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Recycling Ready Mix Concrete Batch Plant Washing Water (SW) for Production Cementious Material

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Abstract: Recycling Ready mix concrete batch plant washing water which known as sludge water and abbreviate(SW) can increase profitability while helping to conserve water and save regular sewage system and environment. In this study, feasibility of recycling SW, was investigated as mixing water for Cementous materials. The main chemical composition and physical properties for randomly obtained SW samples were measured. The properties of cement mortar specimens prepared from freshly SW, filtered SW and fresh SW with $Ca(OH)_2$ additives were compared with that of samples mixed with tap water (TW), the influence of SW on mortar specimens was obviously depended on their chemical and physical analyses. However, within the investigated water samples, replacing TW with fresh SW increased the w/c ratio to reach 25%, while filtered SW and 50% SW samples with $Ca(OH)_2$ additives decreased the w/c ratio with maximum reduction of 27.5% and 10.5% compared to fresh SW. 33.33% of fresh SW increased mortar compressive strength with maximum increment up to 37% at 56 days comparing with TW, however filtered SW reduced mortar compressive strength. In addition, fresh and filtered SW samples had relative flexural/compressive strengths ranged between (0.17-0.26) which close to that made with TW (0.2-0.25). The effect of chemical and physical characteristics of SW were considered and discussed in details.

Key words: Concrete batch plant washing water・Recycling・Sustainable applications・Cementious materials

INTRODUCTION

Batching plants are using a massive amount of clean water to batch concrete, so the government found many sources of waste water in batch plans which generated as a result of washing concrete trucks, washing concrete drum mixers and batching plants. Wastes consist of water, coarse and fine aggregates, cementitious powders and chemical admixtures. For washing of 2100 units mixer drums, 1 m^3 of clean water is used which produce 2100 m^3/day or 0.76 million m^3/year of wastewater. However, one truck need 1500 liter of water to be wash out daily, this water is characterized as hazardous for disposal from the European (Environmental Agency's Special Waste Regulations) and U.S.A (EPA) legislation, as the pH value was over 11.5 and due to the large amount of suspended matter and high alkalinity such water cannot be discharged into urban sewers [1-3].

One concrete truck at the end of each work day contains approximately 200-400 kg of returned plastic concrete, which would need 700–1300 liters of clean water to be washed out. This water should not be disposed of in urban sewers due to its high alkalinity and the large amount of suspended matter which reduce the concrete capillary, water absorption and porosity. Additionally, the setting time is reduced and the flowability is lowered due to residual cement [3-5].

The EPA Publication illustrated that the best ways to avoid problems of water pollution and to ensure SW is not discharged from RMCP to surface waters, ground water or land [6].

SW collecting methods is very important and considers a major parameter in SW characteristics; SW samples kept in 35 liters agitated plastic which usage within two days of collection to study the effect of turbidity, [1]. While Chatveera, *et al*. [3] collecting SW

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samples, three times during two weeks intervals then filter SW samples through a #50 sieve (0.30 mm) to control the size of suspended particles. Both specific gravity and total solids content measurements were performed. Chatveera, *et al*. [7] collected SW from a ready mixing concrete plant (RMCP) in Thailand. Separate the SW samples to clear SW and sediments. Then mix a Proportion of 1:1 by weight were prepared Tsimas, *et al*. [8] collect SW then remove the suspended solid by settling and neutralize the pH by concentrated HCl was added to lower the pH to 7. The neutralized water was mixed with TW in small ratios (0% - 20%). Finally, water was used as mixing water for the production of concrete.

When free water in concrete was saturated with salts, the salts crystallize in the voids near the surface during drying, which cause pressure and scaling. Sodium sulfate and sodium carbonate in ground water cause concrete deterioration, leading to amounts of ettringite and/or gypsum which resulted in cracks due to expansion. Concrete structures exposed to salt solutions should have a low w/c ratio of 0.45 (maximum) to reduce permeability [9].

Many investigators reported that the pH of the water samples was greater than TW and ranged between the values of 12.3 to 13.3 [1, 6]. pH value 5 must be avoided while using HNO3 acidification. Additionally, direct water from truck drum with pH value of 12.5 does not require any reduction [2]. However, the total solids content was equal to 63,400 (ppm), which is greater than the limit of 50,000 ppm specified by ASTM C94 standard [6]. Several studies done in Setting time and water demand for mortar and concrete prepared from SW and the results shown that the initial and settling time increase or nearly the same when use SW in compare with TW [1, 3, 8, 10, 11]. SW samples had a significantly higher solids content than the ASTM C 94 limits which increased mixing water and accelerated setting time. However, SW with higher solids content and stored for four hours had a minimal effect on the setting time and water demand of the concrete mixtures [3, 8, 12]. All SW samples when used for mortar production, improved the compressive strengths at all ages when compared with TW without any treatment [2, 11, 13]. Sandrolini, *et al*. [4] found that samples prepared with SW after 7 days had lower compressive strength than the control sample. However, samples after 28 days reached 97% in comparison with the control samples. Additionally, for 28 days, flexural strengths were lower than control samples, as their mean strength was 90.9% and 95.9% of the control samples. Most of the UK RMCP have developed a system in which they manage to recycle the resources due to their awareness of the environmental problems and the shortage of renewable resources. This system is known as (washing out), [14-15].

Experimental Set Up:

Collecting Sw Samples: Sludge water samples were collected from batch plant mixer after cleaning the mixer. Concrete mixes comprised CEM I 42.5 N cement only, for the different concrete strengths (i.e. mix designs). SW samples were collected from the same batch plant location, for 20 months.

SW samples were collected according to the following steps:

- Batch plant cleaning mixture consisted of 400 liters of TW and 700 kg of limestone.
- Cleaning process was implemented by cleaning the mixer for 2 minutes using TW.
- After cleaning, the SW was collected in a 300-liters tank, for 1hr.
- A 30-liters task was filled from the 300 liters stored water by collecting 10 liters, every 100- liter, to ensure that the collected sample represent the washing water.

After collecting SW sample, it was chemically tested and used in fresh state to be compared with the chemical analyses of the control sample.

Table (1) shows the description of all SW samples from (A-Z) and (AA-AD) which were all used in fresh state as full replacement of TW in making mortar specimens, to be compared with control samples which were made using TW. Samples were collected starting 15/6/2015 to 23/3/2017.

Water Chemical Analyses Tests: The following tests in table (4) were carried out on the used water according to Standard Method for Water Analyses version 21- 2001.

Cement: Ordinary Portland cement (CEMI-42.5N) was used to produce the mortar and concrete mixtures according to Egyptian standards (ES 4756-1) [17]. Cement was tested for the following properties: normal consistancy, setting time and mortar compressive strength tests.

