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Effect of Hydrophobic Water Repellent Admixture on the Compressive Strength of Concrete in Highly Aggressive Water (Dead Sea Water as a Case Study)

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A B S T R A C T

The compressive strength of concrete may be affected by seepage of salt water. Dead Sea water is a hazardous environment for concrete due to high concentration of salts. The aim of this study was to investigate the effect of Dead Sea water on the compressive strength of concrete containing hydrophobic water-repellent admixture, and to determine the optimum dosage of admixture to be used to reduce this effect. Three types of cement were used (Ordinary Portland Cement, Pozzolanic Cement, and Sulphate-Resisting Cement) with various dose rate of hydrophobic water repellent admixture (0%, 2%, and 4% of cement weight). An experimental approach, in which the specimens were divided based on the type of cement and the specimen's age, was adopted. Nine control cubic specimens were cured in plain water to ensure that the required compressive strength was reached and (54) specimens were cured in Dead Sea water. The specimens cured in Dead Sea water were tested at 7 and 28 days to investigate the effect of Dead Sea water on the early and long-term strength. The results showed that a reduction in the 28-day compressive strength occurred in all specimens for the three types of cement used, but with the addition of water repellent, this reduction was alleviated, and the optimum percentage of admixture was 2% of cement weight.

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Introduction

The most important characteristic of concrete is the 28-day compressive strength. Because concrete cannot be made completely waterproof, permeability is one of the factors affecting concrete durability and strength [1]. Permeability becomes critical when concrete is exposed to an aggressive environment where chlorides, sulphates or other deicing substances can penetrate concrete. Dead Sea water is a highly aggressive environment for concrete due to high salinity (280 g/kg) which is nearly 8 times the salinity of all oceans [2]. **Table 1** shows a comparison between the ionic concetration in the Dead Sea water and in the average seawater [3] and [4]. It can be seen that the Dead Sea water is, mainly, composed of chlorides with substential content of magnesium, sodium and unsual quantity of bromine. Unlike the other seas the major component of the Dead Sea water is the Magnesium Chloride 190.2 g/L followed by Sodium Chloride 91.8 g/L and Calcium Chloride 52.4 g/L [2].

Many studies have been made to investigate the effect of using seasand or seawater on the properties of concrete [5] to [7]. A valuable review on the the subject can be found in [5]. Many research has been, also, made to study the effect of seawater on concrete properties [8] to [10]. A comprehensive study on the subjet has been made in [10]. In their paper Islam et al. [8] studied the effect of sea salts on the mechanical properties of concrete in a tidal environment.

Table 1. Ionic concentration in Dead Sea water and in other seawaters

Ione	Symbol	Dead Sea water g/L	Average seawater g/L
Chloride	Cl^{-}	225	19.8
Bromide	Br^{-}	5.6	0.07
Salfate	SO^{2-}	0.5	2.76
Sodium	Na^{+}	36.5	11
Magnesium	Mg^{2+}	46	1.33
Calcium	Ca^{2+}	17	0.43
Potassium	K^{+}	7.8	0.4

A few research has been made to study the effect of Dead Sea water on concrete properties. In their study Al-Rifaie et al. [11]. studeied the effect of Dead Sea water on the mechanical properties of ferrocement. The results showed that there was a sharp decrease in the compressive strength of ferrocement specimens as longer they remained in Dead Sea water. In the study by Heller and Ben-Yair [12]. it was studied the chemical effect of Dead Sea water on pastes and mortars of normal and sulphate-resisting Portland cement. In the experimental work [13] it was studied the effect of Dead Sea water on some of the mechanical properties of hardend concrete such as durability, compressive strength, flexural strength, and bond strength.

The use of permeability reducing admixtures (PRAs) can improve the durability of concrete by reducing water movement and chloride ions penetration. There are various types of permeability reducing admixtures. Among these, there are the so called hydrophobic water repellent admixtures composed of long chain fatty acids or vegetable oils [14]. Many studies have been made to investigate the effect of using PRAs on properties of concrete. In their paper Munn et al. [15]. studied the effect of PRAs on durability related properties of concrete such as compressive strength, drying shrinkage, ..., etc.

