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Influence of grey water on physical and mechanical properties of mortar and concrete mixes

Ayoup M. Ghrair [a,*], Othman A. Al-Mashaqbeh [a], Mohmd K. Sarireh [b], Nedal Al-Kouz [a], Mahmoud Farfoura [a], Sharon B. Megdal [c]

[a] Scientific Research Center, Royal Scientific Society, P.O. Box 1438, Amman 11941 Jordan[1]
[b] Civil Engineering Department, Faculty of Engineering, Tafila Technical University, Tafila, Jordan
[c] Water Resources Research Center, University of Arizona, Tucson, AZ 85721, USA

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ABSTRACT

This project aims to evaluate the potential of reused grey water in concrete and mortar in order to preserve fresh water for drinking purposes. Using both Treated Grey Water and Raw Grey Water (TGW and RGW, respectively) led to a significant increase in the initial setting time and a decrease in the concrete slump value. In addition, there was no effect on mortar soundness properties. The mortar and concrete compressive strength results obtained at 7 days moist curing time showed a significant increase. Mortar and concrete mixes using TGW cast at curing times of 28, 120, and 200 days led to no significant effects on compressive strength. On the contrary, the RGW achieved slightly negative impact on compressive strength at all curing ages. According to the American Society for Testing and Materials (ASTM C109), TGW and RGW are suitable for mortar and concrete production. Furthermore, these results are in harmony with established requirements for ASTM C94.

In conclusion, TGW and RGW are potential alternatives for fresh water in the concrete manufacturing industry.

1. Introduction

Jordan is one of the most water-stressed regions of the world, where water availability and use are low on a per capita basis. Treated wastewater is estimated to be around 84 million cubic meters (MCM)/year, and expected to increase to 117 MCM/year in 2020 [1]. Between 50% and 80% of domestic household wastewater is grey water [2–4]. Where, grey water is defined as the water outflows collected from clothes washers, bathtubs, showers, and sinks [5]. This definition excludes wastewater from kitchen sinks, dishwashers, or toilets.

Globally, on an annual basis the concrete industry is consuming one billion cubic meters of mixing water. In addition, enormous quantities of fresh water is used for washing of the mixer trucks, concrete pumps, equipment, aggregate, curing concrete and ready mix concrete [6,7]. Currently, the concrete industry in Jordan is consuming approximately 8 MCM/year of fresh water. Demand for concrete dramatically increased, with a commensurate increase in concrete industry demand for water, during the last decade due to the growth in population. Jordan's population has doubled during the last 10 years due to natural growth and refugees influxes from neighboring countries. Given the growing and competing demands for freshwater in Jordan and other growing, water-scarce regions, it is necessary and prudent to conduct research on the feasibility of substituting fresh water with lesser quality water, such as grey water, in the concrete industry Silva and Naik [8].

Several studies have investigated the use of treated water in concrete. Mahasneh [9] showed that treated wastewater can be used as mixing water for concrete production, as the mix can achieve more than 90% of the specified strength required. Tay and Yip [10] reported that concrete with improved initial compressive strength could be made with mixing water consisting partially or totally of treated wastewater. In Saudi Arabia, utilizing freshwater and treated wastewater in concrete mixtures was tested and compared. Setting time and compressive strength were evaluated for the concrete. Results showed that the treated wastewater met

* Corresponding author at: Scientific Research Center, Royal Scientific Society, P.O. Box 1438, Al-Jubaiha, Amman 11941, Jordan.
E-mail addresses: ayoup.ghrair@rss.jo, ghrir@yahoo.com (A.M. Ghrair).
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the standards required for concrete production [11]. In Kuwait, a research group carried out experiments on concrete using tap water, primary treated wastewater, secondary treated wastewater, and tertiary treated wastewater. It was found that the setting time increased with decreased water quality. In addition, application of water from primary and secondary treatment processes in concrete showed lower strengths (10% lower than concrete made with tap water at 180 days) and slow strength development for ages up to one year. However, tertiary treated wastewater had no negative impact on concrete physical and chemical properties [12]. Cebeci and Saatci [13] reported that raw sewage reduced compressive strength by 9% at 28 days. In Iran, Shekarchi et al. [6] reported on a study that examined the use of three types of treated wastewater for concrete mixing and curing. The results revealed that application of treated wastewater in concrete is feasible and met the Iranian standards and building codes.

In Malaysia, Lee et al. [14] showed that treated effluent from a sewage treatment plant increases the compressive strength and setting time when compared with using fresh water in concrete.