- Initial and final setting times of cement paste was according to (ES 2421-1) [18].
- Compressive strength of mortar according to (ES 2421-s

Table 1: Description of different batch plant SW samples used as fresh mixing water

Batch plant sampling	Samples description	Groups
A, C, G, AC	Samples were obtained after (8-10) hours of concrete production of which strength was 35 MPa and w/c 0.5	I
B	Sample was obtained after 12 hours of concrete production of which strength was 40 MPa and w/c 0.6	II
D, AB, V, AD, H	Samples were obtained after (10-12) hours of concrete production of which strength was 30 MPa and w/c (0.45-0.47)	III
E, J, AA, P, Q, R, S, T, U	Samples were obtained after (8-12) hours of concrete production of which strength was 25 MPa and w/c (0.61-0.65)	IV
F, I	Samples were obtained after (8-9) hours of concrete production of which strength was 20 MPa and w/c (0.55-0.63)	V
K, L, M, N, O, W, X, Y, Z	Samples were obtained after (1.5-6) hours of concrete production of which strength was 25 MPa and w/c (0.61-0.629)	VI

Additionally, samples (A, B, C, J, K, L, M, N, O, U, V, W, X, Y and Z) were used as mixing water in different conditions other than fresh state to prepare mixes as shown in table (2).

Table 2: Description of different SW samples used in cases other than fresh state

Batch plant sampling	Sample ID	Sample description
W, X, Y, Z	W+add, X+add, Y+add, Z+add	Water samples were used for mixing mortar and concrete specimens as full replacement of TW and 0.1-2.08 gm/l of $Ca(OH)_2$ additives to reach pH value in the range of 13-13.5.
	Wfl, Xfl, Yfl, Zfl	Water samples were filtered then used as mixing water in mortar and concrete specimens.

SW samples (W, X, Y and Z) were used for making mortar and concrete specimens after being filtered to be compared with the same SW samples in fresh state at ages 7, 28 and 56 days. Also, they were used for making mortar and concrete specimens after adding $Ca(OH)_2$ additives.

Table 3: Tests carried out on the used SW [16].

Test	Method	ECP 203-2017 Limits
Turbidity	2130 B. Nephelometric Method	2 gm/l
Alkalinity	2320 B. Titration Method	N. A
Total Hardness	2340 C. EDTA Titrimetric Method	N. A
Cl^- chloride	4500-Cl^- D. Potentiometric Method	0.5 gm/l
SO_4 sulfate	4500-$SO4^{2-}$ D. Gravimetric Method with Drying of Residue	0.3 gm/l
pH	4500-H^+ B. Electrometric Method	= 7
T. D. S	2540 C. Total Dissolved Solids Dried at 180°C	2 gm/l

- Soundness of cement was performed on cement paste using Le'chatelier apparatus according to (ES 2421-1) [18] and was estimated to be (4mm i.e. =10mm).

Mortar Specimens: The ratio of water to cement regarding cement paste in the control mix was (w/c= 0.3). A total number of 57 mixes of mortar were cast. All mixes were cured at 25°C (room temperature), the mixing proportion was (cement/sand=1/3) and a constant water to cement ratio of (w/c= 0.6). Only, water sample was changed. The constituent materials in (kg/m^3) for mortar were (471.7 kg of cement, 1415 kg of sand, 283 kg of water and 2 kg of superplasticizers).

A total number of 30 mortar mixtures from (A-Z) and (AA-AD) were tested for compressive strength. Each mix was tested at ages 7, 28 and 56 days. For each age, 12 cubes (50*50*50 mm) and were used. A total of 15 mortar mixtures (K, L, M, N, O, U, V, W, X, Y, Z, AA, AB, AC and AZ) were tested for flexural strength. Each mix consisted of 9 specimens 40*40*160 mm were tested at 7, 28 and 56 days. The compressive and flexural strengths tests were carried out according to ASTM C109 and ASTM C348 respectively.

Mortar cast using SW other than in the fresh state were also tested for both compressive and flexural strengths tests. Stored samples are (Ad, Bd, Cd, Kd, Ld, Md, Nd, Od, Ud, Vd) and filtered SW (WfI, XFI, YFI, ZFI), **Fresh SW+ $Ca(OH)_2$** (W+add, X+add, Y+add and Z+add).

RESULTS AND DISCUSSIONS

Section (1): The effect of sludge water samples (fresh and filtered) on the properties of cement paste, mortar

Standard Consistency of Cement Pastes: Figure (1) shows that all the cement paste specimens made of different fresh SW samples needed much higher w/c ratio, than that made of TW, to reach the standard consistency paste except samples which contained filtered sludge water. For example sample A increased w/c ratio by 25% when compared to the sample cast using TW: water

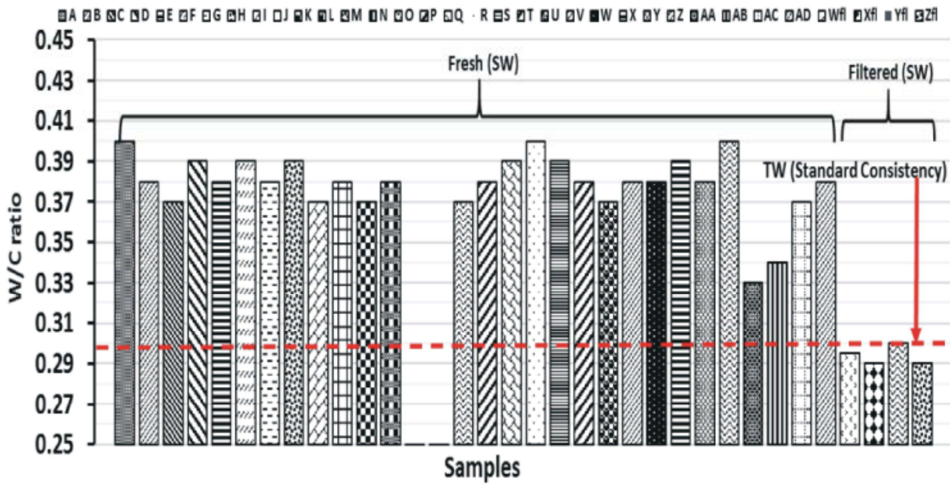

Fig. 1: Standard consistency of paste specimens cast using different SW samples

cement ratio for A was 0.4 and for TW was 0.3). Additionally, cement pastes made using filtered SW samples (Wfl, Xfl, Yfl and Zfl) needed lower w/c ratio to reach the standard consistency in comparison to the same SW samples in fresh state (W, X, Y and Z). For example, sample Z, needed w/c ratio of 0.4 when fresh sludge water was used, while the required w/c was 0.29 in the case of using filtered sludge water to obtain the standard consistency.

Generally, presence of suspended fine particles in SW increases the total fine materials and accordingly increases the water demand. This can provide physical reason of high w/c ratio demand, when using SW in comparison to TW, to reach the standard consistency state of the cement paste. In addition, this water demand increase can be due to additional chemical reasons as follows:

In the normal hydration state (i.e. using TW), hydrated cement particles usually bond firmly together to form an initial envelope surrounding un-hydrated cement particles, resulting in a decrease in the amount of consumed water. Accordingly, such initial envelop increases w/c required to reach the standard consistency state of the cement paste. The hydrated cement has formed a layer surrounding the unhydrated cement, thus water can't penetrate the hydrated layer. In case of dissolving the hydrated layer, water will be consumed by the unhydrated layer. Using mixing water having high alkalinity and calcium hydroxide $Ca(OH)_2$ (i.e. the case of SW) can dissolve the outer layer and increases the rate of water consumption. On the other hand, colloidal matters as part of the high turbidity of SW can penetrate between the hydrated molecules and accordingly increase porosity of the outer layer leading to more water consumption Neville, *et al*. [19]. In addition, high sulfate concentration in SW can penetrate the protective coating and react with C_3A forming calcium sulfoaluminate, which accelerate the hydration of the aluminate which in turn, increase water demand, Steinour, *et al*. [20].

