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Repercussion of seawater for fraternization and curing on structural concrete

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Abstract: In this article, the effects of mixing and curing concrete with seawater on the compressive, tensile, flexural and bond strengths of concrete are investigated. Concrete mixes were prepared by varying coarse aggregates, cement proportions and types. Six groups of concrete mixes were mixed and cured in fresh water, six groups were mixed and cured in seawater, while four groups were mixed with fresh water and cured in seawater. The compressive strength and subsequently the other related strengths of concrete were shown to increase for specimens mixed and cured in seawater at early ages up to 14 days, while a definite decrease in the respective strengths was observed for ages more than 28 days and up to 90 days. The reduction in strength increases with an increase in exposure time, which may be due to salt crystallisation formation affecting the strength gain.

Keywords: seawater; concrete; curing; durability; strength; salt; age

1. INTRODUCTION

Concrete has an excellent structural performance and durability, but is affected by early deterioration when subjected to a marine environment. The most common cause of deterioration is corrosion of the steel reinforcement, with subsequent sapling of concrete. Therefore the selection of materials, mix design, and proper detailing of reinforcement are essential parameters in producing a durable marine structure concrete (Neville and Brooks 1994).

The durability of concrete is generally regarded as its ability to resist the effects and influences of the environment, while performing its desired function (Hoff 1991). The chemical deterioration of concrete subjected to seawater has been a topic of interest to concrete researchers in the last few decades, and the findings have revealed some very important facts, but still it remains to be a dynamic subject for further study and research (Kumar 2000). The primary chemical constituents of seawater are the ions of chloride, sodium, magnesium, calcium and potassium. In seawater containing up to 35,000 ppm of dissolved salts, sodium chloride (NaCl) is by far the predominant salt (about 88% by weight of salts (McCoy 1996)). The pH value of seawater varies between 7.4 and 8.4. Corrosion of reinforcing steel occurs below a pH of 11. Therefore, in cases where concrete is subjected to a highly severe environment, the cement must supply alkalinity (Gani 1997).

The chemical reactions of seawater on concrete are mainly due to the attack by magnesium sulphate ($MgSO_4$). The mode of attack is crystallisation. Potassium and magnesium sulphates (K_2SO_4 and $MgSO_4$) present in salt water can cause sulphate attack on concrete because they can initially react with calcium hydroxide $Ca(OH)_2$, which is present in the set cement formed by the hydration of dicalcium silicate (C_2S) and tricalcium silicate (C_3S). The attack of magnesium sulphate ($MgSO_4$) is particularly damaging, forming soluble magnesium hydroxide ($Mg(OH)_2$), which forces the reaction to form gypsum (Swamy 1991). Chloride ions can penetrate into the concrete and cause accelerated corrosion of the reinforcement. The chemical reaction of the cement paste with the high-chloride content of seawater is generally slight and not a primary cause of concern. Sodium and potassium ions may produce or intensify the alkali aggregate reaction if reactive types are used, and sulphate and magnesium ions cause a weakening action on the cement paste (Uddin *et al*. 2004). According to the ACI Building Code 318-83, sulphate exposure to seawater is classified as moderate, while sulphate attack is classified as severe, when the sulphate ion concentration is higher than 1500 mg/l. ASTM type II Portland cement with a maximum of 10% tricalcium aluminates (C_3A) and with a 0.5 maximum water–cement ratio in normal-weight concrete is permitted for use in this case (Building Code Requirements (318–99) 1999), ASTM (C190 2001);however, there is a controversy over the use of seawater as mixing water. It increases the risk of corrosion of the embedded reinforcing steel, if the structure is to be exposed to air in service. The most damaging effect of seawater on concrete structures arises from the action of chlorides on the steel reinforcement and the buildup of salts (Aburawi and Swamy 2008).

