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Evaluation of Sea Water as a Mixing/Curing of the Concrete

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ABSTRACT

In this paper, sea water, instead of tap water, was used in mixing and curing the concrete. The experimental work consisted of 48 cubic, with 100 mm side length, plus 48 cylinder, with diameter of 100 mm and height of 200 mm. The main parameters were water type, either sea or fresh, and the curing period. The concrete mix were divided into four groups. The first was casted and cured using fresh water (FF) while the second was made from fresh and cured using sea water (FS). The third was casted and cured using sea water (SS) while the last was casted from sea water and cured by fresh water (SF). Specimens of four groups were tested at 7, 15, 28 and 90 days. The compression and splitting tensile tests were investigated to estimate the tensile /compressive strength of the concrete. It was showed that the compressive strength of three groups (FS, SS and SF) increased with concrete age until 28 days then it decreased. On the contrary, the compressive strength of FF increased until 90 days. Compressive strength of SS was 46.9, 64, 59.39 and 19.1 % higher than that of FF at ages 7, 15, 28 and 90 days, respectively. Patterns of the failure did not modify with replacing fresh water with sea water in the mix. The tensile response over the time improved until 90 days for FF group only while tensile strength of other groups increased until 28 days then it decreased. Enhancement rates in the tensile strength of SS were 46.51, 41.3, 75.89 and 54.11 % referenced to FF at ages 7, 15, 28 and 90 days, respectively.

Keywords: Experimental work; Concrete; Sea water; Fresh water; Compressive strength; Tensile strength.

1. INTRODUCTION

The worldwide demand for new concrete structures is significantly increasing for keeping up with urban development, where, in the year of 2016, the amount of cement produced in the world reached 4.20 billion tonnes, and the estimated concrete production was around 25 billion tonnes. The production of aggregates (including both coarse and fine aggregates) reached about 40 billion tonnes in the year of 2014. Although the concrete building construction is necessary, the environmental consequences were taking place due to concrete production in addition uses of it. The production of concrete creates a substantial need for water that directly causes a burden on the already scare natural resource [1].

Engineers commonly believe that sea water is not suitable for use in the concrete, particularly in concrete embedded with reinforcing bars as it may lead to corrosion [2]. Fresh water (tap water) depletion is progressing at a rapid pace globally [3-4] and therefore, it is becoming imperative to use sea water in concrete production because tap water reserves are either limited or its transport is costly.

In all world country, the studies around decreasing use of the fresh water in mixing of the concrete carried out. The fresh water can be clearly stored, if the sea water succeeded in casting or curing the concrete, especially the offshore structures. Otsuki et al. [5] and Okamura et al. [6] showed that using the sea water in mixing the concrete is valid. Additionally, Tjaronge et al. [7] studied using effect the sea water on the concrete properties. It was found that mixing water using the sea water was good [8].

On the contrariwise, many researchers who have several reservations about the use of sea water in the mixing and curing of the concrete such as Akinkurolere et al. [9] and Shayan et al. [10]. They explained that the concrete that mixed with sea water has an early strength in the early days of mixing until 14 days compared to its equivalent mixed with tap water, but this strength weakens with time.

In accordance with standards such as ASTM C1602 [11] or EN 1008 [12], the use of sea water for the production of reinforced or prestressed concrete is prohibited because sea water does not meet the chloride limit, resulting in a high risk of steel corrosion.

Recently, researchers have been interested in searching for cement capable of mixing with salt water. One of these products is blended cements, obtained by partial replacement of OPC clinker with industrial by-products, such as ground-granulated blast furnace slag (GGBFS), fly ash (FA), silica fume (SF) or natural pozzolans and fillers like trass or limestone [13-14].

However, recent technological improvements, in some cases, have made it possible to overcome the use of sea water in the plain concrete, by using nano-materials such as nano silica ($SiO2$) which contributes to a significant acceleration of the cement hydration process. Various studies have confirmed the accelerating effects of nano silica in OPC and blended cementitious systems [15-25].