Three types of blended cement were used with various PRAs dosage rate. They demonstrated that the addition of PRAs to concrete mixes increased the compressive strength with respect to control mixes. Kumar et al. [16]. Studied the effect of the water repellent admixture on the hydration of Portland cement. In presence of the PRA water percolation was reduced while the 28 days compressive strength and durability were increased due to cement paste pores blocking.

In this paper, the effect of curing concrete in Dead Sea water on the compressive strength of concrete was investigated using three types of cement and with hydrophobic water repellent admixture added at various dosage rate. Sixty-three cubic specimens were prepared and tested for compressive strength. The results showed that the Dead Sea water increased the compressive strength at early age due to the presence of large quantity of Calcium Chloride in the water, but the long-time exposure caused a substantial decrease in the compressive strength. The addition of hydrophobic water repellent at moderate dosage decreased the detrimental effects of Dead Sea water on concrete. It is well known that the presence of large quantity of chloride ions in concrete causes corrosion of reinforcing steel, but this is not a matter of concern in this paper. This paper is concerned with the investigation of the effect of Dead Sea water on plain concrete containing water repellent which can be used to produce heavy concrete blocks exposed to Dead Sea water.

EXPERIMENTAL PROGRAM

The concrete mixes were designed and prepared using fine aggregate, coarse aggregate and 3 types of cement: Ordinary Portland Cement (OPC), Pozzolana Portland Cement (PPC), Sulphate Resisting Cement (SRC). The quantity of cement in all mixes was 363.6 kg per cubic meter of concrete. **Table 2** shows the quantities and properties of fine and coarse aggregates used in mixes.

Table 2. Quantities and properties of aggregates in 1 m^3 mix.

	Quantity (kg)	Unit weight (kg/m^3)	Saturated surface dry bulk specific gravity	Absorption %	Fineness modulus
Fine aggregate	746.8	1682	2.4	1.51%	2.8
Coarse aggregate	957.8	1410	2.3	1.7%	-

Nine concrete mixes (3 for each cement type) were prepared using a water-to-cement ratio of 0.55 to attain 28-day cubic compressive strength of 30 MPa. Six of these mixes contained water repellent with various dosage rate (2% and 4% of cement weight). Three mixes did not contain water repellent and superplasticizers were not used in all mixes.

Sixty-three cubic specimens with dimensions (150*150*150) mm were casted. Nine control specimens (3 for each type of cement) with 0% water repellent were cured in plain water and tested after 28 days to ensure that the target compressive strength was reached **Fig.1**. Fifty-four specimens with different cement types and various water repellent percentages were cured in the Dead Sea water. For each type of cement, 9 specimens containing 0%, 2% and 4% of cement weight water repellent were tested for 7-days compressive strength. The remaining 27 specimens were tested for 28-days compressive strength **Fig.2**. All samples were cured in shallow water tanks to minimize the hydrostatic pressure on the specimens.

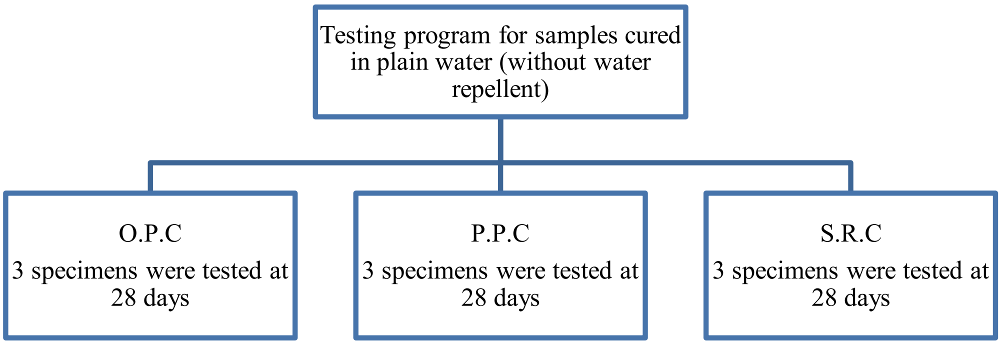


Figure 1: Testing program for concrete specimens cured in plain water.