A number of studies have shown the effects of the mixing and curing of seawater on the compressive strength of cement–sand mortars and corresponding concrete. Research indicates that seawater is not suitable for the mixing and curing of both plain and reinforced concrete in marine conditions (Akinkuro- lere *et al*. 2007). However, concrete made with the seawater may have a higher early strength than normal concrete and the reduction in strength with age can be compensated by reducing the water–cement ratio and that the microstructural examination of concrete detected chloroaluminate salts in some cracks (Shayan *et al*. 2010). Naghoj and Abdel-Rahmna (2005)reported that adding loam to a concrete mix can increase the compressive strength of the concrete under normal conditions and enhance the performance of hardened concrete to resist the aggressive mediums of salty seawater. Recent studies showed that composites have ever proved to be resistant to marine environment (Liu *et al*. 2002), and that the level of fine aggregate replacement by ground blast furnace slag and ground basaltic pumice had a beneficial effect on the compressive strength loss due to seawater attack and abrasion value (Binici *et al*. 2008). Schneider and Chen (2005) reported on the influence of different concentrations of chemical solutions, the quality class of concretes, and the load level of applied stress on the strengths of concrete,and the mechanism of steel reinforcement corrosion. Persson (2003) studied the sulphate resistance of self- compacting concrete at ages of 28 and 90 days. The investigation shows that the concrete cured in a solution with sodium sulphate suffered from a larger loss of concrete mass due to the limestone filler content in the concrete mixes. More recent study observed the performance of concrete under sulphate attack. The research shows that performance needs to be divided into several phenomena: absorption and diffusion of sulphate and the influence of environmental conditions (Ferraris *et al*. 2006). A study conducted by Stark (2002) affirms the importance of controlling the water–cement ratio and permeability of concrete in maximising concrete durability. The study confirmed the importance of the proper ratio of water to total cementitious materials and the resulting permeability as the primary factors determining performance in outdoor exposures. Furthermore, the use of low water– cement ratios provides the greatest resistance to sulphate attack on concrete, and the composition of Portland cement is less important as it relates to performance in sulphate solutions. In addition, the salt crystallisation process of concrete is a major cause for concern as compared to the chemical reaction of aluminates from cement hydration and sulphate from external sources. In effect, concrete can deteriorate by stresses caused by the crystallisation of salts in the pores (Stark 2002, Mehta and Monteiro 2005). Some studies show that the cement content can mitigate the aggressive effect of low water–cement ratios, giving more workability to the mix as well as enhancing the bond strength among concrete components. With high cement contents, the action of micro-cracking works together with the action of crystallisation, resulting in strength loss at earlier ages than is supposed to happen if the crystallisation action is the only governing factor (Zaher and Shihada 2003), judgement concerning the possible sulphate aggression should be passed on the basis of the prediction of the hydrochemistry of the water that washes against the structure during its service (Kaushik and Islam 1995, Portland Cement Association 2003). Further investigation and work is recommended on this subject of using seawater for concrete mixes, as the planet earth is experiencing noticeable shortage of pure clean water sources for future construction work, and the use of seawater to develop durable concrete of lasting performance will be greatly beneficial.

2. EXPERIMENTAL STUDY

The experimental study was carried out using different mixes of concrete mixed and cured in fresh water and seawater in order to determine the effect of the curing conditions for determining concrete strengths, namely, compressive strength, tensile strength, flexural strengthand bond strength. The studied variables of concrete mixes were cement content, type of cement and aggregate type.

2.1 Concrete mix design

Sixteen concrete mixes (A-P) were considered in the present study. Six mixes were mixed and cured in fresh water (ff), six concrete mixes were mixed and cured in seawater (ss) and the last four mixes were mixed with fresh water and cured in seawater (fs). The concrete mixes were tested at ages of 7, 14, 28 and 90 days for compression tests. They were also tested at 28 and 90 days for split tensile, flexural and bond tests. The test specimens were cast using two types of cements: ordinary Portland cement (OPC) and sulphate-resisting cement (SRC). The mix ratios were 1:2:4 with gravel and dolomite used as coarse aggregates. The maximum nominal size of the coarse aggregates was 22 mm, and the sand–gravel ratio was 1:2. The water– cement ratio taken was 0.45. The cement contents used were 350, 400 and 450 kg/m^3. The fresh water used formixing and curing the concrete specimens was drinkingwater according to ASTM C190, and seawater containing about 40,000 ppm of dissolved salts with a pHvalue of about 8.2 was used. A target slump of 50–70 mm was selected for all mixes, and all the required materials for preparing concrete were weighedas per the required proportions. All the specimens were remolded after 24 h of casting and were kept incuring liquid up to the testing date after 7, 14, 28 and90 days. The concrete mixes are shown in detail in Table 1.