In order to reach the standard consistency of 25% to 33%, water was added in the following percentages as shown in Figure (1).

Setting Time of Cement Pastes: Figure (2) shows that the initial setting time of all samples met the Egyptian standard 4756/ 2013 limit (no significant difference between samples contained sludge water and samples made of TW). Mainly about 26 cement paste samples (86.5 % of samples) made of different fresh SW samples did not significantly affect the initial setting time in comparison to TW (for example sample C the initial setting time was 135 min and TW 140 min). However, only 4 samples A, B, G and Q (13% of fresh SW samples) decreased the initial setting time in comparison to TW (for example sample B which decreased the initial setting time by about 14%, as the initial setting time for B was 120 min and TW 140 min). Additionally, 100% of cement pastes made using filtered SW samples (Wfl, Xfl, Yfl and Zfl) did not significantly affect the initial setting time in comparison to the same fresh SW (for example sample Z the initial setting time was 136 min and Zfl 130 min). According to the Egyptian standard 4756- 2013, there is no limit regarding final setting time. For the final setting time, about 20 cement paste samples (66.5 % of samples) made of different fresh SW samples did not significantly affect the final setting time in comparison to TW (for example sample O, the final

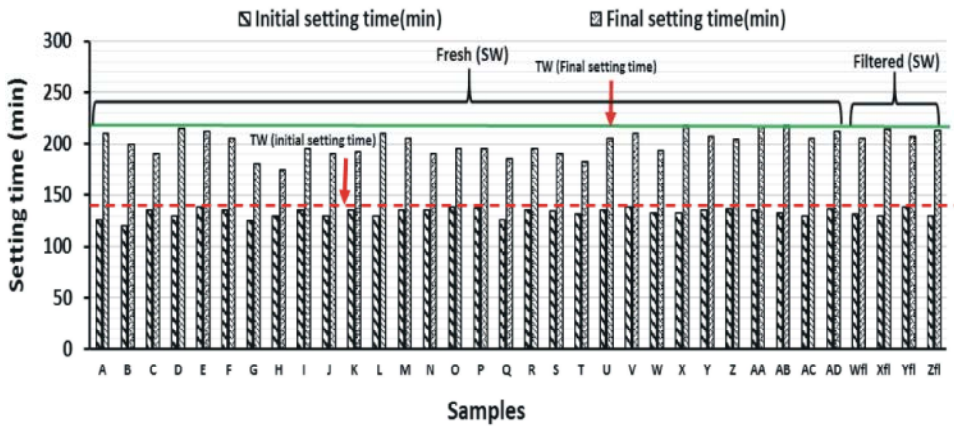

Fig. 2: Initial and final setting times of paste specimens cast using different SW samples

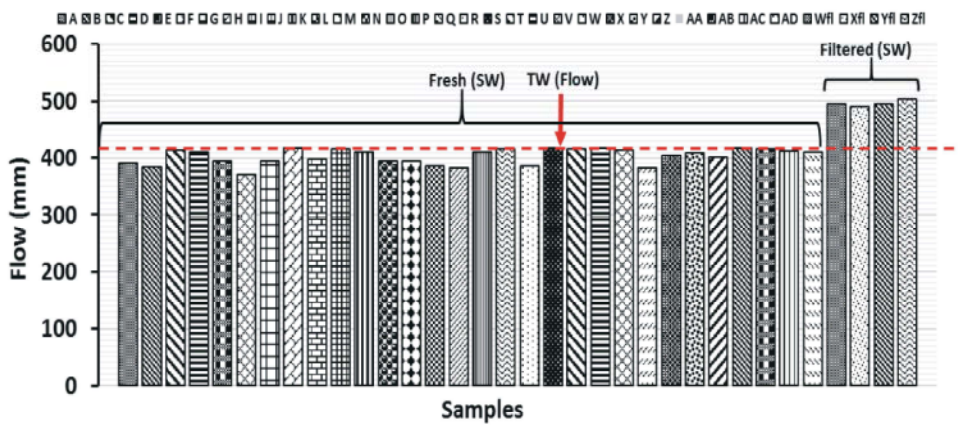

Fig. 3: Flow of mortar specimens cast using different SW samples

setting time was 195 min and TW 215 min). Only, 10 samples (33.3% of fresh SW samples) decreased the final setting time in comparison to TW (for example sample H which decreased the final setting time by about 18.6%, as the final setting time for H and TW, was 175 min and TW 215 min respectively). Also, all cement pastes made using filtered SW samples (Wfl, Xfl, Yfl and Zfl) did not significantly affect the final setting time in comparison to the same fresh SW (for example sample Z, the final setting time was 215 min and Zfl 204 min).

This reduction in the setting times may be related to the increase of the alkali concentration in SW which increases the rate of hydration for cement paste. In addition, increase of alkali concentration increase the temperature above 30 °C (85 °F) (exothermic reaction) which also enhances the rate of hydration.

Flow of Mortar Specimens: Figure (3) shows that samples cast using fresh SW had their flowability slightly affected in comparison to that of TW (for example sample A gave a flow value of 390.15 mm and that of TW was 419.98 mm). However, the flowability of mortar specimens cast using of filtered SW samples (Wfl, Xfl, Yfl and Zfl) increased in comparison to the same fresh SW samples. This may be attributed to almost zero turbidity (for example sample W which increased the flowability with 22.7% as the flow value for W was 382.5 mm and Wfl 495 mm).

Mechanical properties of mortar

Compressive strength of mortar

Fig. (4) Showed the following: When comparing compressive strength of mortar cast using TW with 7 samples of fresh SW (23% of fresh SW samples A, B, C, D, E, G and I), it was shown that compressive strength of mortar specimens of sludge water was higher at 56 days (i.e. up to 37% for sample G which had 43.14 MPa compressive strength in comparison to TW which had 27.13 MPa). All the 7 SW samples provided the following chemical limits,: Alkalinity < 6000 ppm, T.D.S < 3500 ppm, Total hardness < 3000 ppm and Turbidity < 350 N.T.U. On the other hand, 10 samples of fresh SW (33% of fresh SW samples AA, AB, AC, AD, L, M, W, X, Y and Z)