Regarding health considerations, the United States Environmental Protection Agency (EPA) [15] has indicated certain points should be taken into consideration for treated wastewater reuse in concrete production such as: Biological Oxygen Demand (BOD_5) $\leqslant$30 mg/l, Total Suspended Solids (TSS) $\leqslant$30 mg/l, Fecal coliforms $\leqslant$200 CFU/100 ml, and Cl_2 residual 1 mg/l.

The quality of treated wastewater and grey water produced from new treatment plants Jordan meet the EPA standards [16,17]. The Jordanian Standard No. 893/2006 is currently applied to all municipal wastewater treatment systems. However, there is nothing mentioned in this particular standard number 893/2006 about reuse of treated wastewater in construction activities such as concrete or mortar. Therefore, this study aims to evaluate and investigate the potential of using grey water in mortar and concrete mixes. To the authors' knowledge, this is the first study of the use of grey water in place of freshwater in concrete production.

2. Materials and methodology

2.1. Grey water pilot plant in Deir-Alla

In 2011, a pilot grey water collection and filtration system was installed and operated in Deir-Alla, a community in the Jordan Valley, through a funded research project by USAID [16,18]. Two types of grey water were collected from the pilot plant: Raw Grey Water (RGW) and Treated Grey Water (TGW). The collected samples were transferred to labs at the Royal Scientific Society (RSS) and analysed. All water analyses were carried out according to the standard methods for the examination of water and wastewater [19].

2.2. Raw materials preparation and testing

2.2.1. Aggregate

Aggregates are granular materials that are usually chemically inactive. They are dispersed throughout the cement matrix mainly to reduce the cost of the concrete because aggregates are cheaper than cement [20]. The properties of the raw materials used in preparing mortar and concrete mixtures were tested in the RSS laboratories according to national and international standards. These materials include: coarse aggregate, fine aggregate, and cement.

For concrete mixtures, two sizes of coarse aggregates and two types of fine aggregates were used in concrete mixtures, while one type was used in the preparation of mortar. The physical properties for aggregates are shown below in Table 1.

2.2.2. Cement

Pozzolanic Portland Cement (PPC, Type II) manufactured by Jordanian cement company was used in preparing mortar and concrete mixtures. The chemical properties of the cement used are shown in Table 2.

2.3. Sample preparation and curing for mortar

Control mortar mix was designed according to volumetric proportions ranges suggested by Jordanian standards. After the preparation of control mix (distilled water (DW)), two types of grey water were utilized for separate mixes. The other components of mixtures were kept constant as those in the control except water type, which was added for each mix to obtain the same workability as the control mix.

During the mortar mix design process, the flow table was used as a workability indicator for the whole mixes. The test was conducted according to the American standard [22]. The mixing of mortar mixes was performed according to BS-EN 196-1 [21]. A standard mixer was used in the mixing process at laboratory conditions 20 ± 1 °C and 50 ± 10% Relative humidity (R.H). After mix preparation, it was filled in the moulds and compacted by Jolting table, and then the moulds were covered with glass plates and kept in moisture curing cabinet at standard conditions at 20 ± 1 °C and R.H >90% till the next day. After 24 h from casting, samples were taken out from moulds and stored for curing in water tank under standard temperature of 20 ± 1 °C. Normal tap water was used to fill the water tank to proper level. For each mortar mix, twenty-four prisms (40 × 40 × 160 mm) were cast.

Fresh mortar properties were tested directly after mix preparation such as initial setting time and soundness. Generally, initial setting is the time elapsed from adding water to the cement until the time at which the needle cannot penetrate more than 6 ± 2 mm from the bottom of the vicat's mould [23]. Soundness refers to the ability to resist volume expansion. It is determined by Le-Chatelier method IS:4031, where a specimen of hardened cement paste is boiled for 3 h. Then, allow it to cool down to the room temperature in order to measure the distance between the indicator points.

Each of six prisms was tested after various curing time (7, 28, 120, and 200 days). The average of three specimens at each age was calculated in order to compare the results of the different prepared mixes. The compressive strength was evaluated according to the European standard EN 1015-11 [24].

A stereo microscope analysis was conducted for the mortar prisms. Six samples were collected randomly at various cross sections from each mortar mixture at curing age 28 days (6 samples × 3 mortar mixture). Each slide dimensions were 4 cm × 4 cm. The diameter of voids for each image was measured by image analysis software.

Table 1
The physical properties of the used aggregate.