2.2 Specimen Standards

Standard concrete cubes of 150 x 150 x 150 mm^3 were used for measuring the compressive strength. Concrete cylinders for measuring the split tensile strength were 150 x 300 mm^2, and concrete beams at 600 x 100 x 100 mm^3 were employed for flexural strength determination. The pull-out test was carried out by using a high tensile steel bar with a diameter of 20 mm embedded in the center of a standard concretecube of 150 x 150 x 150 mm^3.

2.3 Results and discussion

After the casting and remolding of the concrete specimens, it was noticed that the specimens mixed and cured in seawater had darker surfaces than the reference specimens mixed and cured in fresh water. Inaddition, salt deposits were formed on the surface of specimens cured in seawater. The experimental results for compressive strength (f_c), split tensile strength (f_t), flexural strength (f_f) and bond strength (f_b) are presented in Table 2.

3. COMPRESSIVE STRENGTH

3.1 Mixing and curing conditions

An appreciable increase and early compressive strengths were gained for (ss) and (fs) mixes as compared with the control mixes (ff) up to an age of 7 days. Then, the rate of strength gain in the control specimens (ff) was faster than (ss) and (gs) specimens. At 14 days, all concrete mixes recorded a slight increase in compressive strength f_c, but the rates of increase in (ff) and (ss) mixes were higher than in (fs) mixes. At 28 days, the rate of strength gained was still increasing, and an appreciable compressive strength was noticed for all mixes. However, at 90 days, the rate of strength gained decreased, especially for (ss) and (fs) mixes. The reduction in compressive strength within and after 90 days for (ss) mixes ranged from 3.8% to 14.5% when compared to the values of compressive strength of (ff) mixes. This may be due to the crystallisation of salt in seawater.

The results show that mixing concrete with fresh water before curing in seawater improves the compressive strength of concrete. Figures 1, 2, 3 and 4 clearly show the effect of mixing concrete with seawater, the effect of curing concrete in seawater, and the mutual effect of mixing and curing concrete in seawater on the compressive strength of concrete. The compressive strengths at 7 and 14 days increase by about 3–10% and 1–4% respectively for concrete mixes mixed and cured in seawater for different cement contents. When using gravel or dolomite as the coarse aggregate with a cement content of 350 kg/m^3, the percentage increases were 15% and 14% at 7 and 14 days (Table 5). A decrease in compressive strength by 7–10% and 10–13% is noticeable in mixes with cement contents of 400 and 450 kg/m^3, respectively. On the contrary, a substantial decrease in compressive strength by 5–7% and 25–35%, respectively, is apparent at 28 and 90 days. The compressive strength decreased by 9–14% for concrete mixes mixed by fresh water and cured in seawater at different curing ages (Table 4). In conclusion, mixing and curing concrete in seawater increases the early compressive strength, but the seawater has a negative effect on the compressive strength of concrete at ages over 28 days.

Table 1. Concrete mix proportions.