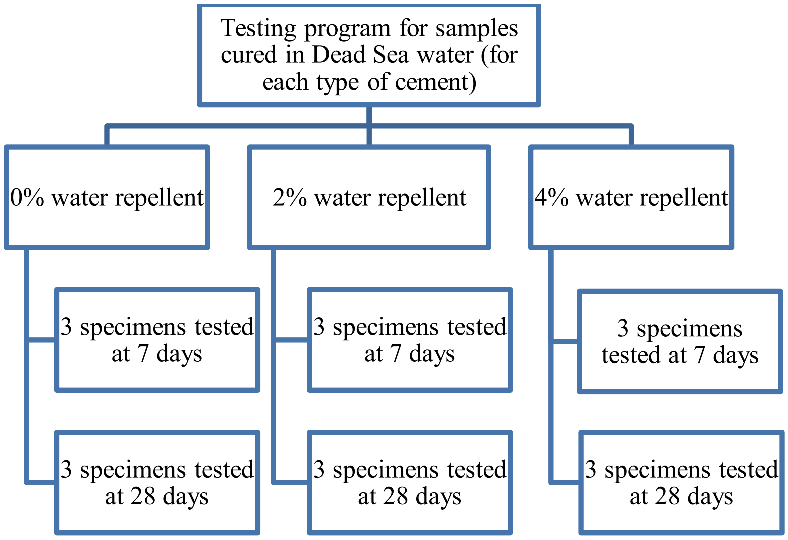


Figure 2: Testing program for concrete samples cured in Dead Sea water (for each type of cement).

RESULTS AND DISCUSSIN

To ensure that the target 28-day average compressive strength was achieved, the test results for specimens with 0% water repellent and cured in plain water were reported in **Table 3** as control specimens. From this Table, it can be seen that the target compressive strength was achieved for OPC and PPC specimens only, while for SRC specimens it was not achieved. This may be expected due to the large content of C_2S in this type of cement which has a long-term effect on concrete strength [17].

Table 3. The 28-day compressive strength (MPa) of concrete specimens cured in plain water, for different types of cement without water repellant (control specimens)

Water repellant (%)	28-day average compressive strength (MPa) Specimens cured in plain water		
	OPC	PPC	SRC

0%	31. 7	30.7	27.5

Table 4 shows the average compressive strength test results after 7 days and 28 days and their ratio, for specimens cured in Dead Sea water. From this Table it can be seen that, at early age, specimens with 0% water repellent have obtained a high compressive strength after 7 days with respect to 28-day compressive strength for all types of cement. This is in accordance with the results obtained in the experimental research [17].in which it was concluded that concrete specimens cured in seawater have a higher 7-day compressive strength than specimens cured in plain water.

Table 4. Average compressive strength after 7 and 28 days (MPa) and their ratio for specimens cured in Dead Sea water for different types of cement and various water repellant dosage rate

Water repellent %	Avearage compressive strength at 7 and 28 days (MPa) Specimens cured in Dead Sea water								
	OPC			**PPC**			**SRC**		
	7 days	**28 days**	**ratio**	**7 days**	**28 days**	**ratio**	**7 days**	**28 days**	**ratio**
0%	22.2	29.0	77%	21.9	26.5	83%	19.4	25.7	75%
2%	25.7	30.5	84%	20.8	25.3	82%	23.0	28.7	80%
4%	20.1	26.3	76%	19.6	25.0	78%	21.8	26.8	81%

For specimens with 2% water repellent an increase in the 7-day compressive strength was achieved for OPC (+16%) and SRC (+19%), while a decrease was achieved for PPC (-5%). It can also be seen that increasing the water repellent content to 4% caused the 7-day compressive strength to drop down with respect to that of samples with 2% water repellent. The sharpest drop down was in OPC specimens (-22%), while for PPC and SRC specimens the decrease was (-6%) and (-5%) respectively. These results are illustrated graphically, for the 7-day compressive strength, in **Fig. 3** which illustrates the variation of the 7-day compressive strength with the variation of the dosage rate of the water repellent for different types of cement.

