Interdependence between Structural Engineering and Construction Management
Edited by Ozevin, D., Ataei, H., Modares, M., Gurgun, A., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-6-2

STRENGTH, SHRINKAGE, AND PERMEABILITY PERFORMANCE OF SEAWATER CONCRETE

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Given the increasing global concern of freshwater scarcity, the use of seawater in concrete mixtures appears to be a way forward towards achieving sustainable concrete, especially in the case of non-reinforced concrete applications or with the use of non-corrosive reinforcement. This paper reports on the results of an experimental study to compare the freshwater- and seawater-mixed concretes in terms of their strength, shrinkage and permeability performance. The experimental program included the following: (i) compressive strength test (at 3, 7, 28, and 56-day ages); (ii) concrete shrinkage test (at Days 4, 7, 14, 21, 28, and 56 following mixing); and (iii) permeability tests (rapid chloride permeability and water absorption at Days 28 and 56 following mixing). As for the study results, seawater concrete showed a slightly higher early-age (i.e., till Day 7) strength performance than that of freshwater-mixed counterpart, followed by a strength performance that is 7–10% inferior to the freshwater concrete after 28 days or later. Also, the shrinkage of seawater concrete was slightly higher than that of freshwater concrete, with a difference of 5% reported after 56 days following mixing. Finally, the permeability performance of hardened concrete in seawater and freshwater mixtures was similar.

Keywords: Sustainability, Seawater-mixed concrete, Compressive strength, Shrinkage test, Rapid chloride permeability, Water absorption.

1 INTRODUCTION

Concrete is the most commonly-used construction material worldwide, typically produced by mixing freshwater, cement, aggregates, and admixtures. The environmental impact of concrete production from its raw ingredients is deemed significant (Miller *et al.* 2016). Consequently, there has been a recent growing interest in other sources of raw materials to reduce energy consumption and save natural resources; i.e., to achieve a more ‘‘green’’ concrete (Rahal 2007; Saeed *et al.* 2012; Younis *et al.* 2018b). In this context, seawater has increasingly emerged among researchers as an alternative mixing water for concrete, bearing in mind the increasing global concern of freshwater scarcity (Mekonnen and Hoekstra 2016) as well as the development of non-corrosive reinforcement such as fiber-reinforced polymer (FRP) to counter possible corrosion (Aly *et al.* 2006, Benmokrane *et al.* 2006). Therefore, combining seawater and FRP reinforcement in structural concrete appears to be plausible from both technical (Younis *et al.* 2017) and economic (Younis *et al.* 2018a) perspectives.

Significant research efforts were devoted in the past few decades to comprehend the effect of seawater mixing on the resulted concrete, evidently from the recent literature surveys of Nishida *et al.* (2013) and Xiao *et al.* (2017) in this regard. As for the strength performance, most studies suggest that the use of seawater results in a slight negative effect on the long-term concrete strength (i.e., 28 days or later) (Kaushik and Islam 1995; Wegian 2010). In contrast, some studies showed a strength increase not only at early ages but also in the long term (Griffin and Henry 1964, Shi *et al.* 2015); this imposes the need for further research in this regard. Moreover, the majority of previous studies were focused on the basic physical and mechanical characteristics of concrete such as workability, setting time, compressive and tensile strength, etc. Studies on the shrinkage or permeability performance of seawater-mixed concrete are scarce (Modupeola and Olutoge 2014, Park *et al.* 2011) and therefore, these topics remain relatively poorly understood. In view of that, the current paper establishes a comparison between freshwater- and seawater-mixed concretes in terms of their strength, shrinkage and permeability characteristics. At first, materials and test methods adopted in this study will be explained. After that, test results will be presented and discussed, from which the conclusions of this comparison will be drawn.

2 EXPERIMENTAL PROGRAM

2.1 Materials

Two concrete mixtures were considered: (i) the conventional freshwater-mixed concrete which is regarded as a reference; and (ii) seawater-mixed concrete. The difference between the two mixtures was only in the mixing water. Seawater was delivered from Al-Khor coastal area in Qatar to the concrete plant, and then fabric-filtered and used for concrete mixing. Chemical characteristics were obtained for both types of mixing water as shown in Table 1. The pH and alkalinity measurements were within the acceptable limits for both water types. The sulfates, chlorides, and dissolved solids in seawater were (as expected) significantly higher than those of the freshwater or even the allowable limits.

Table 1. Chemical characterization of the two mixing waters.

