International Review of Civil Engineering (I.RE.C.E.), Vol. 13, N. 1
ISSN 2036 - 9913 January 2022

Sustainable Use of Brine Water in Concrete Cement Mixes Alter Compression-Bending Strengths

Zeyad A. Alshboul, Husein A. Alzgool, Hadeel Alzghool

Abstract – *Freshwater resources are limited and many regions worldwide are suffering from water shortage due to the rapid increase in population, industrialization and urbanization. Concrete production has shown to consume a substantial amount of water for mixing and curing, and this large consumption has sparked concerted efforts to find sustainable and environmental friendly alternatives for replacing freshwater in order to lower the pressure on water resources. The use of hypersaline by-product brine water discharged from desalination plant has been tested in cement mortar production in order to lower the pressure on water resources and reduce the environmental impact resulted from discharging this effluent to surrounding streams. Discharge brine water to surrounding stream can deteriorate physicochemical and ecological properties of receiving streams as well as accelerate degassing process of dissolved greenhouse gases by lowering solubility coefficient. Compression and Bending strength of cement mortar specimens have been tested after adding different percentages of brine water and with/without Alkali-Resistance Glass Fiber (ARGF). Samples have been cured for 7, 14, 21 and 28 days in 50.5mm×50.5mm×50.5mm cubes and tested using compression testing machine. Adding 3% ARGF to cement mortar mixes has increased 28 curing days bending strength (3 times) and has decreased compression strength 30%. It has been observed that using brine water with ARGF in cement mortar mixes will lower compression strength on the average of 22%±2 and will increase bending strength values 2.7 times. The results show that using ARGF and brine water in cement mortar production seems promising in improving environmental conditions and enhancing the mechanical property in many applications.*

Keywords: *Bending, Brine Water, Compression, Desalination, Glass Fiber*

I. Introduction

Freshwater resources are seriously affected around the world due to the rapid increase in population, climate change, industrialization and urbanization [1]-[3]. More than half of the world population will suffer from water shortage at least on month each year by 2050, and this estimate may be even worse and underestimated. Stress water recourses due to rapid increase in water demand influence the water cycle and this shows the importance of assessing human consumption and determining anthropogenic impacts on water resources. The concrete industry consumes billion tons of freshwater every year for mixing and curing purposes causing the requestnew water resources [4]. Recent estimates have shown that concrete production has been a substantial consumer of global industrial water withdrawals and 75% of the water demand for concrete production is expected to be in poor regions of water resources in 2050[5]. This high rate of water needed for concrete production have sparked concerted efforts to find a sustainable alternatives for instance seawater [6], brine water [7], and effluent water discharged from wastewater treatments plants [8], [9].

Concrete is a major infrastructure material, and in the past 50 years the production rate has exceeded other building materials where per capita concrete consumption exceeds the population growth rate [10].

Therefore, a sustainable use of alternative water resources (e.g. brine water) in concrete production will lower demand pressure on fresh water resources and eases its environmental impact during treatment or discharge. The use of saline water in mixing concrete may change the setting time and the concrete strength. It has been observed that the concrete mixed with saline water shows higher strength in comparison with concrete mixed with freshwater at 15 °C. There has been a recommendation to avoid using salt water in reinforced concrete in order to prevent steel corrosion [11].

However, many studies have shown that the negative impact of chloride ions from seawater is very small or negligible [4], [12]. While 75% of pure water can be recovered from reverse osmosis desalination plant [13], the remaining of feed water of Jerash desalination plant is discharging to the surrounding stream. Discharging brine water to the surrounding environment can cause a substantial deterioration in physiochemical and ecological properties [14]. The use of brine water in concrete mixes may reduce the amount of CO_2 emitted to

 https://doi.org/10.15866/irece.v13i1.20568

the atmosphere from surrounding water bodies [14] as lowering the amount of salt water discharged to surrounding water bodies will lower the emission rate of dissolved greenhouse gases that can be accelerated due to the change in water solubility as well as the hydrological characteristics after salt water addition [15]-[17].

Concrete durability may be affected by the use of brine water in mixing due to the presence of chloride ions.

The environmental impact of discharged brine on the surrounding environment has encouraged researchers to explore sustainable and affordable management techniques [18]. In this work, the possibility of using a hypersaline by-product brine water discharged from Jordan's inland reverse osmosis desalination plant (Jerash Desalination plant) in cement mortar mixes has been tested. Portland Cement used in concrete production has several environmental impact starting from high energy consumption [19] to greenhouse gases emission [20]. In order to lower the environmental impact of traditional concrete cement, many researches have started to investigate the visibility of using other sustainable materials [19], [7], [21]-[24]. Many studies have tested the use of Alkali-Resistant Glass Fiber (ARGF) materials in concrete production and its durability as it is defined to be components towards achieving sustainable construction in future [25], [26]. ARGF is made of high zircona content with minimum value of 16% formulated to improve resistance against aqueous alkaline solution attack.