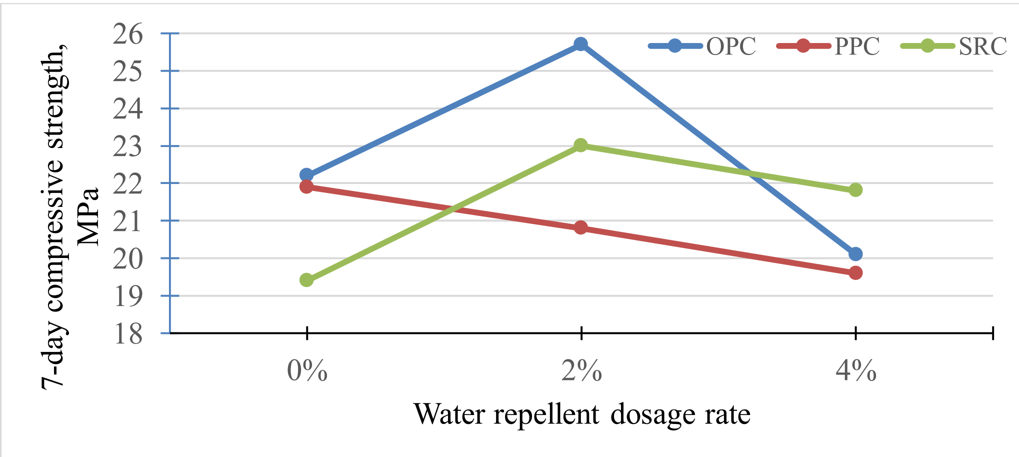


Figure 3 Variation of the 7-day compressive strength for specimens made of different types of cement cured in Dead Sea water with the variation of water repellent dosage rate .

Table 5 shows the results of the 28-day compressive strength for specimens with various percentages of water repellent cured in Dead Sea water. From this Table, it can be seen that there was a decrease in the compressive strength (with respect to plain water curing) for all types of cement when the specimens contained 0% water repellent because of saltwater. The largest decrease occurred for PPC specimens (-14%), while for OPC and SRC specimens the decrease was (-9%) and (-7%), respectively. These results can be visualized graphically in **Fig. 4** for the three types of cement.

Table 5. The 28-day average Compressive strength (MPa) of concrete specimens for different types of cement and various percentages of water repellant

Water repellant (%)	Specimens cured in plain water			Specimens cured in Dead Sea water		
	OPC	PPC	SRC	OPC	PPC	SRC
0%	31.7	30.7	27.5	29.0	26.5	25.7
2%	--	--	--	30.5	25.3	28.7
4%	--	--	--	26.3	25.0	26.8