Aggregate type	Median particle size (mm)	Bulk specific gravity (SSD)	Absorption (%)	Fineness modulus
Coarse aggregate (Hemseyeh)	9.50	2.673	0.9	4.95
Coarse aggregate (Adaseyeh)	4.73	2.673	1.2	5.03
Fine aggregate (Semsmeyeh)	2.36	2.656	1.5	4.96
Fine aggregate (sand)	0.30	2.623	1.0	1.83

Table 2
The chemical properties of the used cement.

Property	Test result (%)	Limitations	Test method
MgO	2.84	⩽5	[21]
Fe_2O_3	5.34	–	[21]
SiO_2	22.01	–	[21]
CaO	48.19	–	[21]
K_2O	0.66	–	[21]
Al_2O_3	5.76	–	[21]
L.O.I	3.95	–	[21]
Chloride content (Cl)	0.031	⩽0.10	[21]
Sulfate content (SO_3)	3.20	⩽3.5	[21]
Insoluble residue	11.93	–	[21]

Table 3
Concrete mixture proportions.

Mix contents	Quantity (kg/m^3)
Hemseyeh[a]	514.7
Adaseyeh[a]	370.3
Semsmeyeh[a]	252.1
Swealeh Sand[a]	502.7
Cement PC 42.5N	418.2
Total water	233.0
Superplasticizer	Zero

[a] Note: Local names for coarse and fine aggregates are shown in Table 1.

2.4. Sample preparation and curing for concrete

Based on the mix design, grading of combined aggregate (Hemseyeh, Adaseyeh, Semsmeyeh, and Swealeh Sand) were chosen to get the best grading mix in order to achieve workability of fresh concrete (slump 15–18 mm) and compressive strength (30 MPa) (Table 3).

2.5. Concrete trial mixes

A number of concrete trial mixes were performed to achieve the fresh properties such as consistency and flow, and hardened concrete strength. For each mix, and after measuring concrete temperature and making slump test, twelve cubes (150 × 150 × 150) mm were prepared and cured according to the Jordan standard JS 1652-2:2004 [25], at (21 ± 2) °C and Humidity of (100%). Three cubes for each mix were tested at 7 days age as strength indication, while the other cubes were tested at 28, 120, and 180 days to obtain compressive strength.

After the preparation of concrete control mix, distilled water was replaced by two types of grey water at different percentages (100, 75 and 50%) in separate mixes. Concrete mixing procedure was performed by using pan mixer. After fresh properties evaluation, concrete mixes were cast in the moulds and compacted by using vibration table. After that, moulds were covered with plastic sheets and kept in standard conditions (21 ± 2 °C and 50 ± 10% R. H.) to the next day. After 24 h from casting, samples were taken out from moulds and stored for curing in water tank under standard temperature (21 ± 2) °C until testing date.

For each concrete mix, and after the completion of mixing, concrete fresh properties including temperature, slump and setting time respectively were tested according to fresh concrete testing standards EN12350-2:2009 [26] and ASTM C 403:08 [27].

For compressive strength test, specimens were tested at 7, 28, 120, and 200 days age. The average of three specimens at each age was calculated in order to compare the results of the different mixtures that were prepared. The whole strength tests were performed according to JS 1652 parts 3, 5, and 6 [25].

3. Results and discussion

3.1. Grey water properties

The quality of mixing water plays an essential role in preparation of concrete [28]. Drinkable water can be used as mixing water for production concrete. Furthermore, some water types that are not suitable for drinking may be fit for concrete [29,30]. Table 4 shows the parameters concentrations of RGW, TGW and the allowable limits of these parameters for mixing water used in the production of concrete. The results show that the Total Suspended Solids (TSS) of RGW and TGW were 436 and 2 mg/L, respectively. According to the PCA [29], 2000 mg/L of in mixing water is tolerated. Furthermore, in case of reusing of wastewater from mixer washout operations 50,000 mg/L can be tolerated. The TDS for both RGW and TGW (980 and 803 mg/L) is lower than the maximum permissible concentration (2000 mg/L).

The total organic of the RGW is 900 mg/L which is higher than the maximum permissible level. The total organic of the TGW is very low (6.97 mg/L). The concentrations of chloride, sulfate, and pH are under the maximum permissible limits. In general, the results clearly show that all chemical and biological parameters concentrations of RGW and TGW are lower than those reported by ASTM C94 [31], except the chemical oxygen demand (COD) and *E. coil* concentrations for RGW.