Concrete mix	Mixing water	Curing water	Coarse aggregate	Cement (kg/m^3)	Cement type	Sand (kg/m^3)	C.A. (kg/m^3)
A	Fresh	Fresh	Gravel	350	OPC	415	1440
B	Fresh	Fresh	Gravel	400	OPC	405	1400
C	Fresh	Fresh	Gravel	450	OPC	405	1400
D	Fresh	Fresh	Dolomite	350	OPC	430	1450
E	Fresh	Fresh	Dolomite	400	OPC	415	1420
F	Fresh	Fresh	Dolomite	450	OPC	405	1420
G	Sea	Sea	Gravel	350	OPC	430	1450
H	Sea	Sea	Gravel	400	OPC	410	1400
I	Sea	Sea	Gravel	450	OPC	405	1420
J	Sea	Sea	Dolomite	350	OPC	435	1470
K	Sea	Sea	Dolomite	400	OPC	420	1415
L	Sea	Sea	Dolomite	450	OPC	405	1420
M	Fresh	Sea	Gravel	350	OPC	415	1440
N	Fresh	Sea	Dolomite	350	OPC	430	1450
O	Fresh	Sea	Gravel	350	SRC	415	1450
P	Fresh	Sea	Dolomite	350	SRC	430	1440

w/c: 0.40 slump: 50–70 mm.

Table 2. Average test results for concrete strength.

Concrete mix	f_c (kg/cm^2)				f_t (kg/cm^2)		f_f (kg/cm^2)		f_b (kg/cm^2)	
	f_{c7}	f_{c14}	f_{c28}	f_{c90}	f_{t28}	f_{t90}	f_{f28}	f_{f90}	f_{b28}	f_{b90}
A	266	320	356	392	21.8	23.2	51.5	60.3	54.6	57.9
B	295	360	399	420	23.5	24.3	54.0	62.2	61.2	65.3
C	320	390	430	445	23.8	25.4	65.2	63.1	62.7	66.2
D	288	370	409	442	37.3	37.8	61.3	65.5	65.6	68.5
E	375	440	475	510	38.7	40.1	67.3	72.3	86.0	88.4
F	402	470	498	535	40.2	41.7	68.9	74.0	87.2	89.9
G	294	331	340	250	17.4	18.2	47.2	47.8	58.2	48.3
H	330	364	375	295	21.2	14.8	49.0	44.6	55.9	50.2
I	361	395	399	332	22.2	16.7	50.7	43.2	57.2	52.4
J	347	385	402	365	32.0	30.1	57.8	56.2	61.5	53.6
K	349	396	415	384	34.5	20.8	58.3	58.4	62.3	53.9
L	362	411	437	402	35.7	21.3	59.5	60.7	63.7	55.2
M	270	315	342	300	21.0	16.1	41.6	32.7	50.5	42.2
N	300	370	400	450	32.1	27.0	57.6	53.8	60.5	70.4
O	370	410	430	395	23.1	17.5	45.8	41.1	56.5	44.2
P	390	440	460	410	35.3	30.3	64.3	54.8	66.5	77.4

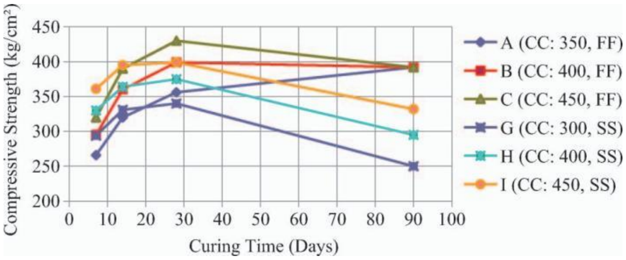

Figure 1. Effect of mixing/curing concrete in seawater on compressive strength of different cement contents; coarseaggregate: gravel.

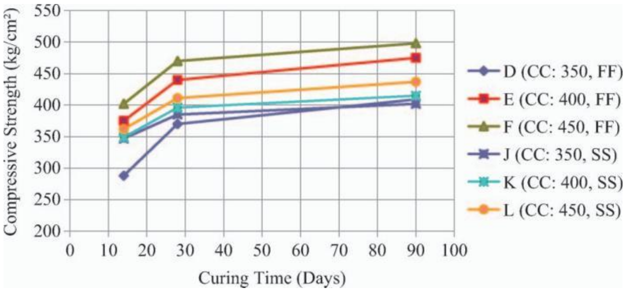

Figure 2. Effect of mixing/curing concrete in seawater on compressive strength for different cement contents; coarse aggregate: dolomite.