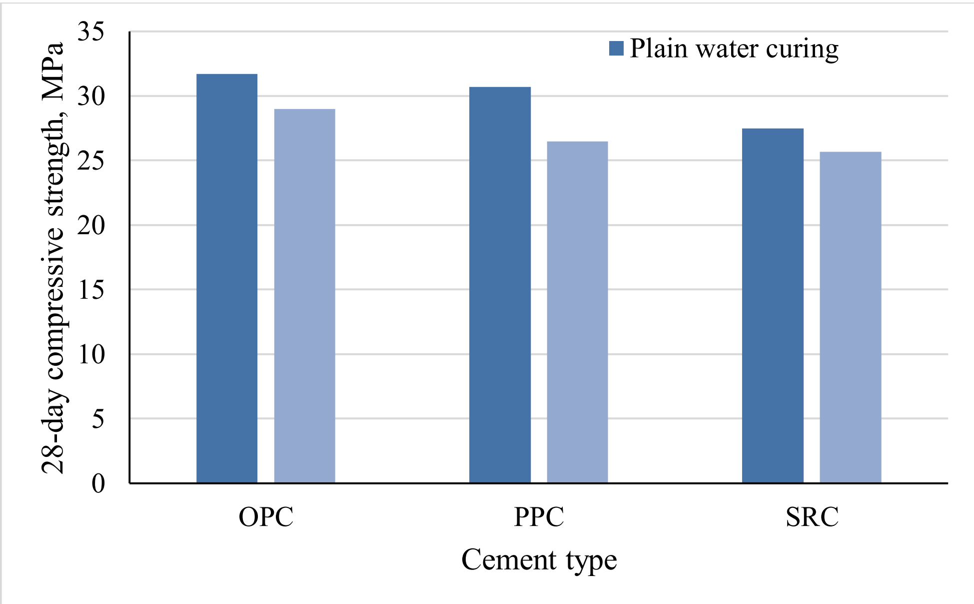


Figure 4: Comparison of the 28-day average compressive strength for specimens containing 0% water repellent cured in plain water and Dead Sea water.

An increase in the compressive strength was achieved for OPC specimens (+5%) and SRC specimens (+12%) by adding 2% water repellent to the mix, with respect to the specimens with 0% water repellent. For PPC specimens, it is interesting to note that the compressive strength was not greatly affected by the water repellent regardless of its percentage. The detrimental effect of increasing the quantity of water repellent can be seen in the third row of **Table 5** and **Fig. 5**.

In fact, by increasing the percentage of water repellent to 4% the compressive strength dropped down for OPC specimens by (-14%) and for SRC specimens by (-7%) with respect to the specimens with 2% water repellent.

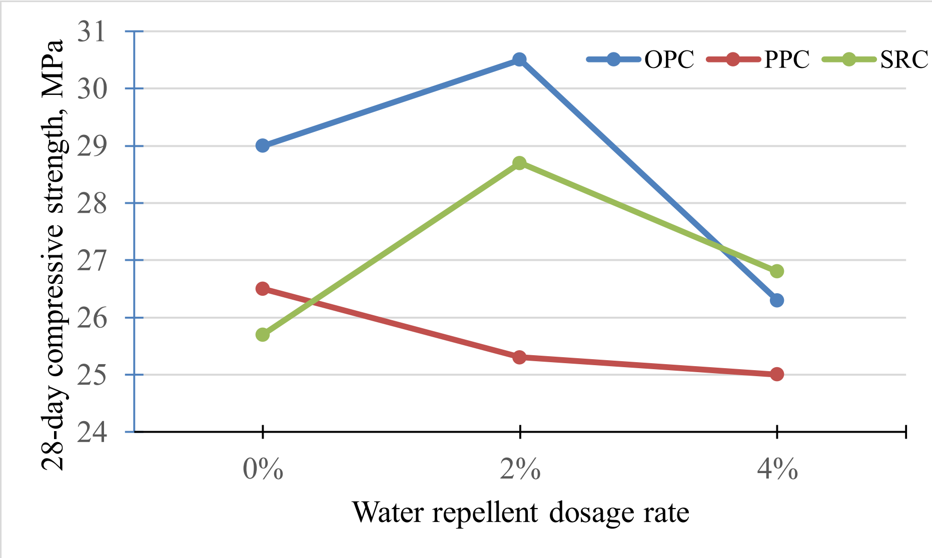


Figure 5: Variation of the 28-day compressive strength for specimens made of different types of cement cured in Dead Sea water with the variation of water repellent dosage rate .

Figs 6, 7 and 8 visualize better the results contained in Table 4 regarding the variation of the compressive strength at 7 and 28 days due to the variation of the dosage rate of water repellent for specimens cured in Dead Sea water and for each type of cement used.