Use of sea water in reinforced concrete by using of corrosion-free reinforcements such as fiber-reinforced polymers (FRP) in addition, reinforcement-free ductile composites containing polypropylene (PP) fibres were investigated by Li et al. [26-27] and Jiangtao et al. [28]. Moreover, the corrosion of reinforcing steel can be mitigated by creating a proper mixture design, which incorporates supplementary cementitious materials (SCMs) or corrosion inhibitors such as sodium nitrite [29-32].

Although the existing literature and codes of practice reveal the effect of mixing and curing of sea water on durability of concrete, it still remains an area requiring further study and research. The beaches of Baltim, which are located on the Mediterranean in the city of Kafr El-Sheikh in the Arab Republic of Egypt, are characterized by black sand rich in minerals such as iron oxides and silicon oxides [33], so as previously listed the presence of these minerals makes the use of salt water containing black particles a great opportunity to achieve good results to be used for mixing and curing.

2. Research importance

Research aim is to study the potential of replacing the fresh water by salt sea water from Baltim beaches in concrete mixtures and identify its mechanical behaviour when mixed and cured with salt sea water. So in this study, the strength behaviour of concrete made and cured with sea water, and its comparison with traditional mixing water (fresh water from water ways, especially the Nile River).

3. Materials used

3.1 Mix designation

The mix used in the current work composed of Portland cement, water, sand and course aggregate (crushed dolomite). The compressive strength of the concrete was designed to give 25 MPa after 28 days. The objective of the current work is using sea water in the concrete mix, instead of tap water, on the mechanical characteristics of the concrete. Two mixes were designed in this study. All proportions of these mixes were identical except the water type, either fresh water (F) or sea water (S). The mix M_F was casted using fresh water while the mix M_S was casted using sea water. Table 1 shows components of the two mixes by weight per one cubic meter.

Table 1 Proportion of the used mixes (kg/m^3)

Mix	Crushed dolomite	Sand	Cement	Water content	Water/Cement	Water type
M_F	1050	770	300	150	0.5	F
M_S						S

F denotes fresh water taken from the tap. S is sea water taken from the Mediterranean at Baltim, Kafrelshiekh city, Egypt.

3.2 Fresh/sea water

The water worked as a greasing material to mixing the aggregate with the cement. Also, the water had a chemical function to interact with the cement for formation the cement paste.

Two types of water were used in this study. The first was fresh waste (F) while the second was sea water (S) taken from the Mediterranean at Baltim, Kafrelshiekh city, Egypt. Sea water was relocated and overstocked in containers, as depicted in Fig 1. These water types were used in the mix and curing the specimens. The chemical compositions were determined and the results were listed in Table 2.

(a) Filling the containers

(b) Storage containers inside the laboratory

Fig 1 Filling, transporting and storing the sea water from the Mediterranean at Baltim to laboratory at faculty of engineering, Kafrelshiekh university, Egypt

Table 2 chemical compositions of fresh/sea water that used in the concrete

	Concentration (ppm)	
Ions	Tap water	Seawater
Calcium	90	389
Chloride	44	18,759
Iron	—	0.512
Potassium	6	329
Magnesium	6	1,323
Sodium	26	9,585
Sulfate	8	2,489
Nitrate	1	0.134

3.3 Fine aggregate (sand)

The sand as a fine aggregate in the mix consisted of grains resulting from crumbling the rocks. The currents of river water bowdlerized the sand from the organic material. The existing sand in Egypt was obtained from the beds of the river in addition zippor. The most commercially are silica sands, often above 98% pure. Sand used had a maximum size of 1.18 mm and specific gravity of 2.5.

3.4 Coarse aggregate (crushed dolomite)

Coarse aggregates are the crushed dolomite. The most types are crushed, graded and quarried. Granite, limestone, and trap rock are crushed type. The limestone type was used in the current work. Crushed dolomite was used with maximum nominal size not more than 10 mm and specific gravity of 2.75.