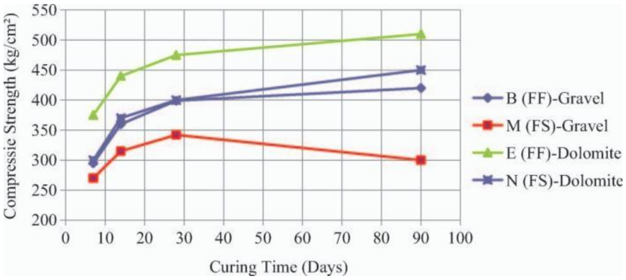

Figure 3. Effect of curing in seawater for different types of aggregates.

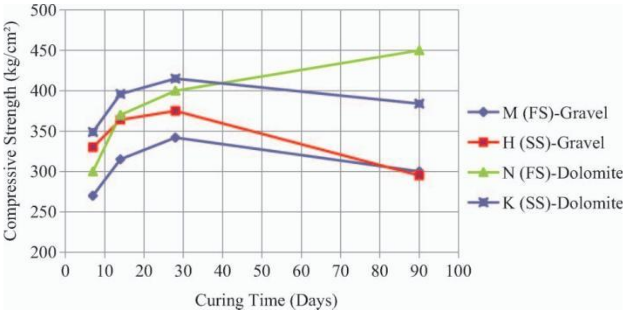

Figure 4. Effect of mixing with fresh water and curing in seawater on compressive strength for different types of aggregates.

3.2 Cement content

Figures 5 and 6 show a noticeable increase in the compressive strength of concrete when the cement content is increased from 350 kg/m^3 to 450 kg/m^3 and when gravel or dolomite is used as the coarse aggregate. The average compressive strengths at 28 days, compared with the corresponding ones at 7, 14 and 90 days, range between 70% to 91%, 90% to 99% and 73% to 110%, respectively, for all mixes as shown in Table 3. The average percentage increase in the compressive strength due to using a cement content of 400 kg/m^3 rather than 350 kg/m^3 and of 450 kg/m^3 rather than 400 kg/m^3 were 6% to 11% for different ages for concrete mixed and cured in fresh water (Table 6). By using seawater in the mixing and curing of concrete, the percentage increase in compressive strengths at different ages were 6% to 15%. It can be concluded that an increase in cement content leads to a concrete with a higher resistance to the attack of seawater and chemical solutions and salts because a exposed to salts in the seawater, a better workability to the mix, and an enhancement of the bond strength among concrete components. The strength loss will be retarded. Therefore, it may be concluded that resistance against all possible forms of deterioration is distinctly improved by using higher cement contents.

3.3 Type of cement

Cubes of concrete mixes (M, N, O and P) were tested for compression, and the average ultimate compressive strengths were determined in order to study the effect of the type of cement on compressive strength. The obtained values of average compressive strengths are given in Tables 2 and 7 and Figure 7 for concrete ages of 7, 14, 28 and 90 days. The average compressive strengths at 7, 14 and 90 days with respect to the corresponding ones at 28 days are from 75% to 110% due to the change in the type of cement (Table 3). The average compressive strengths of sulphate-resisting concrete increased from 5% to 27% regardless of the higher cement content means more cement matrix curing conditions as shown in Table 7. The increase of the compressive strength of concrete due to the use of SRC instead of OPC may be attributed the low percentage of tricalcium aluminates in the SRC (about 3%), so that the effect of attack of the chemical solutions in seawater was relatively limited.