Measure (unit)	Method	Max. limit	Freshwater results	Seawater results
Chloride (mg/L)	BS 1377-3	1000	14.1	18600
Sulfate (mg/L)	BS 1377-3	2000	20.9	2359
Alkalinity (mg/L)	BS 6068-2.51	500	69.5	149
Total dissolved solids (mg/L)	BS 1377-2	2000	62.0	30300
pH at 25 ºC (-)	BS 6068-2.5	6.5–9.0	8.1	8.2

Ready-mix concrete with a 28-day 60-MPa design compressive strength was considered. The mixture proportions per cubic meter of concrete as per BS EN 206 (2013) were 1144 kg of gravel, 756 kg of sand, 158 kg of ordinary Portland cement, 292 kg of blast furnace slag, and 164 kg of water; for which the water-to-cementitious material (w/cm) ratio was 0.34. Blast furnace slag was considered at 65% replacement level as a supplementary cementitious material, being generally observed to enhance the performance of seawater concrete (Nishida *et al.* 2013, Xiao *et al.* 2017). A commercial superplasticizer was added at a dosage of 3.8 kg/m^3 to both concrete mixtures.

2.2 Test Methods

The compressive strength test was performed on concrete cylinders (of 150 mm in diameter and 300 mm in height) in accordance with ASTM C39/C39M (2016). Samples were tested to investigate the effect of two variables: (a) mixing water (seawater/freshwater); (b) testing age (3, 7, 28, and 56 days). Three specimens were considered for each test point.

Concrete shrinkage was measured for both concrete mixtures as per ASTM C157/C157M (2014). For each mixture, three concrete prisms ($100 \times 100 \times 500\ mm$) were cast and then, after one day, immersed in water for 30 minutes. The initial length measurements were taken, and then specimens were kept in a room with air-drying conditions (i.e., temperature of 25 ± 1℃ and humidity less than or equal 50%). The concrete shrinkage measurements were obtained at days 4, 7, 14, 21, 28, and 56 following mixing. For each measurement, the length difference (ΔL) was determined between a reference bar and the concrete prism. The concrete shrinkage at time t, S_t, can be calculated as the change in ΔL_t with respect to that initially measured (ΔL_0) divided by the gauge length ($G = 25.4\ mm$) as shown in Eq. (1):

$$S_t\ (\%) = \frac{\Delta L_t - \Delta L_0}{G} x100 \quad (1)$$

Rapid chloride permeability (RCP) test was performed according to ASTM C1202-71a (2017) as shown in Figure 1. In this test, the concrete specimen (100-mm diameter and 50-mm deep cylinder) was kept under a potential difference of 60 V for six hours between its two ends; the first end was immersed in an NaCl solution and the second in an NaOH solution. During the immersion period, the total amount of electrical current passing through the specimen was measured in Coulombs, which indicates the resistance of the specimen to the chloride penetration and thus the concrete quality.

Figure 1. Rapid chloride permeability test.

Water absorption (WA) test was performed according to BS 1881-122 (2011). Three cylindrical cores (75 mm in diameter and 47 mm in depth) were obtained from the top, middle, and bottom of a 150 mm concrete cube. After that, the samples were dried by a 110 ºC oven for three days and then cooled for one day using a dry airtight vessel. The initial weight (W_1) of each sample was first measured. After that the sample was immersed in water for 30 minutes, then surface-dried and weighed again (W_2). The water absorption can be calculated in Eq. (2):

$$WA\ (\%) = \frac{W_2 - W_1}{W_1} \times 100 \quad (2)$$

3 RESULTS AND DISCUSSION

3.1 Strength

Figures 2 depicts the compressive strength test results. As shown in the figure, the use of seawater led to a slight increase (around 5%) in the concrete compressive strength at the early stage (up to Day 7). However, after 28 days or longer following mixing, the compressive strength of seawater concrete was 7-10% lower than that of freshwater concrete. These results are consistent with previous research (Kaushik and Islam 1995, Nishida *et al.* 2013, Wegian 2010, Xiao *et al.* 2017). The higher early strength of seawater concrete can be attributed to the lower porosity as a result of hydration acceleration, while the lower long-term strength could be attributed to the leaching of hydration products as suggested by Kaushik and Islam (1995).

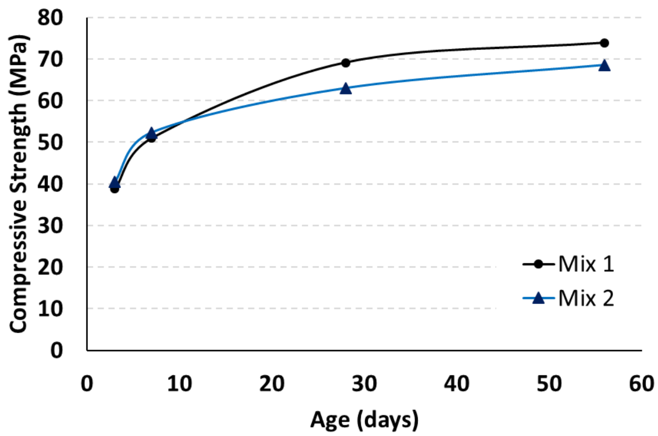

Figure 2. Compressive strength test results (standard deviations are 0.40 MPa for 3-day, 0.95 MPa for 7-day, 1.17 MPa for 28-day, and 1.47 MPa for 56-day measures on average).