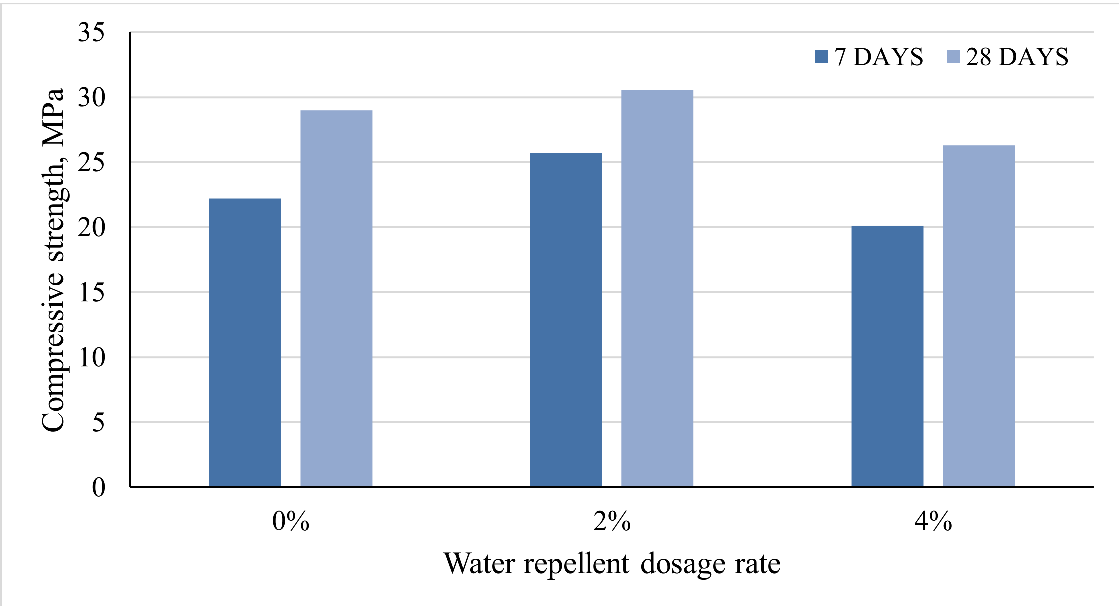


Figure 6: Variation of the compressive strength for OPC at 7 and 28 days for samples cured in Dead Sea water with the variation of dosage rate of water repellent

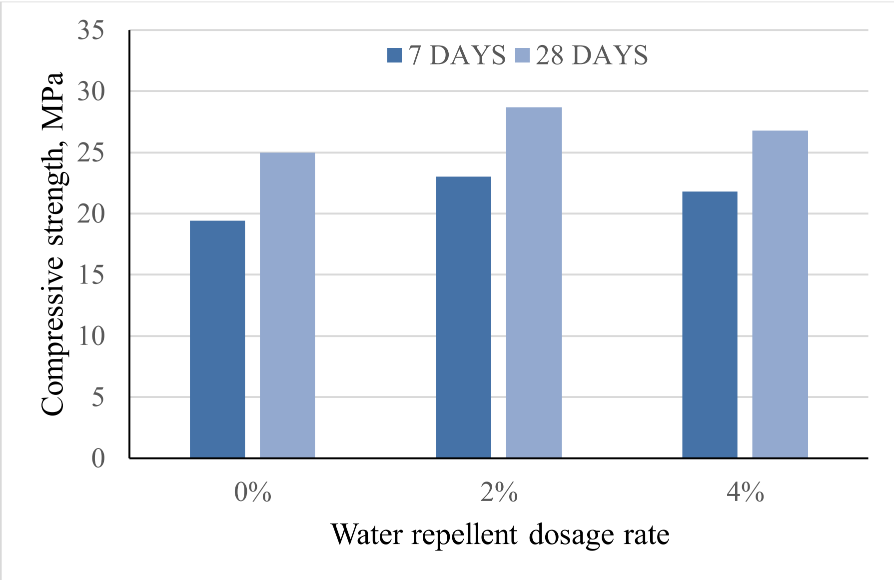
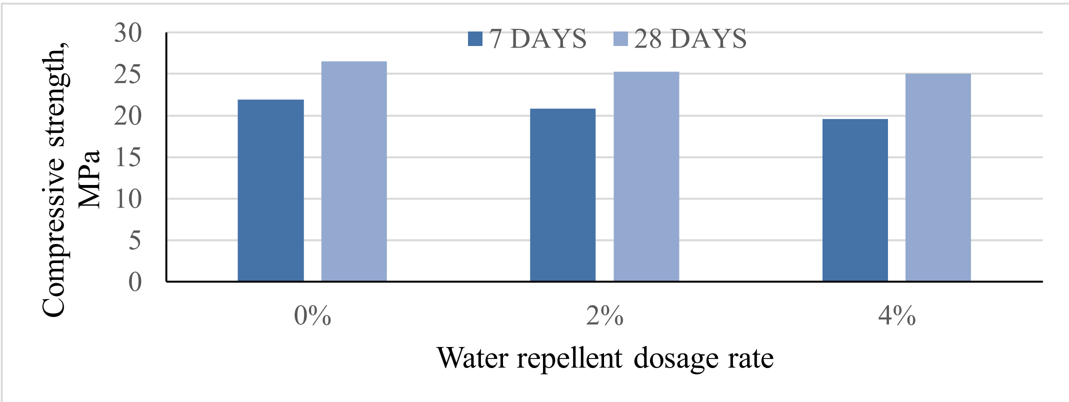