3.4 Types of aggregate

Table 5 and Figures 4 and 5 shows the increase in the compressive strength of concrete due to the use of dolomite instead of gravel in the concrete for all concrete mixes which were mixed and/or cured by fresh water and/or seawater. The results show that the percentage increase in the compressive strength at different ages range from 8 to 14% for a cement content of 350 kg/m^3, from 16 to 21% for 400 kg/m^3 and from 14 to 20% for 450 kg/m^3 for concrete mixes mixed and cured in fresh water. However, for concrete mixes mixed and cured in seawater, the percentage increase of the compressive strengths range from 14 to 31% in cement content mixes of 350 kg/m^3, from 5 to 23% at 400 kg/m^3 and from 4 to 17% for 450 kg/m^3. The results suggest that aggregates should have a good grading and must be resistant against strong chloride solutions and alkali aggregate reactions since deleterious aggregates can react to the penetrating salt ions if the paste does not provide protection against the diffusion of chlorides and the alkali aggregate reaction.

3. 5 Split tensile strength

Cylinder specimens were tested for split tension, and the average ultimate split tensile strength was deter- mined from the failure tensile load. The obtained values of average split tensile strengths are given in Table 2 for all concrete mixes at concrete ages of 28 and 90 days. The percentage values of the split tensile strengths at 90 days with respect to the corresponding ones at 28 days are given in Table 3 for all concrete mixes. The average percentage values of the split tensile strength of concrete mixed and cured in seawater after 90 days range from 60 to 105% of the corresponding ones after 28 days from casting and between 101 to 107% for concrete mixes mixed and cured in fresh water. The decreased percentage values of the split tensile strength for concrete mixed and cured by seawater with respect to the corresponding ones mixed and cured by fresh water are presented in Table 4. It can be seen that the percentage values of the split tensile strengths increased by an average of 10– 49% for all the mixes; and these values were 7–26% and 22–49% after 28 days and 90 days, respectively.

The percentage increase/decrease in the split tensile strengths due to increasing cement contents and by changing the type of aggregate and type of cement are shown in Tables 5, 6 and 7. By increasing the cement content for both seawater concrete and fresh water mixes, the split tensile strength increased by 2–18% after 28 days and by 4–23% after 90 days, respectively, while the percentage increase in split tensile strength increased by 2–7% and 4–5% after 28 and 90 days, respectively, for mixes mixed and cured in seawater (Table 6). Also, using dolomite in the concrete rather than gravel increases the split tensile strength by 38– 46% and 22–40% after 28 and 90 days, respectively, for concrete mixed and cured by fresh water as well as seawater as shown in Table 5. The type of cement has a limited effect on tensile strength as the increase of tensile strength ranges from 8–11% when using SRC instead of OPC as shown in Table 7.

3.6 Flexural tensile strength

Flexural tensile strength tests were conducted on beams under two-point loading, and the average ultimate flexural tensile stress was determined from the failure flexural load. The obtained values of average flexural tensile strengths are given in Table 2 for concrete ages of 28 and 90 days. The percentage values of the flexural tensile strength at 90 days with respect to the corresponding ones at 28 days are given in Table 3 for all mixes. It can be seen that the average percentage values of the flexural tensile strength after 90 days decreased from 74 to 91% of the corresponding ones at 28 days for some mixes and increased by 101–121% for mixes G and K. Further- more, the percentage increase in the flexural strength after 90 days with respect to the strength after 90 days ranges between 107 and 117% for concrete mixes mixed and cured in fresh water. The decreased percentage values of the flexural tensile strength for concrete mixed and cured in seawater with respect to the corresponding ones mixed and cured in fresh water are presented in Tables 4, 5, 6 and 7 for different concrete ages, cement contents and types, and cement and aggregate. The percentage values of flexural strengths decreased by 6–28% and 18–47% after 28 and 90 days, respectively for all the mixes. The percentage increases in the flexural tensile strengths due to using cement with contents of 400 kg/m^3 and 450 kg/m^3 with respect to the corresponding ones with 350 kg/m^3 are shown in Tables 5 and 6, respectively. The increase of the cement content leads to increase the flexural tensile strength by 4–5% after 28 days and 2– 3% after 90 days for mixes mixed and cured in fresh water. It increased by 4% after 28 days and decreased by 4–7% after 90 days for mixes mixed and cured in seawater. In general, using dolomite in the concrete rather than gravel increases the flexural strength by 15–20% after 28 days and by 8–29% after 90 days (Table 5).