To author's knowledge there were no studies investigated the use of ARGF in combination with brine water in cement mortar mixes. If cement in mixes is replaced with sustainable and environmental friendly material, the cement production will be lesser and the environmental burdens would be reduced [27], [28]. This work aims to investigate the effect of replacing freshwater by brine water on compression and bending strengths for cement mortar samples. The experimentations have studied the development of mechanical properties of cement mortar mixes that contain brine water and ARGF in their ingredients.

Compression and bending strengths have been measured for cement mortar specimens that consist of different ARGF percentages in order to obtain the percentage that maximum compression and bending strengths occurs at. During this study, all the samples have been casted in molds made of a non-absorbable material and cured in freshwater immediately after remolding for 7, 14, 21, 28 days.

However, the obtained optimum ARGF percentage has been used in mixtures where freshwater has been replaced by brine water at different percentages while water-cement ratio has been fixed to 0.45 during the experimentations. Reference compression and bending strengths have been obtained from reference samples prepared by using freshwater with cement and sand. The development of compression and bending strengths has been investigated after adding ARGF and brine water to mixtures and the values have been compared with the reference samples in order to find the optimal percentage of the added ARGF and brine water for maximum mechanical properties. More details are presented in methods and materials part for ARGF properties, major physical properties of concrete superplasticizer, and cement mortar preparation and testing. The result section has presented first the physico-chemical characterizations of Brine water. Secondly, compression and bending properties of reference samples have been presented and used for further comparison.

Third, variation in compression and bending strength of cement concrete after ARGF addition has been explained, and the percentage of added ARGF at maximum compression and bending strength values has been determined. The last two subsections present compression and bending development for samples, which contain brine water and ARGF in their contents.

II. Methods and Materials

II.1. Alkali-Resistant Glass Fibers

The Alkali-Resistant Glass Fibers (ARGF) made of a glass having high Zircona content with minimum value of 16% and have been formulated to improve resistance against aqueous alkaline solutions attack. ARGF used in this research (chopped strand 30 mm) meets ASTMC-1116 requirements and it is considered as affordable local material suitable for concrete application (Table I and Fig. 1(a)).

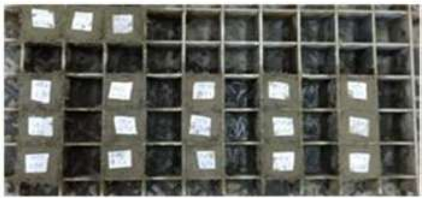
Since the ARGF composition lies within a critical region of Na_2O CaO ZrO_2 SiO_2 system, it has a high durability when used in cement-based products and it significantly increases flexural and tensile strength.

Besides its resistance to fire, since it is made of inorganic materials, ARGF has a negligible smoke emission decomposition resistance, and does not harm human lung during preparation and application (filament thickness ranges from 14 to 20 µm). A high performance concrete superplasticizer (Daracem SP (S)) has been used in mixing samples after ARGF addition (Table II). The additive used conforms to type A, F, D and G materials of ASTM designation C494 and complies with BS 5075 Part I and Part III.

TABLE I
PHYSICAL AND CHEMICAL PROPERTIES OF ARGF
(PROVIDED BY THE MANUFACTURER)

Property	Value
Filament Diameter (mm)	0.1
Fiber Length (mm)	12, 30
Specific Gravity	2.7
Young's modulus of elasticity (GN/m^2)	72 to 74
Tensile Strength (MPa)	1700
Flexural Strength (GPa)	72
Melting Point (°C)	1121
Color	White
Water Absorption	< 1%
Alkali Resistance	High
Concrete Surface	Not Fuzzy
Corrosion Resistance	High
ZrO_2 content	16% by weight

(a)



(b)

(c)

(d)

(e)

Figs. 1. Elements and samples used in compression and bending strength experimentations. (a) Alkali-resistance glass fibers of filament thickness 14 to 20 µm, (b) Molds made of a non-absorbable material with 50.5×50.5×50.5 mm, (c) Remolded f_{bf} beams before curing (d) Cracked f_{bf} beams after bending experimentation, and (e) f_{bf} cube specimens after 24 hours of casting

TABLE II
MAJOR PHYSICAL PROPERTIES OF DARACEM (SP)

The property	The value
Appearance	Dark brown liquid
Specific gravity	1.21 at 20 °C
Air entrainment	Air content by (1 – 2)%
Chloride content	Null
Addition rates ranges	0.4% - 3% by weight of cement

II.2. Cement Mortar Preparation and Testing

Ordinary Portland Cement (OPC) Type I (ASTM C 150), imported from a local supplier, has been used in mixtures preperation.

The typical average values of the compound composition of ordinary Portland cement are given in Table III [29]. Medium and fine size grains (ranged from 1.0 to 5.0 microns) of spherical shape and 98% purity have been used in preparing mixtures. Sand materials has imported from a local supplier, and silicate sand analyses have been performed at central laboratory (Royal Jordanian Scientific Society) (Table IV).