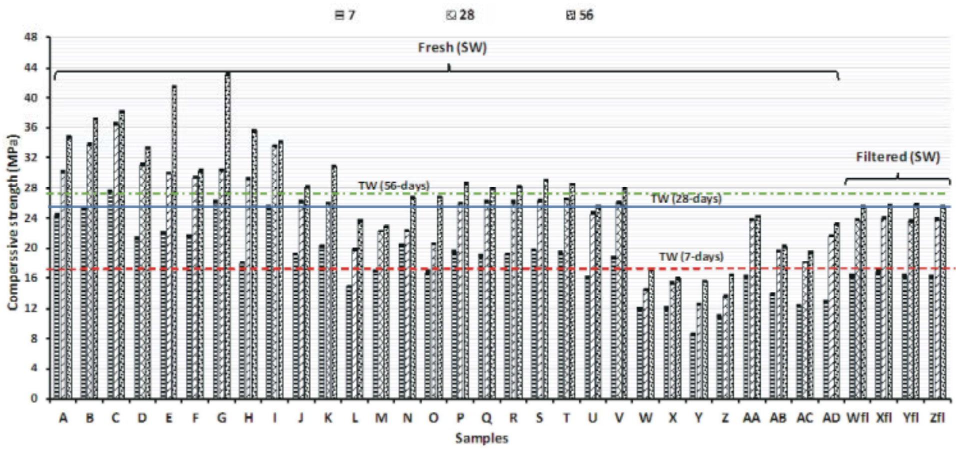

Fig. 4: Compressive strength of mortar specimens cast using different SW samples

decreased the compressive strength of mortar specimens at 56 days (about 42.3% for sample Y which had 15.65 MPa compressive strength in comparison to TW which had 27.13 MPa). This may be due to that, the 10 sludge water samples provided one of the following chemical limits:

- Alkalinity > 6000 ppm.
- Alkalinity < 6000 ppm and T.D.S > 9000 ppm.
- Alkalinity < 6000 ppm, T.D.S < 3500 ppm and Total hardness > 4000 ppm.
- Alkalinity < 6000 ppm, T.D.S < 3500 ppm, Total hardness < 3000 ppm and Turbidity > 500 N.T.U.

Additionally, 6 samples of fresh SW (20% of fresh SW samples J, P, Q, R, S and T) did not significantly affect the compressive strength of mortar specimens at 56 days (for example sample J gave 28.18 MPa compressive strength in comparison to TW which gave 27.13 MPa). All the 6 SW samples satisfied one of the following chemical limits:

- Alkalinity < 6000 ppm, T.D.S < 9000 ppm, Total hardness < 4000 ppm and Turbidity <500 N.T.U.
- Alkalinity < 6000 ppm, T.D.S < 3500 ppm, Total hardness < 4000 ppm and Turbidity <500 N.T.U.
- Alkalinity < 6000 ppm, T.D.S < 3500 ppm, Total hardness < 3000 ppm and Turbidity <500 N.T.U. Table (4-5) shows some examples in relation to the stated conditions.

Filtered sludge water samples (Wfl, Xfl, Yfl and Zfl) gave higher compressive strength than their corresponding samples (W, X, Y and Z) in fresh state at age 56 days. For example, Yfl provided compressive strength of 25.83 MPa, whereas Y resulted in compressive strength of 15.65 Mpa.

It should be noted that all samples were cured (immersed) in tap water till testing age.

Flexural Strength of Mortar: From Figure (5) was found that, the ratio between the flexural and compressive strength ranged between 0.17 and 0.26, which is close to that with using TW (i.e. 0.20 – 0.25). It was observed that the same trend for compressive strength regarding filtered and fresh water applies also for flexural strength at age 56 days. Sample Y gave the lowest compressive strength, while sample K gave highest flexural strength (which was close to that of tap water).

The Effects of Some Chemical Properties of Water on Mortar Samples: The effects of T.D.S., total hardness, PH, turbidity, alkalinity, chlorides and sulfates individually on mortar compressive strength are as follows:

Figures (6) to (12) show that chemical characteristics of SW at different states (i.e. fresh and filtered) have different effects in compressive strength of mortar.

1) Figure (6) shows that T.D.S. values up to 3000 ppm increased the mortar compressive strength. The compressive strength of samples (A, B, C and D) at 56 days reached (34.83, 37.16, 38.09 and 33.38 MPa respectively) in comparison to 27.13 MPa for TW. Increasing TDS, in turn, increased the water Alkalinity and Total Hardness concentration and accordingly increasing cement hydration products – as discussed before in section 4.5.1- leading to higher mortar strengths. In addition, the products of hydration of cement have lower solubility than in the original cement compounds (C_2S, C_3S, C_3A, C_4AF) which form interlaced elongated crystals with high cohesive and adhesive properties. Thus, increase the strength of mortar, Neville, *et al*. [19].

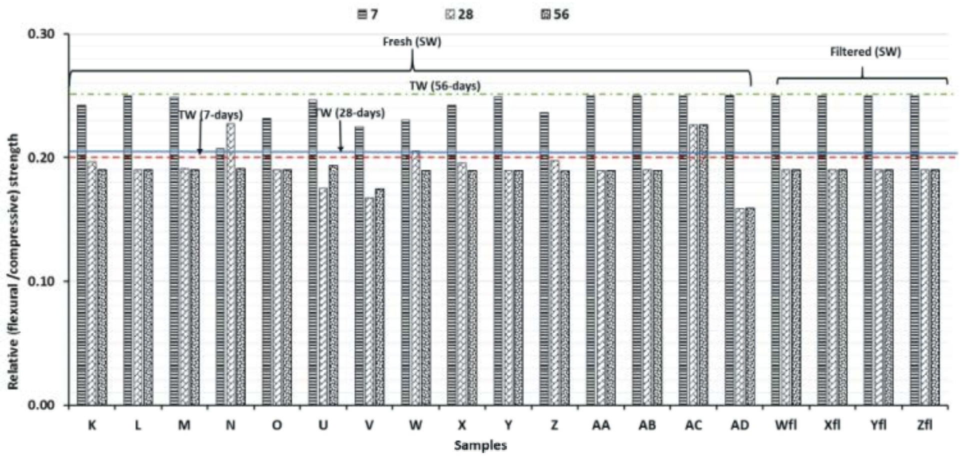

Fig. 5: Relative flexural strength of mortar specimens cast using different SW samples.