3.2 Shrinkage

Figure 3 shows the concrete shrinkage (%) as a function of time for both concrete mixtures. Each test point is the average of three measurements.

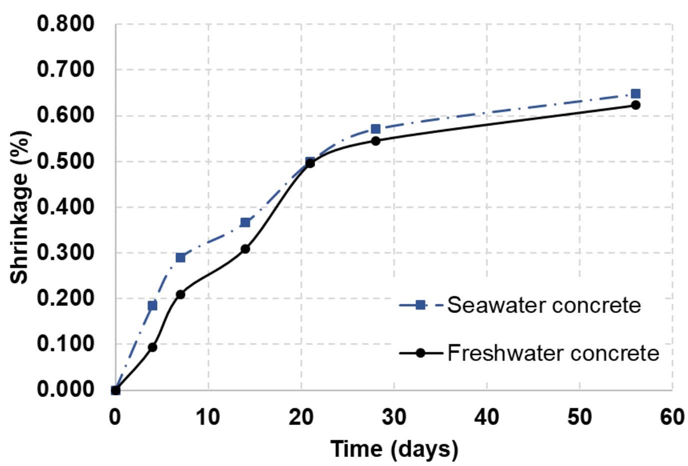

Figure 3. Shrinkage test results (standard deviations are 0.038% for 3-day, 0.076% for 7-day, 0.065% for 14-day, 0.076% for 21-day, 0.096% for 28-day, and 0.092% for 56-day measures on average).

As shown in the figure, the concrete shrinkage exhibited a rapid increase until Day 21 following mixing, after which both curves showed a gentle increase. At Day 56, seawater-mixed concrete showed a slightly higher drying shrinkage (within 5%) than that of the conventional mix. The observed influence of seawater on the drying shrinkage can be related to the presence of chloride in the pore solution, or to the formation of a finer pore structure in seawater concrete (Park *et al.* 2011, Shi *et al.* 2015).

3.3 Permeability

Table 2 presents the results of rapid chloride permeability (RCP) and water absorption (WA) tests. Each concrete mixture was tested at two different periods after mixing, namely, 28 and 56 days. Each test result is the average of two samples. It can be realized that the measurements of RCP and WA at Day 56 are lower than those of Day 28. This can be attributed to the enhancement of concrete due to the ongoing hydration. Besides, the RCA and WA measurements obtained for both mixtures are comparable, which indicates that using seawater had almost no effect on the permeability performance of hardened concrete.

Table 2. Permeability performance test results.

Specimen	**RCP**		**WA (%)**
	Charge passed (coulombs)	Permeability class (as per the standard)	
Freshwater concrete (Day 28)	407	Very low	1.79
Freshwater concrete (Day 56)	369	Very low	1.58
Seawater concrete (Day 28)	439	Very low	1.69
Seawater concrete (Day 56)	349	Very low	1.56

4 CONCLUSIONS

This paper aimed at establishing a comparison between seawater and freshwater concretes in terms of strength, shrinkage, and permeability characteristics. Based on the study results, the following conclusions have been drawn:

- Using seawater resulted in an early slight increase in the compressive strength of hardened concrete (till Day 7), followed by a decrease of around 7–10% as compared to that of freshwater concrete after 28 days or later.
- The shrinkage of hardened concrete in case of seawater mixing was slightly higher than that of the conventional freshwater concrete (about 5% difference as of Day 56 following mixing was observed).
- Using seawater in concrete mixtures showed almost no effect on the permeability and/or resistance to chloride ingression of hardened concrete. Results of RCP and WA tests were almost the same for the two mixtures under comparison.

Acknowledgments

This paper was made possible by the NPRP grant # NPRP 9-110-2-052 from the Qatar National Research Fund (a member of Qatar Foundation). The findings achieved herein solely the responsibility of the authors. Special thanks are due to Readymix Qatar (as a part of LafargeHolcim) for providing the expertise that greatly assists the authors in their research.

References

Aly, R., Benmokrane, B., and Ebead, U. A., Tensile Lap Splicing of Bundled CFRP Reinforcing Bars in Concrete, *Journal of Composites for Construction*, 10(4), 287–294, 2006.