Molds are designed according to (B.S.1881.part (116): 1989) [30] and (B.S.1881.part (118): 1983) [31] in which molds have been made of a non-absorbable material. Molds dimensions have been 50.5×50.5×50.5 mm for compression strength test and 40×40×160 mm beams for performing bending resistance test (Fig. 1(b)). Specimens have been flattened and covered with a nylon layer in order to prevent water evaporation.

All the cement mortar specimens have been cured in freshwater immediately after remolding (24 hours of casting) and tested at curing days 7, 14, 21, and 28 in orderto obtain compression and bending strengths. The water-cement ratio has been fixed to 0.45 for all the specimens and freshwater has been used in preparing the reference samples.

The cement mortar specimens have been shaken for one minute during casting using electric vibrator for each layer until the surface of cement mortar cubes has been leveled. The vibration of the specimens that have contained ARGF (called later f_f) has been performed manually until a proper leveling of each layer was obtained. Compression test has been performed according to BS.1981.PART (116): 1983 using compression testing machine.

TABLE III
APPROXIMATE LIMITS OF PORTLAND CEMENT COMPOSITION (TYPE I) AND SIEVE ANALYSIS OF USED SAND

OPC composition		Sieve analysis of the used sand	
Compound composition	Content (%)	Sieve (in)	Finer percent (%)
$3CaO.SiO_2$	59	No. 4	100
$2CaO.SiO_2$	15	No. 8	99
$3CaO.Al_2O_3$	12	No. 10	98
$4CaO.Al_2O_3.Fe_2O_3$	8	No. 16	97
$CaSO_4$	2.9	No. 30	81
Free CaO	0.8	No. 40	65
MgO	2.4	No. 50	40
Loss of ignition	1.2	No. 100	5
		No. 200	2.9

TABLE IV
SIEVE ANALYSIS AND CHEMICAL COMPOSITION OF SILICATE SAND USED IN PREPARING MIXTURES

Grain size		Sand composition	
Sieve Number	Finer percent (%)	Component	(%)
No. 4	100	LOI	2.84
No. 8	99	SiO_2	93.71
No. 10	98	CaO	0.23
No. 16	97	Fe_2O_3	0.10
No. 30	81	SO_3	1.57
No. 40	65	MgO	0.06
No. 50	40	Al_2O_3	0.95
No. 100	5	Na_2O	0.07
No. 200	2.9	K_2O	0.32
		TiO_2	0.15

96 cubes and 96 beams of cement mortar samples have been prepared for compression and bending strength test where these samples have different brine water replacement percentages (2.5%, 5%, 7.5%, 10%, 15%, 20%, 30% and 40%) (Called later f_b) and triplicate samples were prepared for each curing day test (Figs. 1(c)-(e)). The brine water has been collected from nearby inland desalination plant and filled in sealed PVC containers. Physicochemical properties have been measured in-situ and brine water has been used within three days from sampling days in order to avoid any possible changes in properties. ARGF has been added to the reference mixtures in the percentage of 2%, 2.5%, 3%, 3.25% and mixtures have been cured for 7, 14, 21, and 28 days upon test (triplicate samples of each curing day). Optimal percentage of the added ARGF has been identified as the percentage that maximum compression and bending strengths have occurred at. The reference samples (called later f_R) have consisted of freshwater, cement and sand, where water-cement ratio has been kept at 0.45. 24 reference specimens have been prepared for compression and bending strength test where triplicate samples have been prepared for each curing day test.

Brine water has been added to mixtures in different replacement percentages in combination with ARGF (these samples are denoted later by f_{bf}) at the optimal ARGF percentage that has resulted from the former measurements. Physicochemical properties of brine water, feed water and desalinated water have been obtained from the long-term records of the desalination plant.

III. Results and Discussion

III.1. Brine Water Characterizations

The Mean Turbidity value of the generated brine water has been 0.67±0.05NTU and the water temperature has ranged between 18 °C in winter and 25 °C in the summer. Electrical conductivity and pH values have been 1.4×10^5 μS/cm and 7.2, respectively. Due to the operational conditions, these two values may slightly change during the year (Table V).

III.2. Compression-Bending Property of f_f Specimens

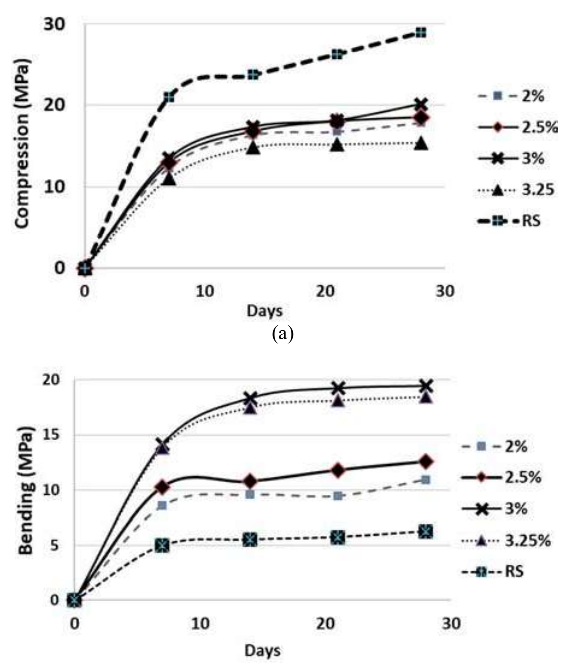
The average compression strength (28 curing days) of f_f specimens has been 19.7 MPa and has ranged from 15.4 to 20 MPa where minimum and maximum values have been registered for 3.25% and 3%, respectively.