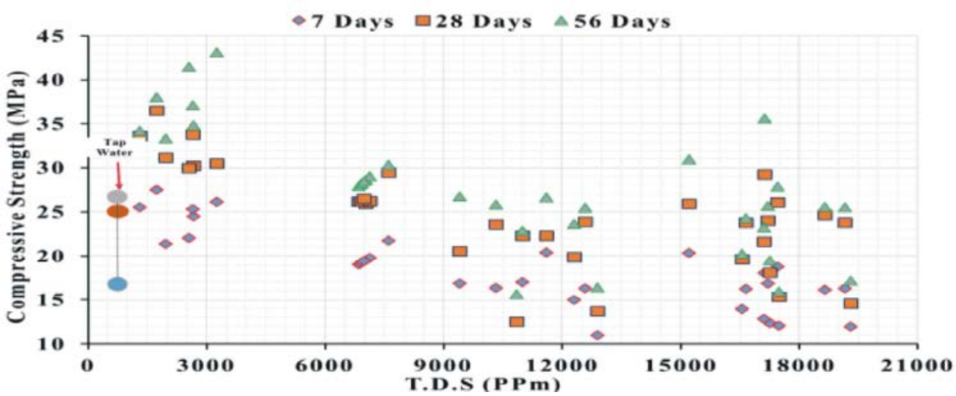

Fig. 6: Effect of T.D.S. on mortar compressive strength

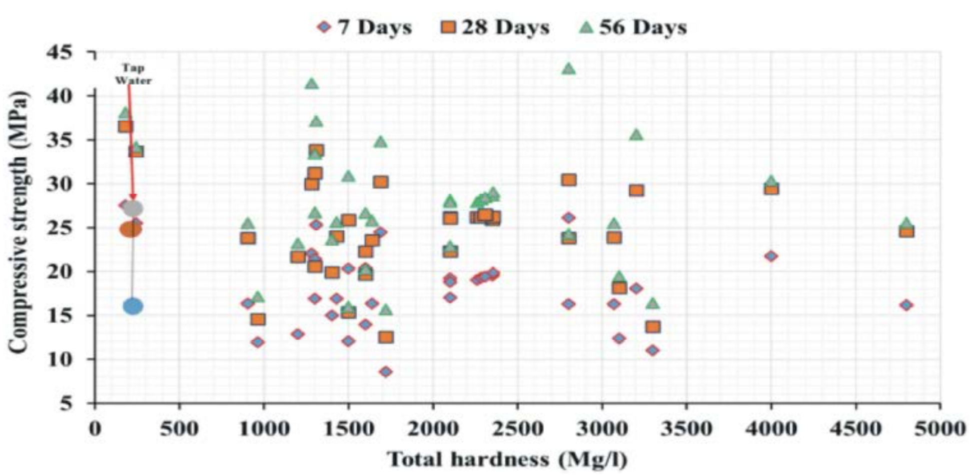

Fig. 7: Effect of Total Hardness on mortar compressive strength

However, the significant increase of T.D.S value (i.e. more than 9000 ppm) in SW decreased the mortar strength which may be related to an increase in chloride and sulfate concentrations which have an adverse effect on mortar strength.

2) Figure (7) shows that mortar specimens cast using SW samples of Total Hardness less than or equal to TW (i.e. less than 310 ppm) and have higher alkalinity than TW gave higher mortar compressive strength than TW. For example, samples C and I reached 38.09 and 34.23 MPa

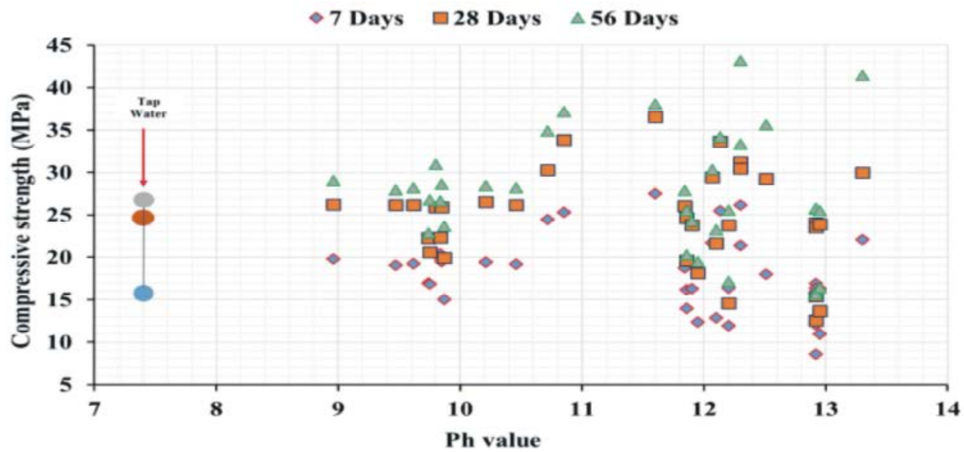

Fig. 8: Effect of pH on mortar compressive strength

respectively at 56 days in comparison to 27.13 MPa for TW. This can be related to:

- In case alkalinity value is more than the total Hardness value, all hardness is expected to be carbonate hardness [21]. The carbonate hardness makes colloidal matters that can close voids in the mortar and accordingly increase strength.
- High value of hydrated lime concentration $Ca(OH)_2$, as a result of the hydration process, attacks the silicates (C_2S, C_3S) and forms calcium silicate hydrated C-S-H which is almost insoluble, forming a gelatinous mass with cohesive manner which increase and improve the compressive strength [22].
- Either in this low range of hardness, the SW samples contain high concentration of colloidal matter (high turbidity) which improve cement hydration and accordingly the mortar strength as discussed before. However, using SW as mixing water in samples in which hardness ranged (i.e. 500 to 5000 ppm) showed reduction in the mortar compressive strength. This can be attributed to an increase in non-carbonated hardness, as the Total Hardness value for those samples was more than the Alkalinity value. The non-carbonated hardness of calcium, magnesium and iron are soluble and accordingly lead to strength reduction.

3) Figure (8) shows that mortar specimens had higher compressive strength when cast using SW having pH values that ranged between 10 to 11.5, if compared to case of using TW. For example, samples (A, B, C and T) at 56 days reached (34.83, 37.16, 38.09 and 28.48 MPa respectively) in comparison to 27.13 MPa for TW. This increase can be related to the better hydration of calcium silicates (C_2S, C_3S) forming calcium silicate hydrate (C-S-H) and accordingly higher strength. In addition, dissolved $Ca(OH)_2$ -from hydration process- and forms colloidal of calcium carbonate which increase the strength by closing microstructural pores.

However, the mortar strengths decreased for pH values between 11.5-13. For this range of pH, the sulfate concentrations also increased for these SW samples. Therefore, strength reduction can be a result of formation of ettringite (C-S-H)/ monosulfate.

Two forms of ettringite are usually formed depending upon the pH of the pore solution:

- At pH = 11.5-11.8 → crystalline ettringite precipitates from solution.
- At pH = 12.5-12.8 → formation of a non-crystalline material that has a similar composition to ettringite. These ettringite crystals expand and decrease mortar mass and strength.
- Further, the increase of pH for values higher than 13 dissolves ettringite according to the following reaction:

$$3CaO.Al_2O_3.3CaSO_4.31H_2O + 6NaOH \xrightarrow{=} 3Na_2SO_4 + 4Ca(OH)_2 + 2Al(OH)_3$$

As $CaSO_4$ (product of the ettringite reaction) can react with NaOH (as a source of high pH) forming $Ca(OH)_2$ which increases the mortar strength. [23].

4) Figure (9) shows that turbidity of SW is higher than that of TW, which in turn increase the mortar compressive strength until the turbidity reach 350 N.T.Us. For example, samples (A, B, C and D) at 56 days reached (34.83, 37.16, 38.09 and 33.38 MPa respectively) in comparison to 27.13 MPa for TW. Any further increase in

