap water which are higher values as compared with 12 and 2.8% obtained in this study. The reason for that behavior is the concentration of chloride ions in seawater. Chloride concentration was 31030 ppm which is higher than 19496 ppm tested here, see references [6, 22].

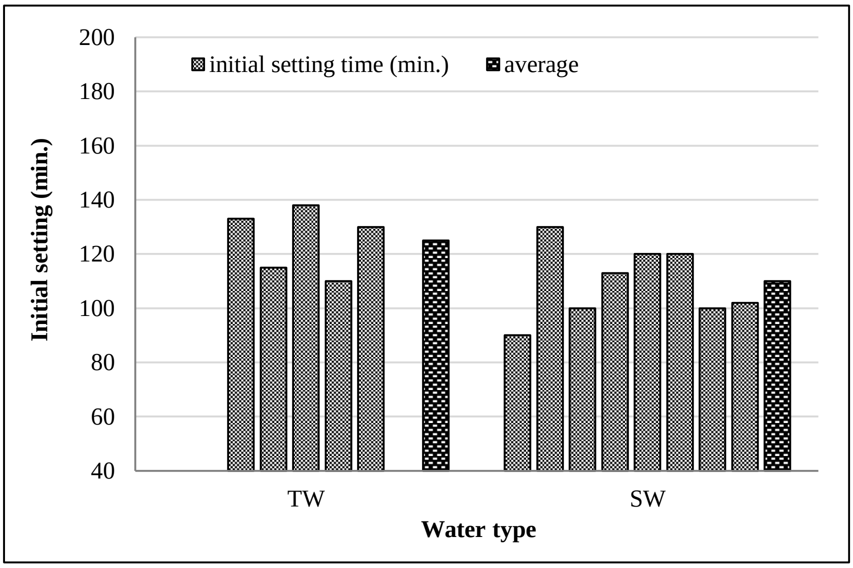

Figure 8. Initial setting time of cement pastes mixed with tap water and seawater

The results of compressive strength tests are shown in Table 4 and Figure 10 for the different mixtures. An increase in concrete strength mixed with seawater for all the mixtures was observed. The strength-ratios (numbers in brackets) as compared to similar concretes mixed with tap water were 109, 105, 103, 108, and 112 percent. A higher increase is obtained for lean mixes with quantity of cement of 300 kg and for rich mixes with quantity of cement of 450 and 500 kg. For normal mixtures with quantity of cement of 350 and 400 kg, concrete strength increased only 3 to 5 percent.

Figure 10 shows also a retrogression in concrete compressive strength for rich mixes with quantity of cement of 450 and 500 kg for concrete mixed with tap water. As the quantity of cement increases, the compressive strength of concrete mixed with tap water also increases till reach maximum value of 418.4 kg/cm^2 at quantity of cement of 400 kg. With further increase, the compressive strength decreases and values of 405.6 and 399.4 kg/cm^2 were obtained for quantity of cement of 450 and 500 kg respectively. In contrast, an improvement of strength of concrete mixed with seawater was observed for rich mixes.

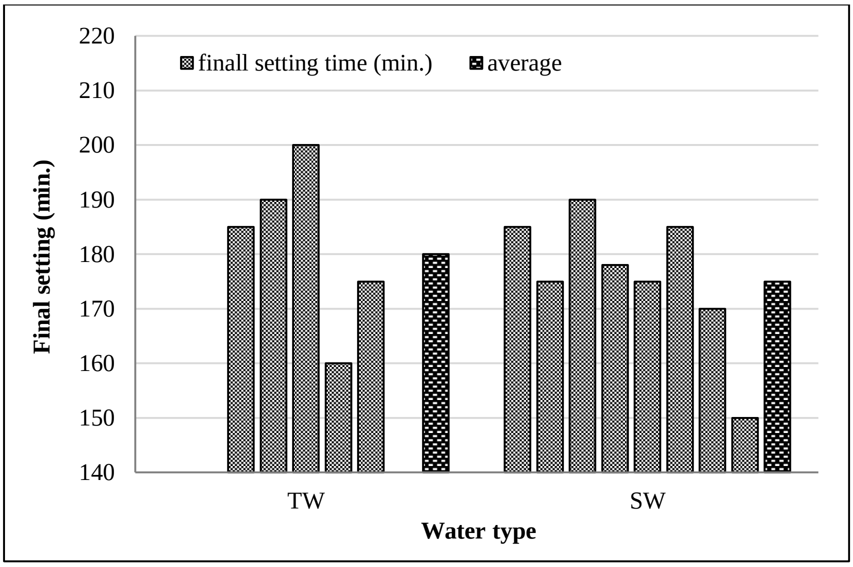

Figure 9. Final setting time of cement pastes mixed with tap water and seawater

Table 4. Compressive strength of Portland cement concretes mixed with tap water and seawater