TABLE V
PHYSICOCHEMICAL PROPERTIES OF BRINE WATER SAMPLES USED IN THE EXPERIMENTATIONS

Test	Sample Brine
Turbidity	0.67NTU
Temperature °C	18-25
Electrical Conductivity (μS/cm)	140000
Fe	<0.03
pH	7.2
Fe^{+2}	<0.10

f_f specimens shown to gain a rapid increase in early compression strength, and on the average 89% of the total compression strength gained within the first 7 days (ranged from 86% to 91%) (Fig. 2(a)). The average value is higher than the early compression strength values gained for reference specimens (average=82%, ranged from 79% to 85%). The mean value of 28 curing days compression strength of the reference specimens has been 1.4 times higher than the one for $f_{f3\%}$ specimens (maximum compression strength value) where adding ARGF to mixes has significantly lowered the compression strength in about 40% approximately.

Bending strength has increased 3 times after adding ARGF to mixtures revealing that there has been a substantial contribution of ARGF to the structure in comparison with the reference specimens (average=6.3 MPa, ranged from 5.9 to 6.85 MPa) (Fig. 2(b)). The mean value of bending strength experiments for f_f specimens (28 curing days) has been 15.4 MPa (ranged from 11 to 19.4 MPa) where the minimum and the maximum value has been registered for $f_{f2\%}$ and $f_{f3\%}$, respectively. However, replacing 3% of the total cement in specimens by ARGF has been optimal (maximum value) for both compression and bending strength values (Fig. 3). This percentage has been used for further measurements for studying the effect of adding brine water to specimens containing ARGF on compression and bending strengths.



Figs. 2. Variation of compression and bending strength for f_f specimens at different *ARGF* percentages. (a) Development of Compression strength for f_f specimens over curing days (7, 14, 21, 28). Reference samples (*RS*) shows higher compression values in compare with samples that *ARGF* inters its composition with slow increase in early compression. (b) Bending strength of f_f specimens at different *ARGF* percentages showing that *RS* have low bending strength over curing time

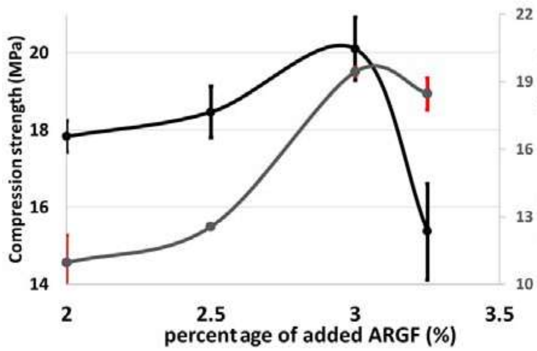


Fig. 3. Variation of compression (black line-primary axis) and bending (grey line-secondary axis) strength for different *ARGF* percentages

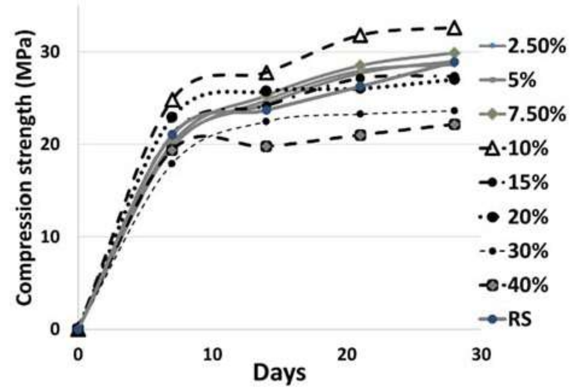
Early development of bending strength for f_f specimens has been observed (for all the ranges) and reached 90% of its total bending strength by day 7 (ranged from 87% to 95%) (Fig. 2(b)) which emphasizes the significant role of adding *ARGF* to cement mortar in order to speed up bending strength in many applications where bending strength of 15.4 MPa is acceptable.