3.5 Sulphate resistant cement

Cement is a material, in powder form, that can be made into a paste by the addition of the water. The most widely used of the construction cements is Portland Cement. Sulphate resistant cement (SRC), CEM I 42.5 N, was used as shown in Fig 2a. It is produced according to Egyptian standards ES 4756/1-2013 [34] and complaint with European specification BS EN 197-1/2011 [35]. The cement used has a grade of 42.5 MPa. The chemical and physical characteristics of the cement used satisfy the Egyptian standard specification No 2421-1993 [36]. This cement was used in the current work to resist sulphates and salts existing in the sea water.

Sulphate Resisting Cement is a type of Portland Cement in which the amount of tricalcium aluminate (C3A) is restricted to lower than 5% and (2C 3A +C4AF) lower than 25%, which reduces the formation of sulphate salts. The reduction of sulphate salts lowers the possibility of sulphate attack on the concrete. The advantages of this cement type are: (1) Loss of ignition ≤ 5 %, (2) Insoluble residues ≤ 5 %, (3) Sulphate ($SO3$) ≤ 3 % and (4) Chloride content (CL^-) ≤ 0.1 %.

(a) Preparing the components; water, sand, dolomite and Portland Cement sulphate resistant

(b) Preparing the forms

(c) Casting the specimens

(d) Releasing the specimens

(e) Curing by immerge in isolated tanks

Fig 2 Steps of preparing, casting and curing the specimens

4. Specimens details

The current experimental work consisted of 48 cubes plus 48 cylinders. The cubic side was 100 mm while diameter and height of the cylinder was 100 mm and 200 mm, respectively. Half of specimens were casted using M_F, that mixed with fresh water, and the other half were casted using M_S, that mixed with sea water. Fig 2 illustrated steps of preparing and casting specimens. All compositions of the mix were prepared, as shown in Fig 2a. A digital scale was used to weigh each part individual then a mechanical mixer, with capacity of 100 liters, was used to manufacture the concrete mix. Fig 2b shows plastic and wood forms that used to figuration the cubes and cylinders while the casting process was illustrated in Fig 2c. After 1 day from casting, the specimens were released, as shown in Fig 2d, in order to begin the immerge process of all specimens inside a lot of tanks, as depicted in Fig 2e.

Table 3 shows details of the cubes and the cylinders. All specimens were divided into 4 groups (G_{FF}, G_{FS}, G_{SF} and G_{SS}). Each group consisted of 12 cubes and 12 cylinders. For each group, curing periods of specimens were 7, 15, 28 and 90 days. Group G_{FF} included the specimens that casted by fresh water (F) and cured using F during the intervals 7, 15, 28 and 90 days. This group consisted of cubes C_{FF7}, C_{FF15}, C_{FF28} and C_{FF90} in addition the cylinders S_{FF7}, S_{FF15}, S_{FF28} and S_{FF90}. The sub-number existing in specimen term denotes the curing period. Details of the other groups were similar to the first group G_{FF}. Specimens of both two groups G_{FF} and G_{FS} were casted by F but immerge water was fresh in G_{FF} and was sea water in G_{FS}. On the other hand, specimens of groups G_{SF} and G_{SS} were casted by sea water but curing water was fresh in G_{SF} and was sea water in G_{SS}. After 1 day from curing time, the specimen was tested. For simplify, testing time was taken equal the immerge time.

Table 3 The cubes/cylinders details

Group ID	Cubic (C)/Cylinder (S) ID	Number of specimens	Mix used	Water mix	Water curing	Curing/testing time (days)
G_{FF}	C_{FF7} S_{FF7}	3	M_F	F	F	7
	C_{FF15} S_{FF15}	3	M_F	F	F	15
	C_{FF28} S_{FF28}	3	M_F	F	F	28
	C_{FF90} S_{FF90}	3	M_F	F	F	90
G_{FS}	C_{FS7} S_{FS7}	3	M_F	F	S	7
	C_{FS15} S_{FS15}	3	M_F	F	S	15
	C_{FS28} S_{FS28}	3	M_F	F	S	28
	C_{FS90} S_{FS90}	3	M_F	F	S	90
G_{SS}	C_{SS7} S_{SS7}	3	M_S	S	S	7
	C_{SS15} S_{SS15}	3	M_S	S	S	15
	C_{SS28} S_{SS28}	3	M_S	S	S	28
	C_{SS90} S_{SS90}	3	M_S	S	S	90
G_{SF}	C_{SF7} S_{SF7}	3	M_S	S	F	7
	C_{SF15} S_{SF15}	3	M_S	S	F	15
	C_{SF28} S_{SF28}	3	M_S	S	F	28
	C_{SF90} S_{SF90}	3	M_S	S	F	90