The RGW contains *E. coil* bacteria over the maximum limits for an open system application of wastewater, where worker has high exposure potential. *E. coil* is now considered as the most important indicator for public health [32]. The most effective materials to controlled microorganisms growth are poly-halogenated phenols, dieldrin emulsions, and copper compounds. The effectiveness of these materials is generally temporary [29]. The TGW contains *E. coil* less than the detection limit. Based on the acceptable criteria for water to be used in concrete which is presented in Table 4, the TGW is suitable for concrete production while the RGW should

Table 4
Grey water quality and the mixing water permissible limits for concrete.

Parameter	Unit	RGW	TGW	Maximum concentration[a]
TSS	mg/L	436	2	2000
TDS	mg/L	980	803	2000
COD	mg/L	900	6.97	500
BOD5	mg/L	536	2.98	–
Cl	mg/L	243	208	500
SO_4	mg/L	222	137	2000
NH_3	mg/L	24	4.5>	No specific limit
pH	–	7.5	7.9	6–8
E. coil	MPN/100 ml	1.70E+05	<1	<200[b]

[a] Mixing water permissible limits according to ASTM C94 [31] or EN 1008 [35,32,30].
[b] The maximum limits for an open system application of wastewater [15].

Table 5
Fresh properties of cement paste.

Water type	Wt. of cement (g)	Water (CC)	Water/cement (W/C) (%)	Initial setting time (min)	Needle penetration[a] (mm)	Soundness (mm)
RGW	500	147	29.4	200	4	1
TGW	500	148	29.6	205	4	1
Control	500	146	29.2	180	6	1

[a] Standard consistency is 6 ± 2 mm [33].

be tested and compared with specimens made with drinkable or distilled water to insure that the impurities in RGW do not adversely affect the mechanical properties of concrete [33]. The RGW should be pretreated to reduce the microorganism content before the water can be in direct contact with humans [34]. Regarding to the Jordanian standard specifications, there is no available limits for dissolved impurities in mixing water and their possible negative impact on concrete properties.

Based on the results of grey water analyses, it is important to mention here that the efficiency removal of TSS, COD, BOD5 and *E. coil* for the pilot filtration plant were 99.5%, 99.2%, 99.4% and 100%, respectively. These values are higher than those reported by Ghrair et al. [16]. These differences of efficiency removals are mainly due to the variation in the quality of RGW. The RGW sample in this study was collected directly from the network before the pilot plant while in the previous study RGW sample was collected from the septic tank. Furthermore the analyses results of TGW are in harmony with that recorded with Ghrair et al. [16].

3.2. Grey water effects on cement paste

The results (Table 5) show that the initial setting time of cement paste mixed with RGW and TGW were up to +20 and +25 min compared to control. One possible explanation for this slight increase in initial setting time is the high content of dissolved solids in RGW and TGW (Table 4). Shekarchi et al. [6] and Al-Ghusain et al. [12] reported that the dissolved salts can increase the initial setting time up to +70 min in case of using treated domestic wastewater on cement paste. Furthermore, the water/cement (W/C) ratio shows slight increases up to 0.2 and 0.4% for RGW and TGW, respectively. The increase of W/C ratio could be explained by the fact that the RGW and TGW contain dissolved solids, suspended solids and organic materials. This content of material represents the extra weight of water that led to this increase in W/C ratio.

In addition, the results of soundness test of cement by Le-Chateliers method show no significant differences between using RGW, TGW and control. According to the requirement of Jordan standard (no. 30-1/2007) [36], the maximum expansion must be ⩽10 mm.

These results are in harmony with ASTM C94 [31] requirements on initial setting time where the initial setting time of cement paste made with the questionable water must not be more than 60 min earlier nor more 90 min later than that made with the same cement using distilled water.

3.3. Effects on mortar properties

The results presented in Fig. 1 reveals that mortar made with TGW at curing time 2, 28, 120, and 200 days has no negative effect on the mortar compressive strength. However, using RGW as mixing water led to reduction in the compressive strength at curing time 2, 28, 120, and 200 days. This could be due to the effect of organic content which may have contributed to mortar strength reduction.

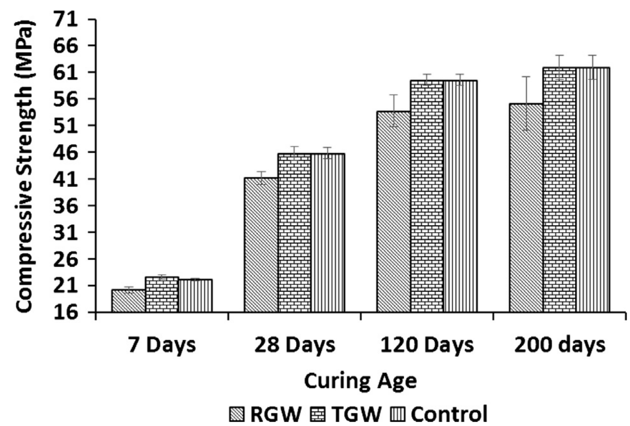

Figure 1. Influence of RGW and TGW on mortar compressive strength at various wet curing ages (7. 28, 120, and 200 days).