3.7 Pull-out bond strength

Cube specimens were pulled-out from their embedded bar and the average ultimate pull-out bond strength was determined from the failure pull-out bond load. The obtained values of average bond strengths are shown in Table 2 for all mixes and concrete ages of 28 and 90 days. The percentage values of the bond strength at 90 days with respect to the corresponding ones at 28 days are given in Table 3 for all concrete mixes. The average percentage values of the bond strength after 90 days mixed and cured in seawater 83– 92% of the corresponding ones after 28 days from casting. For mixes mixed and cured in fresh water, the percentage values for bond strength were 103–107%. The percentage increase/decrease values of the bond strength for concrete mixed and cured in seawater withrespect to the corresponding ones mixed and cured by fresh water are given in Table 4. The percentage values of the bond strength decreased by 6% for concretemixes A and G and increased by 9–30% and 17–39% after 28 and 90 days, respectively for all other mixes. The percentage increases in bond strengths due to the increase of cement content and changing the cement type and aggregate are given in Tables 5, 6 and 7, respectively. The bond strength increased by 3–11% after 28 days and by 2–11% and 4% after 90 days for mixes cured in fresh and seawater, respectively with the use of dolomite rather than gravel for concrete mixed and cured in fresh water as well as sea water (Table 5). The percentage increases in bond strength are 9–11% and 5–9% after 28 and 90 days due to the use of SRC instead of OPC in the mixes as shown in Table 7.

Table 3. Aged concrete strengths percentage with respect to 28 days strength

Concrete mix	f_{c7}/f_{c28}, %	f_{c14}/f_{c28}, %	f_{c90}/f_{c28}, %	f_{t90}/f_{t28}, %	f_{f90}/f_{f28}, %	f_{b90}/f_{b28}, %
A	75	90	110	107	117	106
B	74	90	105	103	115	107
C	74	91	104	107	112	106
D	70	91	108	101	107	104
E	79	93	107	104	107	103
F	81	94	107	104	107	103
G	86	97	73	105	101	83
H	88	97	79	70	91	90
I	91	99	83	75	85	92
J	86	96	91	61	74	87
K	84	95	93	60	121	87
L	83	94	92	60	122	87
M	79	92	88	77	79	84
N	75	93	112	84	93	116
O	88	97	82	67	90	78
P	85	96	86	86	85	116

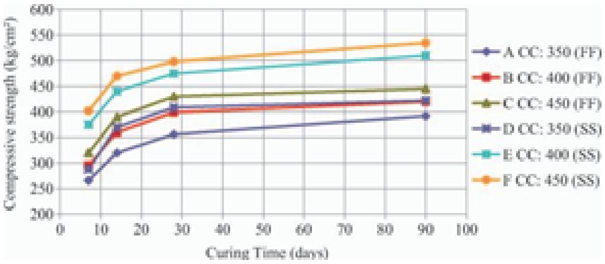

Figure 5. Effect of changing cement content and type of aggregate on compressive strength for concrete mixed and cured in fresh water.

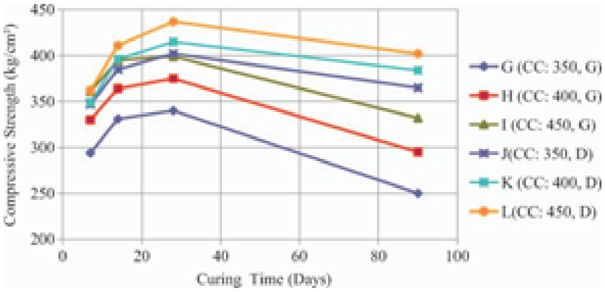

Figure 6. Effect of changing cement content and type of aggregate on compressive strength for concrete mixed and cured in seawater.