5. Test setup

A compression test was carried out on the cubes using compression machine with capacity of 2000 kN, as shown in Fig 3a. This test was used to find the compressive strength of the concrete. To determine the tensile strength of the concrete, a splitting test was investigated using the compression machine, as depicted in Fig 3b. Both two tests were carried out according to Egyptian code [37]. The maximum load was recorded by using the digital screen of the machine. After the test, each specimen was depicted and the failure pattern was specified.

(a) Compression test of cubes (b) Splitting test of cylinders

Fig 3 Test setup of specimens

6. Results and discussion

The specimens were divided into new four groups; G7, G15, G28 and G90. G7 and G15 consisted of cubes and cylinders that tested at 7 and 15 days, respectively. G28 and G90 consisted of cubes and cylinders that tested at 28 and 90 days, respectively.

6.1 Compressive characteristics

6.1.1 Compressive behavior

The compressive strengths, f_c, of the tested mixtures at the age of 7, 15, 28 and 90 days for all cubes were calculated using Equation (1) and represented in Table 4.

$$f_c = \frac{P_m}{A_c} \quad (1)$$

where f_c is the compressive strength in *MPa*, P_m is the applied maximum compressive load in *N* and A_c is the cubic cross-sectional area = 10000 mm^2.

Comparison between the average compressive strength (f_{ca}) of the four groups at different curing time was depicted in Fig. 3. Generally, it was shown that the sea water had a significant effect on the average compressive strength of the tested specimens.

The average compressive strength significantly affected by the water quality, river water or sea water.

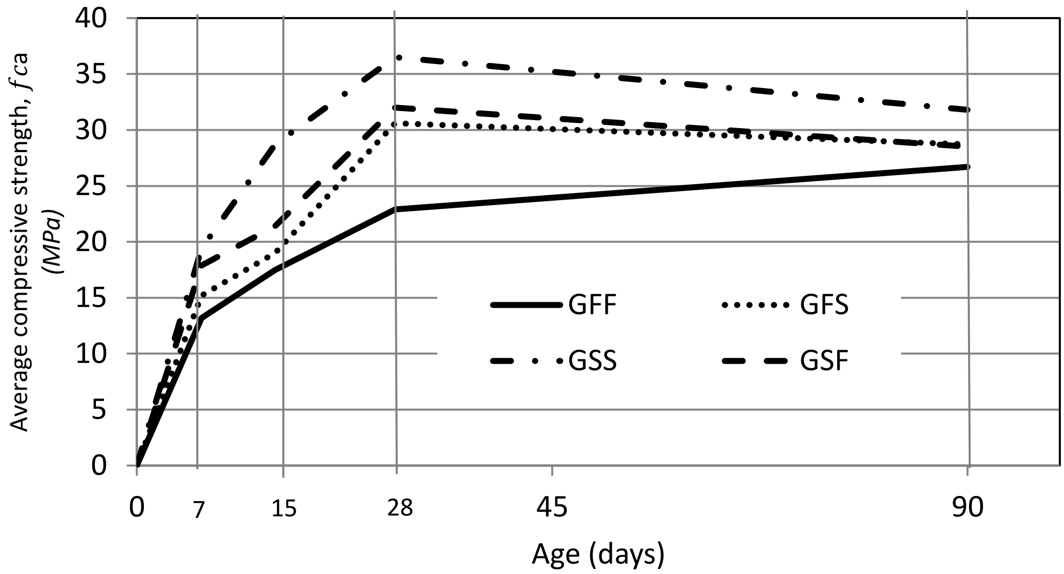

Fig. 3 Compressive strength versus age for the tested mixtures.