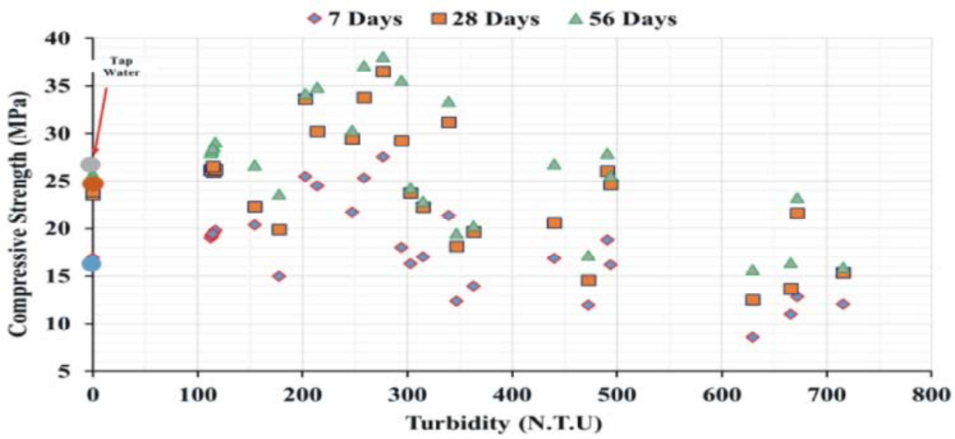

Fig. 9: Effect of Turbidity on mortar compressive strength

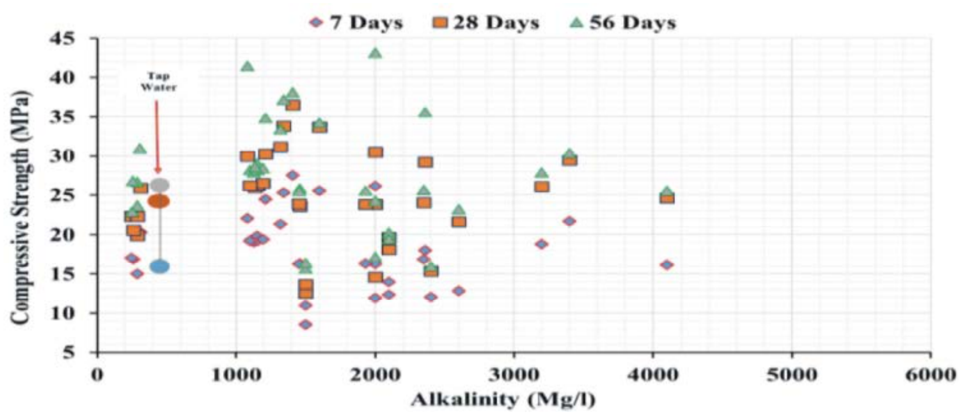

Fig. 10: Effect of Alkalinity on mortar compressive strength

turbidity, decrease the mortar compressive strength. This can be due to limited increase in suspended particles leading to an increase in mortar strength. However, when particles increased -forming dissolved noncarbonated hardness- the mortar strength reduced, as illustrated before.

5) Figure (10) shows that increasing Alkalinity more than 2000 mg/l increased mortar compressive strength, due to the increase in carbonate hardness, which makes calcium, in soluble state combine with silicate to form C_2S or C_3S or combining with Al_2 to form C_3A (cement components), as illustrated before in the effect of total hardness on mortar compressive strength. For example, samples (F, H, G and V) at 56 days reached (30.36, 35.6, 43.14 and 27.93 MPa respectively) in comparison to 27.13 MPa for TW.

6) Figure (11) shows that at low chloride concentration (200-300 ppm) the SW mortar compressive strength is more than that of TW. For example, samples (A and G) at 56 days reached (34.83 and 43.14 MPa respectively) in comparison to 27.13 MPa for TW. While, any further increase in chloride concentration decrease slowly mortar strength. This maybe related to that, chloride ions react with C_3A to form Friedel's salt [24] according to reactions:

$$Ca(OH)_2 + 2NaCl \overset{=}{\rightarrow} CaCl_2 + 2Na^+ + 2OH^- \quad (1)$$

$$C_3A + CaCl_2 + 10H_2O \overset{=}{\rightarrow} C_3ACaCl_2 + 10H_2O \quad (2)$$

$Ca(OH)_2$ (i.e. as a result of hydration) reacts with NaCl to form $CaCl_2$ which react with C_3A to form Friedel's salt ($C_3A.CaCl_2.10H_2O$) which consume C_3A without increasing the mortar strength. Additionally, the ettringite ($C_3A.\ CaSO_4.\ 12H_2O$) react with NaCl forming Kuzzel Salt ($C_3A.\ 0.5CaSO_4.\ 0.5CaCl_2.\ 10H_2O$) according [25] reactions:

$$C_3A.CaSO_4.12H_2O + NaCl \rightarrow 0.5Ca.SO_4.0.5CaCl_2.\ 10H_2O + Na^+ + 0.5SO_4^{2-} + H_2O$$

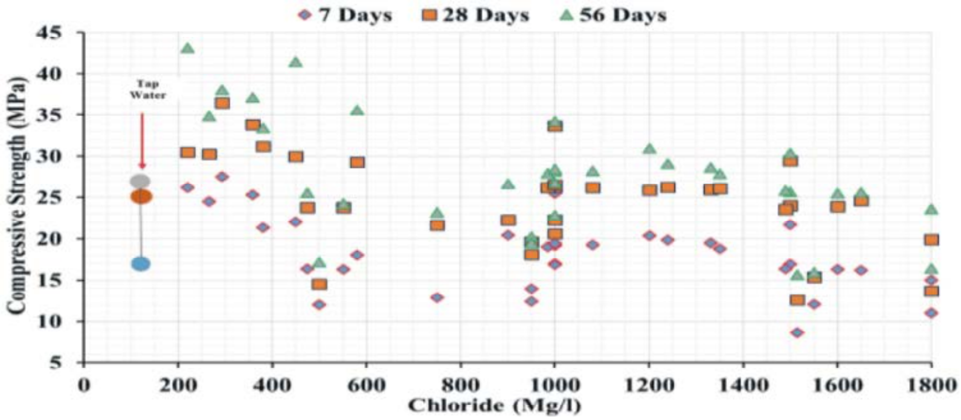

Fig. 11: Effect of Chloride on mortar compressive strength

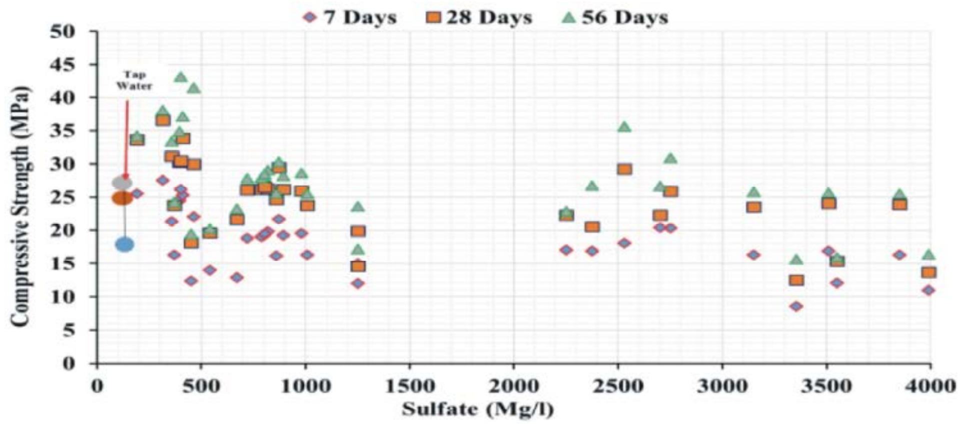

Fig. 12: Effect of Sulfate on mortar compressive strength

These bindins decreases the strength of mortar and increases the concentration of Sodium ions Na+ in the mortar which may cause alkali attack by replacing Si^{4+} ions with Na+ ions in (C-S-H).