III.3. Optimal Percentages of Brine and ARGF in Specimens for Maximum Compressive Strength

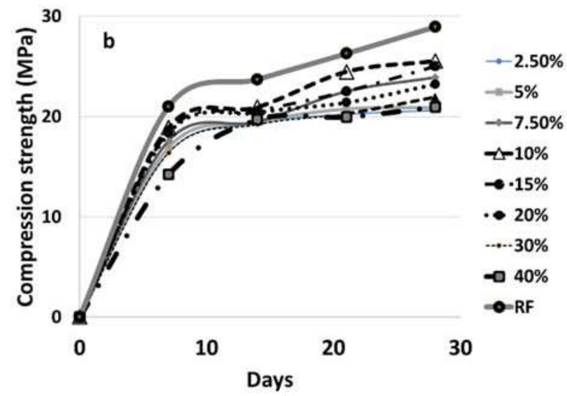
f_b specimens have gained on the average 88%±5 of its maximum compression strength by day 7 and this gained percentage has not been changed by changing the percentage of added brine water. This early and rapid increase in compresion strength has been also observed for concrete mixtures that have been mixed with brine water and sea water, [4], [33]. Maximum compression strengths have been registered for $f_{b10\%}$ (32.6 MPa) and $f_{bf10\%}$ (25.5 MPa) and the minimum values have been registered for $f_{b40\%}$ (22 MPa) and $f_{b2.5\%}$ (20.6 MPa) (Fig. 4(a)). There was an early and rapid increase in compression strength for f_{bf} specimens (average= 88%±4) and this percentage has not been changed by changing the percentage of added brine water where minimum and maximum values have been registered for $f_{bf10\%}$ and $f_{bf40\%}$, respectively (Fig. 4(b) and Fig. 5). f_{bf} specimens compression strength (mean value=22.7±3 MPa) was 22%±2 MPa less in comparision with the compression strength of f_R specimens. $f_{b5\%}$, $f_{b7.5\%}$ and $f_{b10\%}$ specimens have higher compression strength values in comparison with f_R specimens and the mean value of the compression strength for f_b specimens has been 27.5 MPa±3 (Fig. 5). However, $f_{b10\%}$ specimens have registered maximum compression values with and without ARGF addition and this percentage can be used in applications where 20.6 MPa compression strength is accepted.

III.4. Enhancement of Concrete Bending Property by ARGF-Brine Addition

94% of maximum bending strength has been reached by day 7 for f_b specimens (early bending development).



(a)



(b)

Figs. 4. (a) Compression growth for specimens of different brine water percentages where maximum and minimume compression strengths have registered for $f_{b10\%}$ and $f_{b40\%}$, respectively. and (b) Compression strength development for f_{bf} samples where maximum and minimum values are registered for $f_{bf10\%}$ and $f_{bf40\%}$ samples (note that RS have higher compression value over curing time).

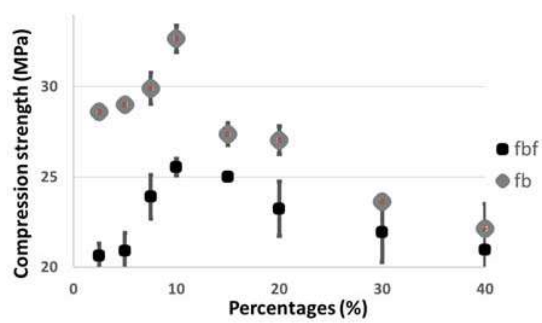


Fig. 5. Comparison of compression strength values for specimens of different brine water percentages without *ARGF* addition (f_b, in dots/grey color) and with *ARGF* addition (f_{bf}, sequares/black color)

Early bending development has been also observed when using seawater in concrete mixtures.

However, early bending strength has been correlated with the percentage of added brine water for f_b specimens (r^2=0.26, Spearman $\rho<0.05$) where minimum (5.7 MPa±0.06) and maximum (6.6 MPa±0.4) mean values have been registered for $f_{b5\%}$ and $f_{b15\%}$, respectively (Fig. 6 and Fig. 7(a)).

All the f_{bf} specimens have bending strength values greater than the mean compression strength values for f_R specimens where the average bending strength 28 curing days for f_{bf} specimens 2.7 times greater than the one for the reference samples. The mean value of the bending strength for f_{bf} specimens has been 17.1 MPa±0.16 (ranged from 14.4 to 19.8 MPa) where the minimum and the maximum values are registered for $f_{bf40\%}$ and $f_{bf10\%}$, respectively (Fig. 7(b)). 90% of 28 curing days bending strength values reached by day 7 revealing that ARGF-brine addition to cement concrete will accelerate bending development in compared to f_R specimens.