Three cubes were prepared and tested for every sample. At 7 days, the control average compressive strength for cubes mixed and cured by using the river water (fresh water), group G_{FF}, was 13.2 MPa while other groups either mixed or cured by using the sea water yielded higher average compressive strengths of 15.2, 19.4 and 17.9 MPa for G_{FS}, G_{SS} and G_{SF} groups, respectively. The same pattern was observed at curing ages of 15, 28 and 90 days. The average compressive strengths of G_{FF}, G_{FS}, G_{SS} and G_{SF} groups at 15 days were 17.5, 19.0, 28.7 and 21.4 MPa, respectively, while their counterparts 28 days were 22.9, 30.6, 36.5 and 32.0 MPa, respectively. At 90 days, the average compressive strength recoded for G_{FF} group was the highest value among the other curing periods unlike other groups subjected to sea water. of 26.7, 28.7, 31.8 and 28.5 MPa, respectively. The average compressive strengths of G_{FF}, G_{FS}, G_{SS} and G_{SF} groups at 90 days were 26.7, 28.7, 31.8 and 28.5 MPa, respectively. Specifically, cubes that mixed and cured by using sea water recorded the highest average compressive strength at all different curing time compared to other groups. The average compressive strength of G_{SS} group was 19.4, 28.7, 36.5 and 31.8 MPa at 7, 15, 28 and 90 days, respectively.

Table 4 Results of the tested cubes

Group ID	Cubic ID	Compressive strength f_c (MPa)			Average compressive strength f_{ca} (MPa)
		Cubic 1	Cubic 2	Cubic 3	
G_{FF}	C_{FF7}	12.6	13.6	13.4	13.2
	C_{FF15}	14.2	21.5	16.8	17.5
	C_{FF28}	23.5	21.9	23.3	22.9
	C_{FF90}	26.1	26.5	27.5	26.7
G_{FS}	C_{FS7}	14.3	15.6	15.7	15.2
	C_{FS15}	18.4	19.5	19.1	19.0
	C_{FS28}	31.6	29.5	30.7	30.6
	C_{FS90}	28.1	29.2	28.8	28.7
G_{SS}	C_{SS7}	19	19.7	19.5	19.4
	C_{SS15}	29	28	29.1	28.7
	C_{SS28}	35.6	37.7	36.2	36.5
	C_{SS90}	31.5	33.4	30.5	31.8
G_{SF}	C_{SF7}	18.9	16.4	18.4	17.9
	C_{SF15}	21.6	22.4	20.2	21.4
	C_{SF28}	32.9	31.3	31.8	32.0
	C_{SF90}	28.2	27.8	29.5	28.5

6.1.2 Comparison of compressive strengths

Table 5 shows the increasing ratio of the average compressive strength at 7, 15, 28 and 90 days in comparison with the control group G_{FF}. As mentioned earlier, results showed that group G_{SS} recorded the highest increasing ratio of compressive strength among all tested groups at different ages. On the contrary, group G_{FS} recorded the lowest increasing ratio of compressive strength at 7, 15 and 28 days while group G_{SF} yielded the lowest value at 90 days. The increasing ratio of the average compressive strength of C_{FS7}, C_{SF7} and C_{SS7} specimens was 15.15, 35.6 and 46.97%, respectively, higher than the control group (G_{FF}) at 7 days while the counterparts increasing ratios at 15 days were 8.57, 22.28 and 64%, respectively. The average compressive strength of the tested specimens obtained higher increasing ratios at 28 days. On the other hand, the compressive strength of the tested groups did not significantly increase at 90 days compared to G_{FF} group. Results showed that the increasing ratio of C_{FS28}, C_{SF28} and C_{SS28} specimens was 33.62, 39.74 and 59.39%, respectively, compared to 7.49, 6.74 and 19.10%, respectively, at 90 days.

Table 5 Compression results of the cubes at different ages.