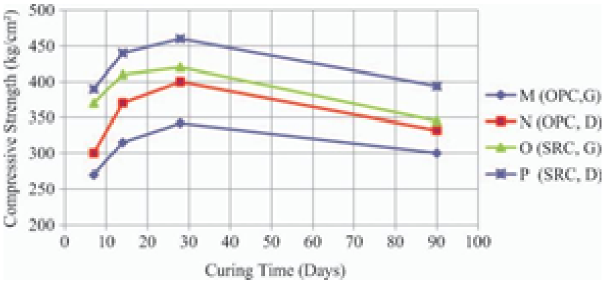

Figure 7. Effect of type of cement content on compressive strength; 400 kg/m³ for different types of gravel.

Table 4. Effect of curing conditions on concrete strengths.

				Percentage increase									
				f_c				f_t		f_f		f_b	
Conc. mix	Curing condition	Cement content	Aggregate	7	14	28	90	28	90	28	90	28	90
A,G	ff,ss	350	Gravel	710	74	5	35	20	22	8	35	76	17
B,H	ff,ss	400	Gravel	73	71	6	30	10	39	9	28	9	23
C,I	ff,ss	450	Gravel	711	72	7	25	7	34	10	32	9	21
B,M	ff,fs	400	Gravel	79	13	714	711	11	34	23	47	18	35
D,J	ff,ss	350	Dolomite	715	74	2	17	14	48	6	35	6	22
E,K	ff,ss	400	Dolomite	7	10	13	25	11	48	28	19	28	39
F,L	ff,ss	450	Dolomite	10	13	12	25	26	49	28	18	23	39
E,N	ff,fs	400	Dolomite	20	716	16	23	17	33	14	26	30	20

(7) indicates increase of strength for mixes mixed and cured in seawater.

Table 5. Effect of aggregate type on concrete strengths.

				Percentage increase									
				f_c				f_t		f_f		f_b	
Conc. mix	Mixing	Curing	Cement content	7	14	28	90	28	90	28	90	28	90
A,D	f	f	350	8	14	13	11	41	39	16	8	18	15
B,E	f	f	400	21	18	16	18	39	39	20	13	9	25
C,F	f	f	450	20	17	14	17	41	39	18	15	28	25
G,J	s	s	350	15	14	15	31	46	40	18	15	6	26
H,K	s	s	400	5	8	10	23	39	29	16	12	10	7
I,L	s	s	450	4	4	9	17	38	22	15	29	11	5

Table 6. Effect of cement content on concrete strengths.

				Percentage increase									
				f_c				f_f		f_f		f_b	
Conc. mix	Mixing	Curing	Cement content	7	14	28	90	28	90	28	90	28	90
A/B	F	F	350/400	10	11	11	7	7	5	5	3	11	11
B/C	F	F	400/450	8	8	7	6	2	4	4	2	3	2
G/H	S	S	350/400	11	9	10	15	18	23	4	77	74	4
H/I	S	S	400/450	9	8	6	11	5	11	4	74	2	4

(7) indicates decrease in strength.

Table 7. Effect of cement type on concrete strengths.

			Percentage increase									
			f_c				f_t		f_f		f_b	
Conc. mix	Cement content	Aggregate type	7	14	28	90	28	90	28	90	28	90
M,O	400	Gravel	27	24	20	9	9	8	9	24	11	5
N,P	400	Dolomite	23	16	13	5	9	11	10	2	9	9

CONCLUSION

Based on this study, the following conclusions may be drawn:

(1) Concretes mixed and cured in seawater have higher compressive, tensile, flexural and bond strengths than concretes mixed and cured infresh water in the early ages at 7 and 14 days. The strengths after 28 and 90 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. The use of SRCs may help resist damage of concrete exposed to seawater.

The increase of cement content and the use of SRC in concrete improve the resistance of concrete for deterioration against seawater and salty solutions.

(4) Care should be taken in the manufacturing of concrete to produce impermeable dense con- crete in order to resist the attack of seawater.
(5) A meaningful test method is needed for evaluating the effect of seawater under contin- uous and alternating exposures.

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