Mortar relative strength index (R_s) can be defined as the ratio of the compressive strength of mortar or concrete to that of the control [37]. Table 6 represents the mortar relative strength index of mixes using RGW and TGW at wet curing age of 7, 28, 120, and 200 days.

The relative index indicates that using RGW as mixing water for mortar production led to a significant reduction in the compressive strength between 8.9 and 10.8%. While addition of the TGW led to slightly increase in compressive strength at early curing age (7 days) while the R_s on long term (above 28 days) shows no significant differences between using distilled water and TGW. According to the ASTM C109 [38], water is suitable for production concrete if mortar made with it have strength at 7 days curing time equal or less than 10% reduction than of control samples made with drinkable or distilled water.

The stereo microscope was utilized for produce three-dimensional photos and low magnification observation. Fig. 2 shows that there is no significant differences in air void size and distribution between mortar specimens that made with TGW, RGW and distilled water. There is no micro cracks effect on the surface of mortar specimens. The mortar specimen structure and the matrix between aggregate are structurally intact.

3.4. Effects on concrete properties

The best indicator for the concrete workability is slump value. The results of slump test on concrete using RGW TGW and Distilled water as mixing water are presented in Fig. 3. The results reveal that using RGW and TGW led to decrease in slump 3.5 and 3 cm, respectively. This might be due to the fact that the dissolved solids lower the concrete slump value. This observation is consistent with previous studies [6,13].

The compressive strength of concrete utilizing RGW, TGW and DW at curing age 7, 28, 120, and 200 days are presented in Fig. 4. In comparison with concrete made by distilled water, the compressive strength of concrete made by RGW and TGW at 7 days shows a slight increase. However, the compressive strength of

Table 6
Mortar and concrete relative strength index of mixes using RGW and TGW.

Curing time (day)	Mortar relative strength index (%)		Concrete relative strength index (%)	
	RGW	TGW	RGW	TGW
7	−8.9	+2.4	+0.8	+3.8
28	−10.1	0.0	−7.7	−0.6
120	−9.8	0.0	−13.9	−2.4
200	−10.8	0.0	−10.2	−1.9

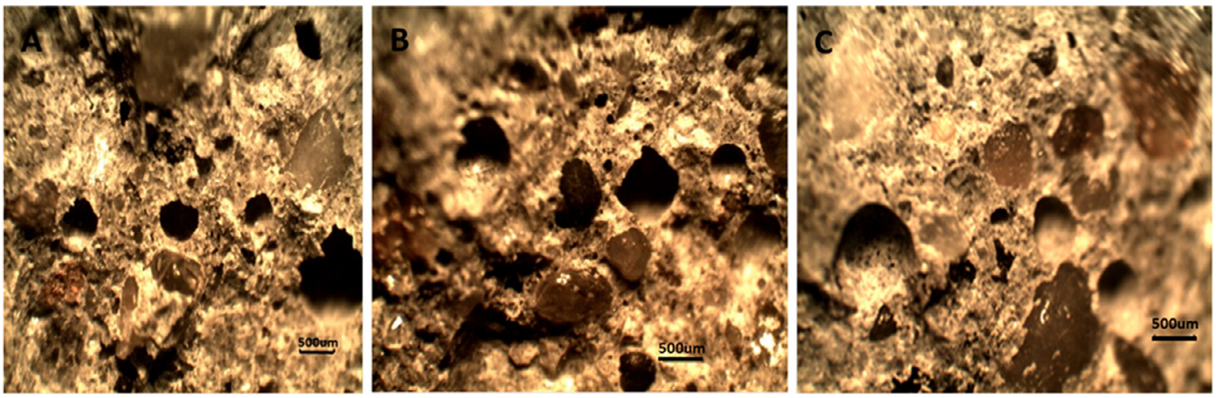

Figure 2. Stereo microscope images at 30× magnification of mortar specimens performed with (A) TGW, (B) RGW, and (C) distilled water.

TGW at 28 and 120 days curing age show no significant differences. AbdolChini and Mbwambo [39] reported that the properties of concrete are not affected by the use of recycled water. The concrete that made with RGW shows reduction in the compressive strength up to 7.7 and 13.9% at 28 and 120 days, respectively (Table 6).