Group ID	Cubic ID	Average compressive strength, f_{ca} *(MPa)*	Increase in f_{ca} (%)
G_7	C_{FF7}	13.2	--
	C_{FS7}	15.2	15.15
	C_{SF7}	17.9	35.60
	C_{SS7}	19.4	46.97
G_{15}	C_{FF15}	17.5	--
	C_{FS15}	19.0	8.57
	C_{SF15}	21.4	22.28
	C_{SS15}	28.7	64.00
G_{28}	C_{FF28}	22.9	--
	C_{FS28}	30.6	33.62
	C_{SF28}	32	39.74
	C_{SS28}	36.5	59.39
G_{90}	C_{FF90}	26.7	--
	C_{FS90}	28.7	7.49
	C_{SF90}	28.5	6.74
	C_{SS90}	31.8	19.10

C_{FF7}, C_{FF15}, C_{FF28} and C_{FF90} were considered as a reference specimen for groups G_7, G_{15}, G_{28} and G_{90}, respectively.

6.1.3 Failure patterns of the cubes

Fig. 4 shows the failure pattern of tested cubes of different groups at curing age 28 days after compressive test. All groups exhibited non-explosive failure. Moreover, visual inspection showed that most of the tested cubes failed due to vertical cracks appeared firstly at the middle of the cubes followed by vertical cracks near the ends.


(a) F-F group *(b) F-S group*


(c) S-F group *(d) S-S group*

Fig. 4 Failure mode of cube specimens at curing age 28 days.

6.2 Splitting tensile characteristics

6.2.1 Tensile strength and failure pattern

The splitting tensile strength (f_t) of the tested cylindrical samples was determined by Eq. (2) and listed in Table 6.

$$f_t = \frac{2P_m}{\pi DL} \quad (2)$$

where f_t is the splitting tensile strength in *MPa*, D is the cylinder diameter = 100 *mm* and *L* is the cylinder length = 200 *mm*.

Table 6 Splitting tensile results of test mixtures.

Group ID	Cylinder ID	Splitting tensile strength f_t *(MPa)*			Average splitting tensile strength f_{ta} *(MPa)*
G_{FF}	S_{FF7}	1.29	1.26	1.32	1.29
	S_{FF15}	1.39	1.34	1.41	1.38
	S_{FF28}	1.49	1.31	1.43	1.41
	S_{FF90}	1.41	1.52	1.45	1.46
G_{FS}	S_{FS7}	1.58	1.35	1.51	1.48
	S_{FS15}	1.75	1.84	1.81	1.8
	S_{FS28}	1.95	2.1	2.19	2.08
	S_{FS90}	1.85	2.22	1.93	2.00
G_{SS}	S_{SS7}	1.74	1.92	2.01	1.89

	S_{SS15}	2.12	1.83	1.9	1.95
	S_{SS28}	2.58	2.39	2.47	2.48
	S_{SS90}	2.34	2.27	2.14	2.25
G_{SF}	S_{SF7}	1.94	1.85	1.43	1.74
	S_{SF15}	2.01	1.85	1.81	1.89
	S_{SF28}	2.25	2.35	2.39	2.33
	S_{SF90}	1.83	1.96	2.00	1.93

Three cylinders were tested for each group at different curing ages of 7, 15, 28 and 90 days. The average splitting tensile strength (f_{ta}) was calculated and plotted in Fig. 5. Results showed that the average splitting tensile strength of the control cylinders (F-F) group significantly increased as the curing age increased from 7 to 90 days. Values of the average splitting tensile strength of the F-F group were 1.29, 1.38, 1.41 and 1.46 MPa at 7, 15, 28 and 90 days, respectively. Generally, all groups exhibited average splitting tensile strength higher than the F-F group. Specifically, cylinders that mixed and cured by using sea water (G_{SS} group) recorded the highest average splitting tensile strength among all tested groups at all ages. The average splitting tensile strength of G_{FS}, G_{SS} and G_{SF} groups at 7 days was 1.48, 1.89 and 1.74 MPa, respectively in comparison with 1.29 MPa for G_{FF} group. The average splitting tensile strength of G_{FS}, G_{SS} and G_{SF} groups increased up to 28 days then decreased. The average splitting tensile strengths of G_{FS} group at 15, 28 and 90 days were 1.80, 2.08 and 2.00 MPa, respectively while their counterparts of G_{SS} group were 1.95, 2.48 and 2.25 MPa, respectively. Group G_{SF} recorded the lowest average splitting tensile strength among the tested groups at 90 days of 1.93 MPa while the average splitting tensile strengths at 15 and 28 days were 1.89 and 2.33 MPa, respectively. After the splitting tensile test, all groups exhibited the same failure pattern, the cylinders got split into two halves as depicted in Fig. 6.