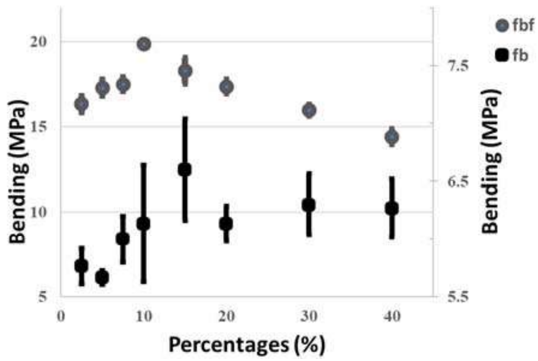
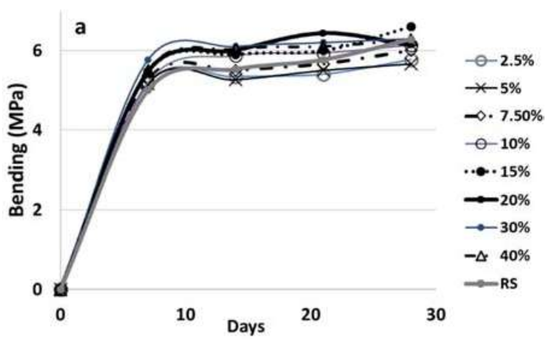
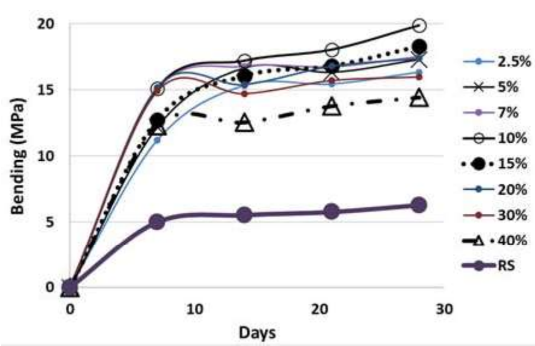


Fig. 6. Impact of adding *ARGF* and brine water to cement mortar on bending property. Variation of bending strength values for specimens of different brine water percentages without adding *ARGF* (squares/grey-secondary axis) and with adding *ARGF* (dots/black-primary axis)



(a)



(b)

Figs. 7. Enhancement of bending property after ARGF and brine water addition. (a) Slight change in Bending strength for f_b specimens over 7, 14, 21, and 28 curing days, and (b) Substantial increase in bending properties after brine water and 3% ARGF addition to mixes and maximum and minimum values are registered for $f_{bf10\%}$ and $f_{bf40\%}$

IV. Conclusion

The effect of using hypersaline water (brine) discharged from RO desalination plants on compression and bending properties of cement mortar mixes has been tested. The experimentations have also investigated the use of hypersaline water in combination with Alkali-Resistance glass fiber and if these combinations will enhance mechanical properties, compression and bending strengths, for cement mortar mixes. Based on the experimental results, an increase in the early compression strength after adding Alkali-Resistance glass fiber to cement mortar mixes and has been observed, and this addition has significantly lowered the 28 days compression strength in about 40%. Maximum compression strength has been found out for samples of 3% ARGF content. At this percentage, maximum bending value has been observed with substantial increase in bending property (3 times) for all mixes after ARGF addition. Samples of 10% brine water content have maximum compression values and the minimum values have been registered for 40% brine water replacement. However, brine water addition increases compression strength property and slightly decreases bending strength. A substantial increase (2.7 times) in bending property has been observed for samples after adding brine water and ARGF, where maximum and minimum values have been registered for samples of 10% and 40% brine water content, respectively (ARGF fixed at 3%). Further researches may investigate the durability of cement concrete mixes after brine water addition and the effect of adding brine water in combination with ARGF in CO_2 release rate and other mechanical properties.

Acknowledgements

The authors gratefully acknowledge the help of the staff at the structural engineering laboratory at Ajloun National University. This project is funded by Scientific Support Research Fund (Ajloun National University).

References

[1] Srinivasan V, Seto K, Emerson R, Gorelick S. The impact of urbanization on water vulnerability: A coupled human–environment system approach for Chennai, India. *Global Environ Change.* 2013;23:229-39. doi: 10.1016/j.gloenvcha.2012.10.002

[2] Sun Y, Tong S, Fang M, Yang YJ. Exploring the effects of population growth on future land use change in the Las Vegas Wash watershed: An integrated approach of geospatial modeling and analytics. *Environ Dev Sustainability*. 2013;15. doi: 10.1007/s10668-013-9447-z

[3] Schleich J, Hillenbrand T. Determinants of Residential Water Demand in Germany. *Ecol Econ.* 2009;68:1756-69. doi: 10.1016/j.ecolecon.2008.11.012

[4] Nishida T, Otsuki N, Ohara H, Garba-Say Z, Nagata T. Some Considerations for Applicability of Seawater as Mixing Water in Concrete. *J Mater Civ Eng.* 2013;27:B4014004. doi: 10.1061/(ASCE)MT.1943-5533.0001006

[5] Miller S, Horvath A, Monteiro P. Impacts of booming concrete production on water resources worldwide. *Nature Sustainability.*