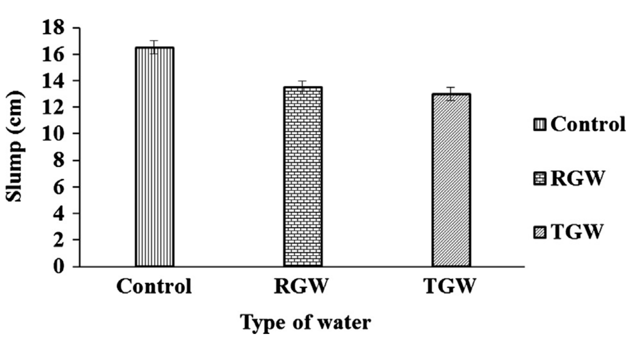

Figure 3. Slump of concrete using RGW, TGW and DW as mixing water.

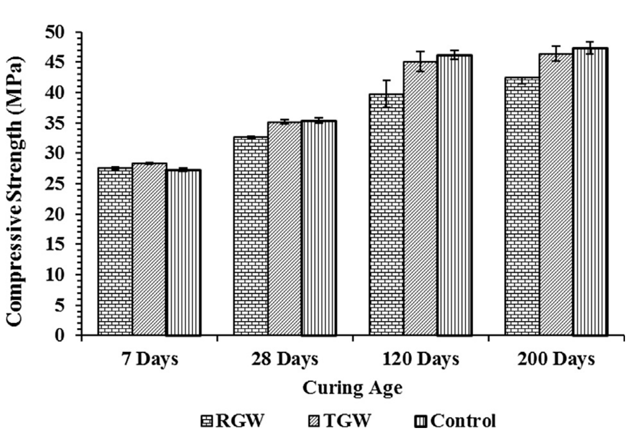

Figure 4. The compressive strength of concrete utilizing RGW, TGW and distilled water at curing age 7, 28, 120, and 200 days.

Despite of the relative reduction in compressive strength due to using wastewater there is a slow and continuous strength development up to 200 days. This result is consistent with Al-Ghusain and Terro [12], who concluded that a slow strength was gradually developed up to 360 days for a concrete made with treated wastewater. According to the IS 456-2000 [40] and Kucche et al. [28], the reduction of compressive strength of concrete should not be more than 15% of the mean compressive strength of concrete specimen made with drinkable or distilled water.

The effect of dilution of RGW, using distilled water dilution ratio of (RGW:DW) 1:0, 3:1, and 1:1, on the development of concrete compressive strength is presented in Fig. 5. It is clear that there are no significant effects of dilution of RGW on compressive strength at various curing ages up to 120 days except 50% dilution that shows a slight trend in enhancement of the compressive strength over short term period (less than 120 days). However, over long term of wet curing age (200 days), 50% dilution of RGW can significantly enhanced its compressive strength.

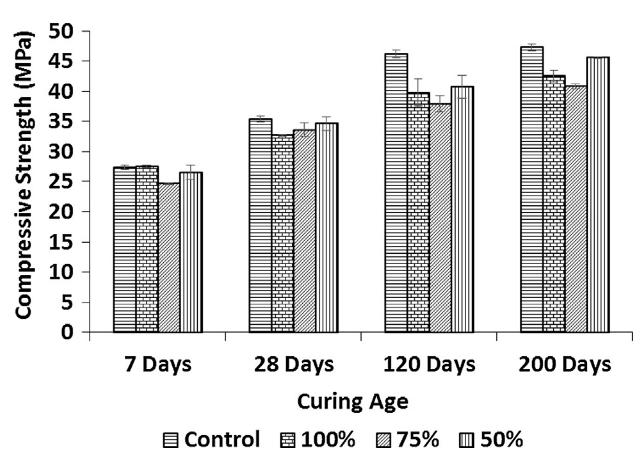

Figure 5. The effect of dilution ratio of RGW ((RGW:DW); 1:0, 3:1, 1:1) on the development of concrete compressive strength at curing age 7, 28, 120 and 200 days.

The water absorption parameter is one of the most important indicators of the concrete potential durability and quality [30]. The average water absorption of concrete performed with RGW, TGW, and distilled water is 1.69, 1.75, and 1.74%, respectively. The result shows that the effect of using grey water as mixing water on water absorption is not significant. This result is in agreement with Shekarchi et al. [6] who reported that utilizing treated wastewater as mixing water does not affected the concrete durability and water absorption.

4. Conclusions

The results of grey water quality and the allowable mixing water limits for concrete show that the TGW is suitable for concrete production. However, the RGW should be pretreated to reduce the microorganism content before the water can be in direct contact with humans.