ASTM C1202-17a, *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*, ASTM International, West Conshohocken, PA, USA, 2017.

ASTM C157/C157M-08, *Standard Test Method for Length Change of Hardened Hydraulic-Cement*

Mortar and Concrete, ASTM International, West Conshohocken, PA, USA, 2014.
ASTM C39/C39M-16b, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*. ASTM International, West Conshohocken, PA, USA, 2016.
Benmokrane, B., Aly, R., and Ebead, U. A., Tensile Lap Splicing of FRP Reinforcing Bars in Concrete, *ACI Structural Journal*, ACI, 103(6), 857–864, 2006.
BS 1377-2, *Methods of Test for Soils for Civil Engineering Purposes. Classification Tests*. BSI, 1990.
BS 1377-3, *Methods of Test for Soils for Civil Engineering Purposes. Chemical and Electro-Chemical Tests*, BSI, 1990.
BS 1881-122, *Testing Concrete. Method for Determination of Water Absorption*, BSI, 2011.
BS 6068-2.50, *Water Quality. Physical, Chemical and Biochemical Methods. Determination of pH*, BSI, 1995.
BS 6068-2.51, *Water Quality. Determination of Alkalinity. Determination of Total and Composite Alkalinity*, BSI, 1996.
BS EN 206, *Concrete Specification, Performance, Production and Conformity*, BSI, 2013.
Griffin, D. F., and Henry, R. L., *The Effect of Salt in Concrete on Compressive Strength, Water Vapor Transmission, and Corrosion of Reinforcing Steel*, Port Hueneme, California, 1964.
Kaushik, S. K., and Islam, S., Suitability of Sea Water for Mixing Structural Concrete Exposed to a Marine Environment, *Cement and Concrete Composites*, 17(3), 177–185, 1995.
Mekonnen, M. M., and Hoekstra, A. Y., Four Billion People Facing Severe Water Scarcity, *Science Advances*, 2(2), e1500323, 2016.
Miller, S. A., Horvath, A., and Monteiro, P. J. M., Readily Implementable Techniques Can Cut Annual CO_2 Emissions from The Production of Concrete by Over 20%, *Environmental Research Letters*, IOP Publishing, 11(7), 74029, 2016.
Modupeola, A. G., and Olutoge, F. A., The effect of seawater on shrinkage properties of concrete, *International Journal of Research Engineering and Technology*, 2(10), 1–12, 2014.
Nishida, T., Otsuki, N., Ohara, H., Garba-Say, Z. M., and Nagata, T., Some Considerations for Applicability of Seawater as Mixing Water in Concrete, *Journal of Materials in Civil Engineering*, American Society of Civil Engineers, 27(7), B4014004, 2013.
Park, S. S., Kwon, S. J., and Song, H. W., Analysis Technique for Restrained Shrinkage of Concrete Containing Chlorides, *Materials and Structures*, 44(2), 475–486, 2011.
Rahal, K., Mechanical Properties of Concrete with Recycled Coarse Aggregate, *Building and Environment*, 42(1), 407–415, 2007.
Saeed, H. A., Tagnit-Hamou, A., Ebead, U. A., and Neale, K. W., Stoichiometric Study of Activated Glass Powder Hydration, *Advances in Cement Research*, 24(2), 91–101, 2012.
Shi, Z., Shui, Z., Li, Q., and Geng, H., Combined Effect of Metakaolin and Sea Water on Performance and Microstructures of Concrete, *Construction and Building Materials*, 74, 57–64., 2015.
Wegian, F. M., Effect of Seawater for Mixing and Curing on Structural Concrete, *The IES Journal Part A: Civil and Structural Engineering*, Taylor and Francis, 3(4), 235–243, 2010.
Xiao, J., Qiang, C., Nanni, A., and Zhang, K., Use of Sea-Sand and Seawater in Concrete Construction: Current Status and Future Opportunities, *Construction and Building Materials*, Elsevier Ltd, 155, 1101–1111, 2017.
Younis, A., Ebead, U. A., and Nanni, A., *A Perspective on Seawater/FRP Reinforcement in Concrete Structures*, Proceedings of the Ninth International Structural Engineering and Construction Conference, Resilient Structures and Sustainable Construction, ISEC Press, Valencia, Spain, St-38, 2017.
Younis, A., Ebead, U., and Judd, S., Life Cycle Cost Analysis of Structural Concrete Using Seawater, Recycled Concrete Aggregate, and GFRP Reinforcement, *Construction and Building Materials*, 175, 152–160, 2018a.
Younis, A., Ebead, U., Suraneni, P., and Nanni, A., Fresh and Hardened Properties of Seawater-Mixed Concrete, *Construction and Building Materials*, 190(C), 276–286, 2018b.