2018;1.
doi: 10.1038/s41893-017-0009-5
[6] Wegian FM. Effect of seawater for mixing and curing on structural concrete. *The IES Journal Part A: Civil & Structural Engineering*. 2010;3(4):235-43.
doi: 10.1080/19373260.2010.521048
[7] Fattah KP, Al-Tamimi AK, Hamweyah W, Iqbal F. Evaluation of sustainable concrete produced with desalinated reject brine. International *Journal of Sustainable Built Environment*. 2017;6(1):183-90.
doi: https://doi.org/10.1016/j.ijsbe.2017.02.004
[8] El-Nawawy OA, Ahmad S. Use of treated effluent in concrete mixing in an arid climate. *Cem Concr Compos.* 1991;13(2):137-41.
doi: https://doi.org/10.1016/0958-9465(91)90009-7
[9] Tay JH, Yip WK. Use of Reclaimed Wastewater for Concrete Mixing. *J Environ Eng.* 1987;113(5):1156-61.
doi:10.1061/(ASCE)0733-9372(1987)113:5(1156)
[10] Gagg CR. Cement and concrete as an engineering material: An historic appraisal and case study analysis. *Eng Failure Anal.* 2014;40:114-40.
doi: https://doi.org/10.1016/j.engfailanal.2014.02.004
[11] Neville A. Seawater in the Mixture. *Concr Int.* 2001;23:48-51.
[12] Otsuki N, Saito T, Tadokoro Y. Possibility of Sea Water as Mixing Water in Concrete. *Journal of Civil Engineering and Architecture*. 2012;6:1273-9.
doi: 10.17265/1934-7359/2012.10.002
[13] Afonso MD, Jaber JO, Mohsen MS. Brackish groundwater treatment by reverse osmosis in Jordan. *Desalination*. 2004;164(2):157-71.
doi: https://doi.org/10.1016/S0011-9164(04)00175-4
[14] Roberts DA, Johnston EL, Knott NA. Impacts of desalination plant discharges on the marine environment: A critical review of published studies. *Water Res.* 2010;44(18):5117-28.
doi: https://doi.org/10.1016/j.watres.2010.04.036
[15] Alshboul Z, Lorke A. Carbon Dioxide Emissions from Reservoirs in the Lower Jordan Watershed. *PLoS One*. 2015;10(11):e0143381.
doi: 10.1371/journal.pone.0143381
[16] Tumendelger A, Alshboul Z, Lorke A. Methane and nitrous oxide emission from different treatment units of municipal wastewater treatment plants in Southwest Germany. *PLoS One*. 2019;14(1):e0209763.
doi: 10.1371/journal.pone.0209763
[17] Alshboul Z, Encinas-Fernández J, Hofmann H, Lorke A. Export of Dissolved Methane and Carbon Dioxide with Effluents from Municipal Wastewater Treatment Plants. *Environ Sci Technol*. 2016;50(11):5555-63. Epub 2016/05/11.
doi: 10.1021/acs.est.5b04923
[18] Pramanik B, Shu L, Jegatheesan V. A review on the management and treatment of brine solutions. *Environ Sci: Water Res Technol*. 2017;3.
doi: 10.1039/C6EW00339G
[19] Maier PL, Durham SA. Beneficial use of recycled materials in concrete mixtures. *Construction and Building Materials*. 2012;29:428-37.
doi: https://doi.org/10.1016/j.conbuildmat.2011.10.024
[20] Collins F, Sanjayan J. The Challenge of the Cement Industry Towards the Reduction of Greenhouse Emissions. *IABSE Symposium Report*. 2002;86:1-11.
doi: 10.2749/222137802796337152
[21] Kwan WH, Cheah CB, Ramli M, Chang KY. Alkali-resistant glass fiber reinforced high strength concrete in simulated aggressive environment. *Materiales de Construcción*. 2018;68(329):e147.
doi: 10.3989/mc.2018.13216
[22] Elchalakani M, Aly T, Abu-Aisheh E. Sustainable concrete with high volume GGBFS to build Masdar City in the UAE. *Case Studies in Construction Materials*. 2014;1:10-24.
doi: https://doi.org/10.1016/j.cscm.2013.11.001
[23] Xiaochun Q, Xiaoming L, Xiaopei C. The applicability of alkaline-resistant glass fiber in cement mortar of road pavement: Corrosion mechanism and performance analysis. *International Journal of Pavement Research and Technology*. 2017;10(6):536-44.
doi: https://doi.org/10.1016/j.ijprt.2017.06.003
[24] Mangi, S., Memon, Z., Khahro, S., Memon, R., Memon, A., Potentiality of Industrial Waste as Supplementary Cementitious Material in Concrete Production, (2020) *International Review of Civil Engineering (IRECE)*, 11 (5), pp. 214-221.
doi: https://doi.org/10.15866/irece.v11i5.18779
[25] Yang S, Yu M, Dong K, Yang Y. Properties of Alkali-Resistant Glass Fiber Reinforced Coral Aggregate Concrete. *Materials (Basel)*. 2020;13(16):3450.
doi: 10.3390/ma13163450
[26] Arabi N, Molez L, Rangeard D. Durability of Alkali-Resistant Glass Fibers Reinforced Cement Composite: Microstructural Observations of Degradation. *Periodica Polytechnica Civil Engineering*. 2018;62(3):653-9.
doi: 10.3311/PPci.10631
[27] Meyer C. The greening of the concrete industry. *Cem Concr Compos.* 2009;31(8):601-5.
doi: https://doi.org/10.1016/j.cemconcomp.2008.12.010
[28] Mehta PK. Greening of the Concrete Industry for Sustainable Development. *Concr Int.* 24(7).
[29] Neville AM, Brooks JJ. *Concrete Technology*: Longman Scientific & Technical; 1987.
[30] B.S 1881 P. Method of Determination of Compressive Strength of Concrete Cube. British Standard Institution. 1983;3PP.
[31] Institution BS. Testing concrete: method for determination of determination of flexural strength. BS 1881: part 118. 1983.
[32] Alzgool H. Strength Characteristics of Concrete with Brine and Olive Oil Mill Wastewaters. *International Journal of Engineering Research and Technology*. 2020;13:2831.
doi: 10.37624/IJERT/13.10.2020.2831-2838
[33] Mangi S, Makhija A, Raza M, Khahro S, Jhatial A. A Comprehensive Review on Effects of Seawater on Engineering Properties of Concrete. *Silicon*. 2020;12.
doi: 10.1007/s12633-020-00724-7