7) Figure (12) shows that at low sulfate concentration (i.e. less than 500 ppm), mortar specimen's compressive strength of samples cast using SW were higher than that made of TW. For example, samples (A, B, C and D) at 56 days reached (34.83, 37.16, 38.09 and 33.38 MPa respectively) in comparison to 27.13 MPa for TW. On the other hand, any increase in sulfate concentration rapidly decrease mortar strength. High sulfate concentration causes expansion and reduces strength of mortar as sulfates react with the aluminum in cement to form ettringite and gypsum Mulwa, *et al*. [26]. On the other hand, decalcification of the C-S-H and accordingly reduction of mortar strength, can occur when high concentration sulfate solution exist with low pH as shown in the following equation, Piazza, *et al*. [27], Atkinson, *et al*. [28] and Diamond, *et al*. [29]:

$$3Ca^{2+} + SiO_3^{2-} + CO_3^{2-} + SO_4^{2-} + 5H_2O \xrightarrow{=} 3CaO.SiO_2 + CO_2SiO_3 15H_2O$$

Section (2): The effect of sludge water samples (fresh + $Ca(OH)_2$ Additives) on the Properties of Mortar Cement Paste.

Physical Properties of Cement Paste: The test results and analyses of the physical properties are as follows:

Standard Consistency of Cement Pastes: Figure (13) shows that cement pastes cast using SW samples in (fresh + $Ca(OH)_2$) state (W+add and Z+add) decreased w/c ratio to reach the standard consistency in comparison to the same SW samples in fresh state (W and Z) (for example, sample W+add decreased the w/c ratio by 10.5% and sample Z+add decreased the w/c ratio by 10% when compared to sample that cast using fresh SW: w/c ratio was for W 0.38 and w/c for W+add 0.34, while w/c ratio was for X 0.36 and w/c for Z+add 0.4). However, cement pastes samples cast using (X+add and Y+add) SW

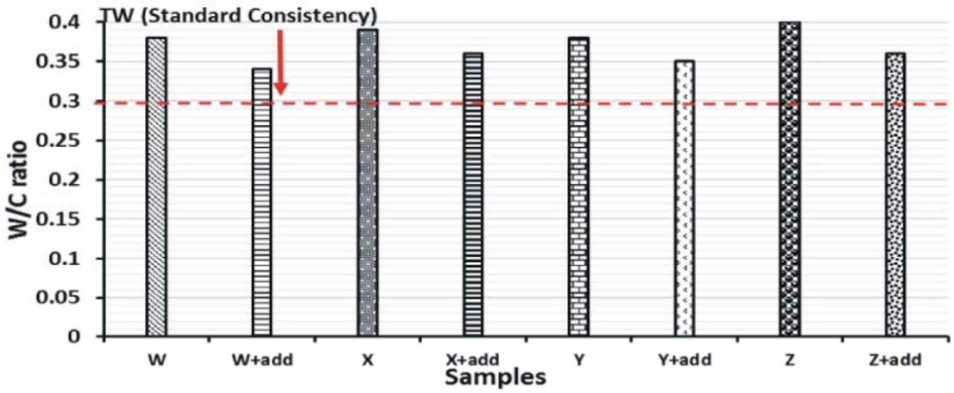

Fig. 13: Standard consistency water/cement of paste specimens cast using different SW samples

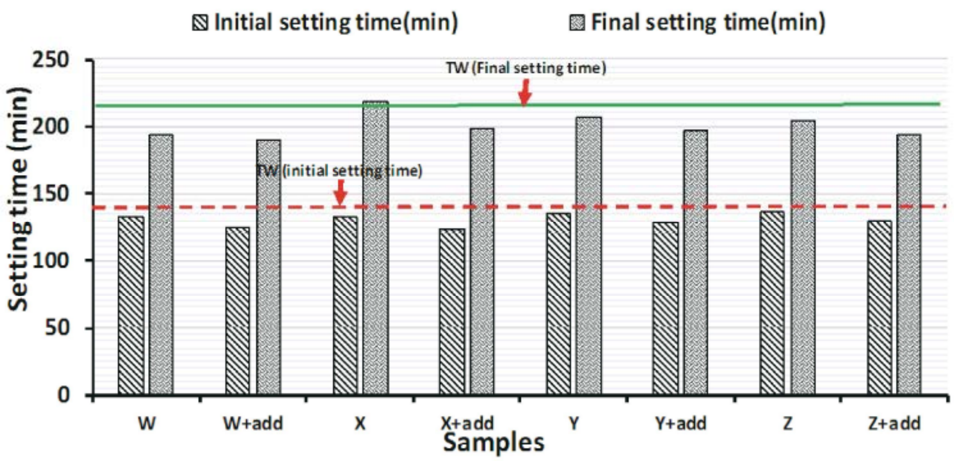

Fig. 14: Initial and final setting times for paste specimens cast using *different SW samples*.

samples had no significant effect on the w/c ratio to reach the standard consistency in comparison to the same SW samples in fresh state (X and Y) (for example sample X+add which had a w/c ratio 0.36 and w/c ratio for X was 0.39, while Y+add which had a w/c ratio 0.35 and w/c ratio for Y was 0.38). The same explanation mentioned previously in section (1), applies here as well.

Setting Time of Cement Pastes: Figure (14) shows that of cement pastes cast using SW samples in (fresh + $Ca(OH)_2$) state (W+add, X+add, Y+add and Z+add) did not significantly affect both the initial and final setting time in comparison to the same fresh SW.

Flow of Mortar Specimens: Figure (14) shows that the flowability of mortar specimens cast using SW samples in (fresh + $Ca(OH)_2$) state (W+add, X+add, Y+add and Z+add) decreased in comparison to the same fresh SW samples. Sample X had its flowability decreased by 13.3%. This perhaps could be attributed to sludge water contained high amount of suspended solids which decreased the flowability of the mortar and the presence of high concentration of $Ca(OH)_2$ increased the rate of hydration and accordingly reduced the flowability.

Mechanical Properties of Mortar Specimens

Compressive Strength of Mortar: Figure (15) shows that replacing TW by (fresh SW with $Ca(OH)_2$ additives) decreased the compressive strength of mortar specimens (W+add and Z+add) at age 56 days in comparison with the same SW samples in fresh state (by about 19.6% for sample Z which had 16.41 MPa compressive strength in comparison to Z+add which had 13.19 MPa). However, the other two samples of SW samples (X+add and Y+add) did not have their compressive strength significantly affected of mortar specimens at age 56 days in comparison with the same SW samples in fresh state. For example, sample X gave 17.17 MPa compressive strength in comparison to X+add which gave 15.10 MPa.