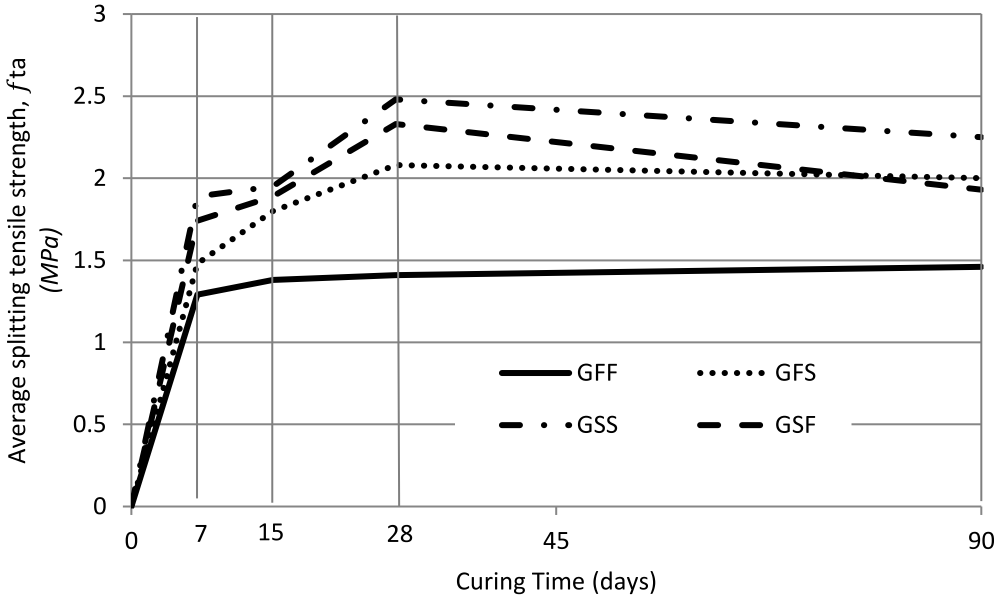

Fig. 5 Compressive strength versus curing for the tested mixtures.

Fig. 6 Failure pattern of cylindrical sample of S-S group after splitting tensile test at curing age 28 days.

6.2.2 The increase ratio of the splitting tensile strength

Table 7 shows the increasing ratio of the average splitting tensile strength for specimens mixed and cured by using sea water at 7, 15, 28 and 90 days in comparison with the control group (G_{FF}) which mixed and tested by using fresh water (tab water). Results showed that group G_{SS} recorded the highest increasing ratio of average splitting tensile strength among all tested groups at different ages in covenant with the average compressive strength results. On the contrary, group G_{FS} recorded the lowest increasing ratio of tensile strength at 7, 15 and 28 days while group G_{SF} yielded the lowest value at 90 days. The increasing ratio of the average splitting tensile strength of S_{FS7}, S_{SF7} and S_{SS7} specimens was 14.73, 34.88 and 46.15%, respectively, higher than the control group (G_{FF}) at 7 days while the counterparts increasing ratios at 15 days were 30.43, 36.96 and 41.30%, respectively. The highest increasing ratios of the average splitting tensile strength for the tested specimens were recorded at 28 days. The average splitting tensile strength for all groups was decreased at 90 days compared to results at 28 days except G_{FF} group. Results showed that the increasing ratio of C_{FS28}, C_{SF28} and C_{SS28} specimens was 47.52, 65.25 and 75.89%, respectively, compared to 36.99, 32.19 and 54.11%, respectively, at 90 days.

Table 7 The increase in average splitting tensile strength.