The initial setting time of cement paste performed with RGW and TGW increased and the water/cement ratio shows a slight increase. These results are in harmony with established requirements for ASTM C94.

The results for mortar made with TGW at curing time 7, 28, 120, and 200 days show no negative effect on the mortar compressive strength. However, using RGW as mixing water led to reduction in the compressive strength up to 10%. Despite the relative reduction in compressive strength due to using wastewater there is slow strength development but continuously up to 200 days. Furthermore, there is no significant effect of using RGW or TGW on soundness value of mortar. According to the ASTM C109 or AASHTOT 106, TGW and RGW are suitable for mortar production.

The compressive strength of concrete made with TGW at 28, 120, and 200 days curing age is not negatively impacted when compared to concrete made with distilled water. However, the concrete that made with RGW shows reduction in the compressive strength up to 13.9% at 120 days. According to the IS 456-2000, TGW and RGW are suitable for concrete production.

The effect of grey water as mixing water on concrete water absorption and durability is not significant.

Dilution of RGW by 50% distilled water leads to significant enhancement of concrete compressive strength when compared to use of undiluted RGW.

In conclusion, TGW and RGW are potential alternatives for fresh water in the concrete production industry. Based on this study, the authors recommend that governmental managerial institutions, ministries, and authorities develop specific regulations in building codes for the use of grey water in concrete production as a step in reduction of fresh water consumption in Jordan and elsewhere.

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References

[1] Jiries A. Water resources in Jordan advanced water supply and wastewater treatment: a road to safer society and environment. NATO Sci Peace Secur Ser C: Environ Secur 2011:193–9.

[2] Redwood M. Greywater irrigation: challenges and opportunities. In: CAB reviews: perspectives in agriculture, veterinary science, nutrition and natural resources. London (UK): CAB International; 2008. No. 063.

[3] Eriksson E, Auffarth K, Henze M, Ledin A. Characteristics of grey wastewater. Urban Water 2002;4:85–104.

[4] Burnat J, Eshtayah I. On-site greywater treatment in Qebia Village. In: McIlwaine S, Redwood M, editors. Palestine greywater use in the middle east. Ottawa (Canada): IDRC; 2010. Online: http://web.idrc.ca/en/ev-152492-201-1-DO_TOPIC.html [accessed on 31 March 2012].

[5] Al-Jayyousi Odeh R. Grey water reuse: towards sustainable water management. European conference on desalination and the environment, fresh water for all, Malta, 4–8 May, 2003, vol. 156(1–3). European Desalination Society, International Water Association; 2003. p. 181–92. Published in desalination, Elsevier.

[6] Shekarchi M, Yazdian M, Mehrdadi N. Use of biologically treated waste water in concrete. Kuwait J Sci Eng 2012;39(2B):97–111.

[7] Naik TR. Sustainability of the cement and concrete industries. In: Chun YM, Claisse P, Naik TR, Ganjian E, editors. Proc int conf sustainable construction materials and technologies, 11–13. Coventry: Taylor and Francis, London; 2007. p. 19–25. ISBN 13:978-0-415-44689-1.

[8] Silva M, Naik TR. Sustainable use of resources – recycling of sewage treatment plant water in concrete. In: Second international conference on sustainable construction materials and technologies, main proceeding. ISBN: 978-1-4507-1490-7.

[9] Mahasneh BZ. Assessment of replacing wastewater and treated water with tap water in making concrete mix. Research Gate Net; 2005. Available online http://www.ejge.com/2014/Ppr2014.223mar.pdf.

[10] Tay J, Yip W. Use of reclaimed wastewater for concrete mixing. J Environ Eng 1987;113(5):1156–61.

[11] Saricimen H, Shameem M, Barry M, Ibrahim M. Testing of treated effluent for use in mixing and curing of concrete e-prints: https://eprints.kfupm.edu.sa/1745/; 2008.

[12] Al-Ghusain I, Terro MJ. Use of treated wastewater for concrete mixing in Kuwait. Kuwait J Sci Eng 2003;30(1):2003.

[13] Cebeci OZ, Saatci AM. Domestic sewage as mixing water in concrete. ACI Mater J 1989;86(5):503–6.

[14] Lee OS, Salim MR, Ismail M, Ali MI. Reusing treated effluent in concrete technology. Jurnal teknologi 2001;34(F):1–10.

[15] Environmental Protection Agency (EPA). Guidelines for water reuse technical issues in planning water reuse systems. Washington (DC): U.S Agency for International Development; 2004 [EPA/625/R-04/108, chapter 3].