Figure 7: Variation of the compressive strength for SRC at 7 and 28 days for samples

cured in Dead Sea water with the variation of dosage rate of water repellent

Figure 8: Variation of the compressive strength for PPC specimens cured in Dead Sea water for 7 and 28 days with the variation of dosage rate of water repellent



It is interesting to note the effect of Dead Sea water on the color of specimens after 28 curing days. **Figure 9** and **Fig. 10** show that OPC or SRC specimens without water repellent, cured in dead Sea water have a dark color, while specimens of the same type of cement cured in plain water have a light color. **Figure 11** shows the effect of water repellent on the color of specimens cured in Dead

Sea water. In fact, it can be seen that specimens containing water repellent, cured in Dead Sea water, maintained their light color for the three types of cement as if they had been cured in plain water. **Figure 12** shows the considerable quantity of salt crystallized on the surface of the specimen after 28 curing days in Dead Sea water.

Figure 9: Comparison of specimen's color in different curing conditions. Left OPC specimen without water repellent cured in Dead Sea water, right same specimen cured in plain water.

Figure 10: Comparison of specimen's color in different curing conditions. Left SRC specimen without water repellent cured in dead sea water, right specimen cured in plain water.

Figure 11: Specimens colour with water repellent cured in Dead Sea water. Left OPC sample, middle PPC sample, right SRC sample

Figure 12: Salt crystallization on the surface of specimens cured in Dead Sea water

CONCLUSIONS

Dead Sea water is hazardous for concrete for the high concentration of salts. This paper investigated the effect of Dead Sea curing water on the compressive strength of concrete containing hydrophobic water-repellent admixture and determined the optimum dosage ratio of admixture to be used. From the results, it can be seen that a high 7-day compressive strength was achieved with respect to the 28-day compressive strength for all specimens cured in Dead Sea water regardless of the cement type. This early high strength can be increased with the addition of 2% water repellent for OPC and SRC specimens.

Curing specimens in Dead Sea water caused a decrease in the 28-day compressive strength.

This decrease in the compressive strength can be alleviated by the addition of 2% water repellent for OPC and SRC specimens; no benefit was obtained for PPC specimens. The further increase of the water repellent dosage rate did not give any improvement for the compressive strength; indeed, it caused a sharp drop in the compressive strength especially for OPC and SRC specimens. cured in plain water.

This is due to the fact that high dosage of water repellent forms a water-resistant barrier, which weakens the cement hydration. Curing specimens in Dead Sea water caused the specimens to have a very dark color. By adding water repellent admixture, the specimens could maintain their light color as if they had been

REFERENCES

[1] Neville, A. M. (2011). Properties of Concrete, 5th ed. Harlow: Pearson.