Mixture	Compressive strength (kg/cm²)	
	TW	SW
1	320.6	350.5 (109.3)
2	357	374.5 (104.9)
3	418.4	429.9 (102.8)
4	405.6	437.6 (107.9)
5	399.4	448.6 (112.3)

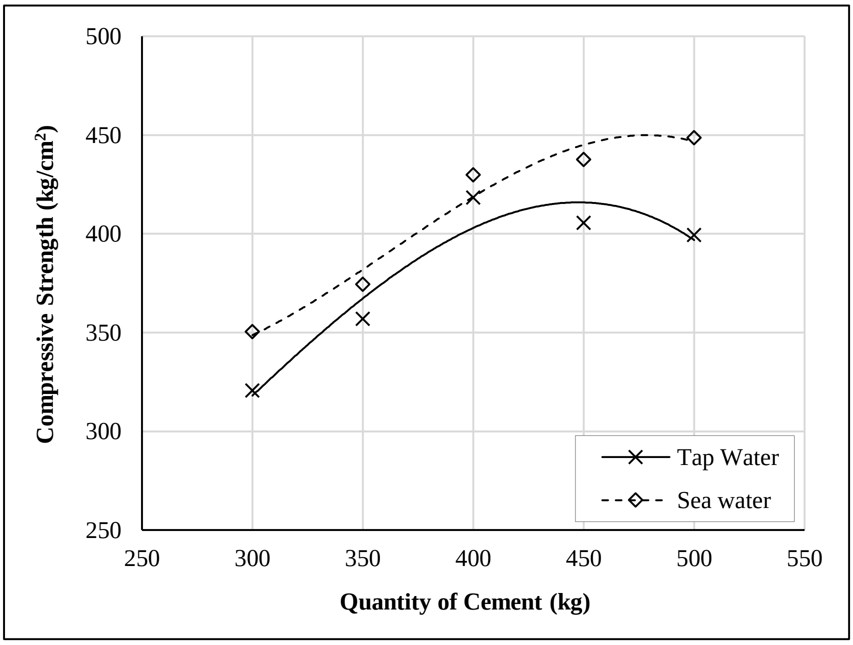

Figure 10. Compressive strength of Portland cement concretes mixed with tap water and seawater

Seawater beneficial effect on early strength development confirmed repeatedly in literature. Mohammed et al., found the use of seawater causes an earlier strength gain after 28 days compared to tap water which was attributed to improvement of the microstructure of concrete due to the acceleration of hydration process with the presence of chloride [11].

5. Conclusion

Seawater gives good results in concrete. It accelerates setting of cement but the effect is not so pronounced so as to cause a trouble in concrete. Seawater also improves 28-day compressive strength of concrete especially for rich mixes with quantity of cement of 450 and 500 kg. A retrogression of concrete strength was observed for rich mixtures with quantity of cement of 450 and 500 kg for concrete mixed with tap water while an improvement was observed for seawater mixed concrete and which may be a valuable conclusion. Therefore, especially in coastal region where fresh water is rarely found, there is a possibility of using seawater with rich mixtures but long-term durability especially chloride-induced corrosion should be carefully considered. Long-term durability of seawater mixed concrete will be discussed on later reports.

6. Declarations

6.1. Author Contributions

Conceptualization, A.I.G., M.Y.E. and A.H.A.E.; methodology, A.I.G., M.Y.E. and A.H.A.E.; formal analysis, A.I.G.; investigation, X.X.; resources, A.I.G.; writing—original draft preparation, A.I.G.; writing—review and editing, A.I.G.; supervision, M.Y.E. and A.H.A.E. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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