[16] Ghrair AM, Al-Mashaqbeh OA, Megdal SB. Performance of a grey water pilot plant using a multi-layer filter for agricultural purposes in the Jordan Valley. CLEAN – Soil, Air Water 2015;43(3):351–9. doi: http://dx.doi.org/10.1002/clean.

[17] Ammary BY. Wastewater reuse in Jordan: present status and future plans. Desalination 2007;211:164–76.

[18] Al-Mashaqbeh O, Ghrair AM, Megdal S. Grey water reuse for agricultural purposes in the Jordan Valley: household survey results in Gore-Deir Alla. Water 2012;4(3):580–96.

[19] American Public Health Association (APHA). Standard methods for the examination of water and wastewater. Washington DC: American Public Health Association (APHA); 2006.

[20] Moavenzadeh F. Concise encyclopedia of building and construction materials. Cambridge (Massachusetts): The MIT Press; 1990. p. 689.

[21] European standard BS-EN 196-1&2. Methods of testing cement. Part 1: determination of strength and Part 2: chemical analysis of cement; 2013.

[22] ASTM C230/C230M. Standard specification for flow table for use in tests of hydraulic cement. West Conshohocken (PA): ASTM International; 1990. , www.astm.org.

[23] ASTM C-109 or AASHTOT-106. Compressive strength of hydraulic cement mortar; 2010.

[24] European standard EN 1015-11. Methods of test for mortar for masonry; 2007.

[25] JS 1652-1. Concrete – testing hardened concrete. Part 2: Making and curing specimens for strength tests; 2004.

[26] European standard EN 12350-2. Testing fresh concrete, slump-test; 2009.

[27] ASTM C 403/C. Standard test method for time of setting of concrete mixtures by penetration resistance; 2008.

[28] Kucche KJ, Jamkar SS, Sadgir PA. Quality of water making concrete: a review of literature. Int J Sci Publ 2015;5(1):1–10. ISSN 2250-3153.

[29] Portland Cement Association (PCA). Design and control of concrete mixtures. Engineering Bulletin 001,4th ed., Illinois – USA; 2003.

[30] Neville AM. Properties of concrete. 5th ed. London (England): Pearson Education Limited; 2011. p. 2866.

[31] ASTM C94/C94M-14b. Standard specification for ready mix concrete; 1994.

[32] Cement Concrete & Aggregates Australia. Use of recycled water in concrete production report; 2007. http://www.ccaa.com.au/imis_prod/documents/Library%20Documents/CCAA%20Reports/RecycledWater.pdf.

[33] ASTM C 191. Time of setting of hydraulic cement by vicatneedle; 2008.

[34] Viessman WJ, Hammer MJ. Water supply and pollution control. 4th ed. New York: Harper and Row; 1985.

[35] European standard EN 1008. Mixing water for concrete—specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete; 2002.

[36] JS 30-1. Composition specifications and conformity criteria for common cements; 2007.

[37] Alqedra MM, Arafa M, Mattar M. Influence of low and high organic wastewater sludge on physical and mechanical properties of concrete mixes. J Environ Sci Technol 2011;4(4):354–65.

[38] ASTM C-109 or AASHTOT-106. Compressive strength of hydraulic cement mortar; 2010.
[39] AbdolChini S, Mbwambo WJ. Environmentally friendly solutions for the disposal of concrete wash water from ready mixed concrete operations. In: CIB W89 Beijing International Conference, 21–24 October. , http://infohouse.p2ric.org/ref/06/05817.pdf.
[40] IS 456. Plain and reinforced concrete code of practice; 2000.

Ayoup M. Ghrair is an assistant researcher at Royal Scientific Society, Jordan, since 2009. **Ph.D.** in geochemistry and nanomaterials, Hohenheim University, Stuttgart, Germany.

Othman Al-Mashaqbeh is an assistant researcher at Royal Scientific Society, Jordan, since 2000. **Ph.D.** in civil engineering, University of Technology, Sydney, Australia, 2010.

Mohmd Sarireh, **Ph.D.** Assistant Professor, Construction Engineering, Department of Civil Engineering, Tafila Technical University.

Nedal Ahmad Alkuoz, Bachelor Degree of Civil Engineering QA Engineering and Technical lab of soil in Royal Scientific Society.

Dr. Mahmoud E. Farfoura received his PhD. degree in computer science from National Taiwan University of Science and Technology in 2013. Currently, he works as a researcher and IT Specialist in Royal Scientific Society for more than 14 years.