Group ID	Cylinder ID	Average splitting tensile strength f_{ta} *(MPa)*	Increase in f_{ta} (%)
G_7	S_{FF7}	1.29	--
	S_{FS7}	1.48	14.73
	S_{SF7}	1.74	34.88
	S_{SS7}	1.89	46.51
G_{15}	S_{FF15}	1.38	--
	S_{FS15}	1.80	30.43
	S_{SF15}	1.89	36.96
	S_{SS15}	1.95	41.30
G_{28}	S_{FF28}	1.41	--
	S_{FS28}	2.08	47.52
	S_{SF28}	2.33	65.25
	S_{SS28}	2.48	75.89
G_{90}	S_{FF90}	1.46	--
	S_{FS90}	2.00	36.99
	S_{SF90}	1.93	32.19
	S_{SS90}	2.25	54.11

6.2.3 Predicted splitting tensile strength

$$f_{tt} = 0.6\sqrt{f_{cu}} \quad (3)$$

where f_{tt} is the theoretical splitting tensile strength in *MPa*.

The splitting tensile strength was theoretically estimated depending on the compressive strength according to the recommendations of the Egyptian code ECP 203-2017 [38] using Eq. (3). Results were listed in Table 8 and compared with the experimental splitting tensile strength (f_{te}). It was shown that Egyptian code ECP 203-2017 [38] over-estimated the splitting tensile strength of the tested specimens. The ratio between the experimental and the theoretical splitting tensile strength ranged from 0.47 to 0.72.

Table 8 Comparison between the experimental and the theoretical splitting tensile strength of the tested groups.

Cylinder ID	Experimental splitting tensile strength f_{te} *(MPa)*	Theoretical splitting tensile strength f_{tt} *(MPa)*	f_{te}/f_{tt}
S_{FF7}	1.29	2.18	0.59
S_{FF15}	1.38	2.51	0.55
S_{FF28}	1.41	2.87	0.49
S_{FF90}	1.46	3.10	0.47
S_{FS7}	1.48	2.34	0.63
S_{FS15}	1.8	2.62	0.69
S_{FS28}	2.08	3.32	0.63
S_{FS90}	2.00	3.21	0.62
S_{SS7}	1.89	2.64	0.72
S_{SS15}	1.95	3.21	0.61
S_{SS28}	2.48	3.62	0.68
S_{SS90}	2.25	3.38	0.66
S_{SF7}	1.74	2.54	0.69
S_{SF15}	1.89	2.78	0.68
S_{SF28}	2.33	3.39	0.69
S_{SF90}	1.93	3.20	0.60

7. Conclusion

In this experimental program, using both sea and fresh water were used in mixing and curing of the concrete. Specimens used were cubes and cylinders. Cubic side was 100 mm while diameter and height of the cylinder were 100 mm and 200 mm, respectively. 48 cubic plus 48 cylinder were casted and cured using either sea or fresh water. Specimens were cured/tested at 7, 15, 28 and 90 days. Specimens were divided into four groups which each group consisted of 12 cubic and 12 cylinder. The first (FF) was casted/cured by fresh water. 2nd group (FS) was made from fresh water and cured using sea water. Sea water was used in casting and curing of 3rd group (SS) while the 4th one (SF) was made from sea water and cured by fresh water. The splitting tensile and compression experiments were executed to get the tensile and the compressive characteristic of the mix. Based on the tests result, the following conclusion can be drawn:

1. The concrete compressive behaviour of FS, SS and SF improved with time until 28 days then it decreased while the compressive behaviour of FF improved until 90 days.
2. Compressive strength of SS was bigger than FF by 46.9, 64, 59.39 and 19.1 % at ages 7, 15, 28 and 90 days, respectively.
3. Using sea water in the concrete had negligible effect on failure modes of specimens.
4. The splitting tensile response against time increased until 90 days for FF-specimens. On the other hand, the tensile strength of three groups (FS, SS, SF) increased until 28 days then it decreased.
5. Improving rates in the tensile response of SS-cylinders were found 46.51, 41.3, 75.89 and 54.11 % compared with FF-cylinders at ages 7, 15, 28 and 90 days, respectively.

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