[2] Wisniak, J. (2002). "The Dead Sea – A Live Pool of Chemicals," Indian Journal of Chemical Technology, 9(1), 79-87.

[3] Effect of Polypropylene Fiber Admixture on Compressive Strength of Ceramsite Concrete. (2021). International Journal of Frontiers in Engineering Technology, 3(1). https://doi.org/10.25236/ijfet.2021.030104

[4] Effect of Polypropylene Fiber Admixture on Compressive Strength of Ceramsite Concrete. (2021). International Journal of Frontiers in Engineering Technology, 3(1). https://doi.org/10.25236/ijfet.2021.030104

[5] Xiao, J., Qiang, C., Nanni, A., & Zhang, K. (2017). Use of sea-sand and seawater in concrete construction: Current status and future opportunities. Construction and Building Materials, 155, 1101–1111. https://doi.org/10.1016/j.conbuildmat.2017.08.130

[6] Li, Y.-L., Zhao, X.-L., Singh Raman, R. K., & Al-Saadi, S. (2018). Thermal and mechanical properties of alkali-activated slag paste, mortar and concrete utilising seawater and sea sand. Construction and Building Materials, 159, 704–724. https://doi.org/10.1016/j.conbuildmat.2017.10.104

[7] Zhang, W. (2014). Feasibility Study of Concrete Production Using Sea Sand Wased by Reclaimed Water. Advanced Materials Research, 1015, 231–234. https://doi.org/10.4028/www.scientific.net/amr.1015.231

[8] Islam, M. S., Mondal, B. C., and Islam, M. M. (2010). "Effect of Sea Salts on Structural Concrete in a Tidal Environment," Australian Journal of Structural Engineering, 10(3), 237–252. DOI: 10.1080/13287982.2010.11465048.

[8] Islam, M. M., Islam, M. S., Modal, B. C., and Islam, M. R. (2010). "Strength Behaviour of Concrete Using Slag with Cement in Seawater Environment." Journal of Civil Engineering (IEB), 38(2), 120–140.

[10] Mangi, S. A., Makhija, A., Raza, M. S., Khahro, S. H., & Jhatial, A. A. (2020). A Comprehensive Review on Effects of Seawater on Engineering Properties of Concrete. Silicon, 13(12), 4519–4526. https://doi.org/10.1007/s12633-020-00724-7

[11] Al–Rifaie, W. N., Alhasat, E., & Ahmed, W. K. (2018). Impact of dead sea water on the mechanical properties of ferrocement. MOJ Civil Engineering, 4(5), 374–377. https://doi.org/10.15406/mojce.2018.04.00131

[12] Heller, L., & Ben-Yair, M. (2007). Effect of dead sea water on portland cement. Journal of Applied Chemistry, 12(11), 481–485. https://doi.org/10.1002/jctb.5010121103

[13] AL-Baijat, H. (2019). "Effect of Dead Sea Water on Durability, Strength, Flexure and Bond on Hardened Concrete," International Journal of Civil Engineering and Technology (IJCIET), 10(5), 138-147.

[14] ACI, (2016). "Report on Chemical Admixtures for Concrete (ACI 212.3R-16)." Farmington Hills, MI: American Concrete Institute.

[15] Munn, R. L., Kao, G., and Chang, Z. T. (2005). "Durability Performance of Australian Commercial Concrete Modified with Permeability Reducing Admixture," 22nd Biennial of the Concrete Institute of Australia, Melbourne 17-19 October 2005, Concrete Institute of Australia.

[16] Kumar, M., Singh, N. P., and Singh, N. B. (2009). "Effect of Water Proofing Admixture on the Hydration of Portland Cement," Indian Journal of Chemical Technology, 16, 499-506.

[17] Savva, P. A., & Petrou, M. F. (2015). A new approach for internal curing of high performance concrete to reduce early-age volume variations. Concrete Repair, Rehabilitation and Retrofitting IV,