Authors' information

Ajloun National University, Jordan.

Zeyad Alshboul, Irbid-Jordan 1982, PhD in the field of Water and Environmental Engineering, Koblenz-Landau University, Landau, Institute for Environment, Germany, PhD. Water and Environmental Engineering. He is working in many projects tracking greenhouse gases emissions from surface water systems and sustainable use of effluent and brine water. The current research interest is a sustainable use of water and wastewater resources for lowering its environmental Impact. Dr. Alshboul is a member of Jordan Engineers Association.

Husein Alzgool, Ajloun-Jordan 1963, Civil Engineering-Structural Engineering, Rostov, Russia 1991. Structural Engineering. He is working on Structural and materials engineering at Ajloun National Engineering Dr. Alzghool is a member of Jordan Engineers Association.

Hadeel Alzghool, Ajloun-Jordan, 1992 Civil Engineering-Geotechnical Engineering, Jordan University of Science and Technology, Irbid-Jordan, 2019, Geotechnical Engineering. She is working on stabilization of highly expansive soil using alkali resistant glass fiber. The current research project is a sustainable use of engineering materials in constructions. MSc. Eng. Hadeel is a member of Jordan Engineers Association.

Praise Worthy Prize

International Review of Civil Engineering (I.RE.C.E.), Vol. 13, N. 1
ISSN 2036 - 9913 January 2022

The Role of a Project Manager in Fostering Green Construction Projects

Yazan Issa Abu Aisheh

Abstract – *This research aims to identify the competencies required for project managers in Amman in order to overcome challenges in green construction projects and deliver them successfully. This research has adopted the analytical descriptive and field study methods, where a special questionnaire has been designed and distributed to 100 construction companies and organisations, including consultants, contractors and international and academic institutions. The research sample consists of project managers, engineers and any other position for people who have sufficient experience in the construction phase generally and in sustainable construction projects particularly. The received 84 questionnaires have been analysed using the Statistical Package for the Social Sciences (SPSS) software. Results show that risk challenges in green construction projects have ranked higher than cost and time challenges. The personal attributes of the project manager have ranked higher than the required knowledge areas and skills. This study recommends identifying the importance of green buildings to Amman society, including residents and government officials. It also recommends the training of project managers in Amman so they develop the required competencies for managing green construction projects successfully.*

Keywords: *Amman, Jordan, Green Construction Projects, Project Manager Competencies, Risk, Sustainability*

Nomenclature

A	Highest Weight
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
DGNB	Deutsche Gütesiegel Nachhaltiges Bauen
CO_2	Carbon Dioxide
EPA	Environmental Protection Agency
IPMA	International Project Management Association
JGBC	Jordan Green Building Council
KGBCS	Korean Green Building Certification System
LEED	Leadership in Energy and Environmental Design
n	Number of Respondents
RII	Relative Importance Index
SPSS	Statistical Package for the Social Sciences
Wi	Weight Given to the ith Response
Xi	Frequency of the ith Response

I. Introduction

Buildings are critical elements of people's daily life [1]. The provision of shelter is included in the Universal Declaration of Human Rights. Buildings have a tremendous impact on productivity, health, and happiness. However, buildings account for more than one-third of worldwide energy use and are the primary source of greenhouse gas emissions in the majority of countries [2]. The building industry is one of the largest industries in the world [3], [4], which is why massive amounts of concrete and cement, 12 and 3 billion tons, respectively, are produced each year [5]. Furthermore, one ton of the major element in cement manufacturing, clinker, contributes to the release of another ton of CO_2 into the environment [6]-[13]. The notion of sustainable construction was born tactically in the building sector and civil engineering in 1994 [14]. Sustainability is defined as addressing today's demands without compromising future generations' ability to meet their own [15], [16]. The building industry is an important contributor to long-term growth [17]-[20]. With the incorporation of sustainability into the construction field, new project objectives have been added to transfer projects away from closely focused ambitions, which may be enhanced at the expense of other significant factors such as robustness and societal, environmental and economic improvement [21], [22]. Sustainable construction techniques are required in order to improve the industry's social, economic, and environmental elements [23]-[27]. Building construction companies from all around the world have combined the green concept into their construction strategies in order to decrease environmental damage [28], [29]. Furthermore, several countries have established and implemented