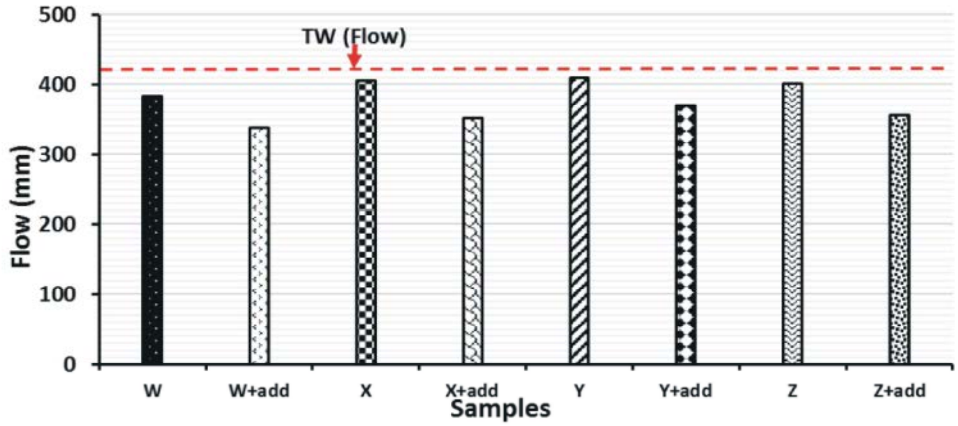

Fig. 15: Flow ratio of mortar specimens cast using different SW samples

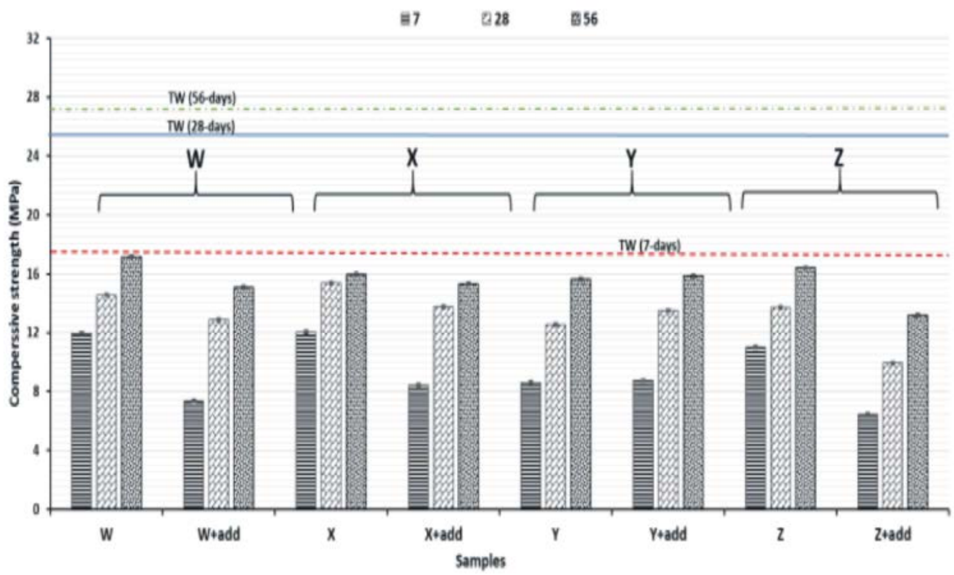

Fig. 16: Compressive strength of mortar specimens cast using *different SW samples*

Flexural Strength of Mortar: Figure (16) was shown that the ratio between the flexural and compressive strength ranged between 0.18 and 0.25, which is close to that when using TW (i.e. 0.20 – 0.25).

Study the Effect of Some SW Samples Chemical Properties on Mortar Strengths: Figures (18) to (24) show that chemical characteristics of SW at different states (i.e. fresh + $Ca(OH)_2$ additives) have different effects on compressive strength of mortar. Figure (18) shows that the mortar strengths for all SW at 7, 28 and 56 days are less than the mortar strensgths for TW. This is because, T.D.S. increased more than 3000 ppm and reached more than 19000 ppm. However, Figure (19) shows that increasing total hardness, decreased mortar strength. Additionally, figure (20) shows that increasing pH value more than 13 increased the mortar strength. Furthermore, figure (21) shows that the turbidity is more than 200 N.T.U., which decreased the mortar strength. Also, figure (22) shows that $Ca(OH)_2$ additives decreased the alkalinity value of SW samples (W, X, Y and Z) and decreased the strength of mortar as discussed before in section (1). Figure 23) shows that the SW mortar specimens strengths was less than the TW mortar specimens strengths and any increase in chloride concentration decreased slowly the SW mortar strength. Finally, figure 24) shows that the SW mortar specimens strengths is less than the TW mortar specimens strengths and any increase in sulfate concentration rapidly decrease SW mortar strengths as discussed before.

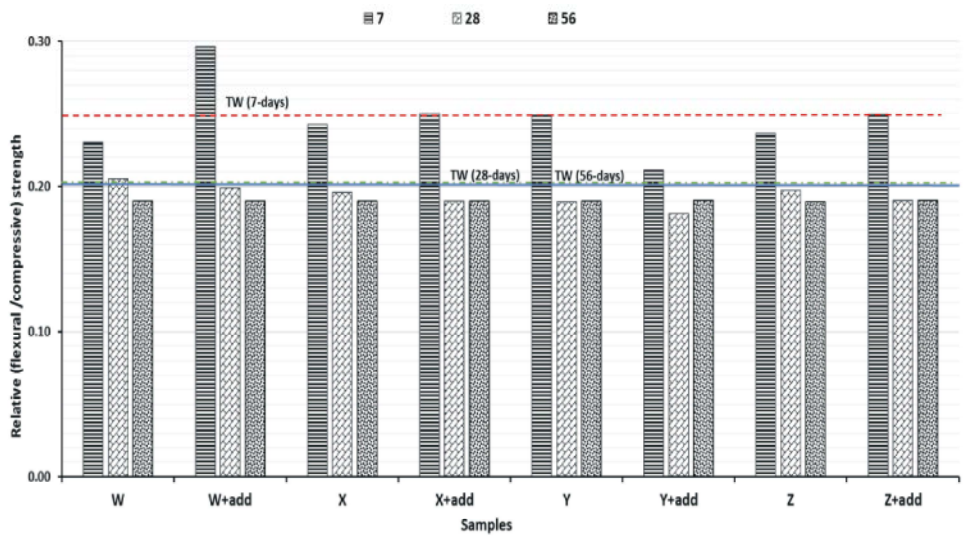

Fig. 17: Relative flexural strength of mortar specimens cast using *different SW samples*

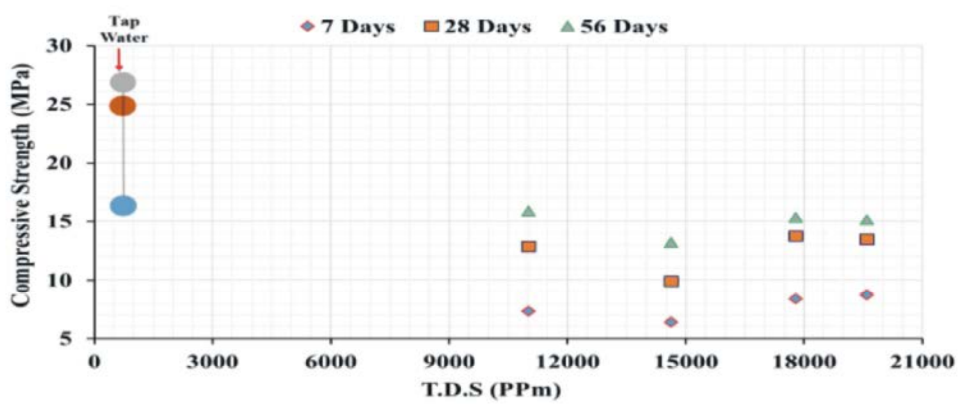

Fig. 18: Effect of T.D.S. on mortar

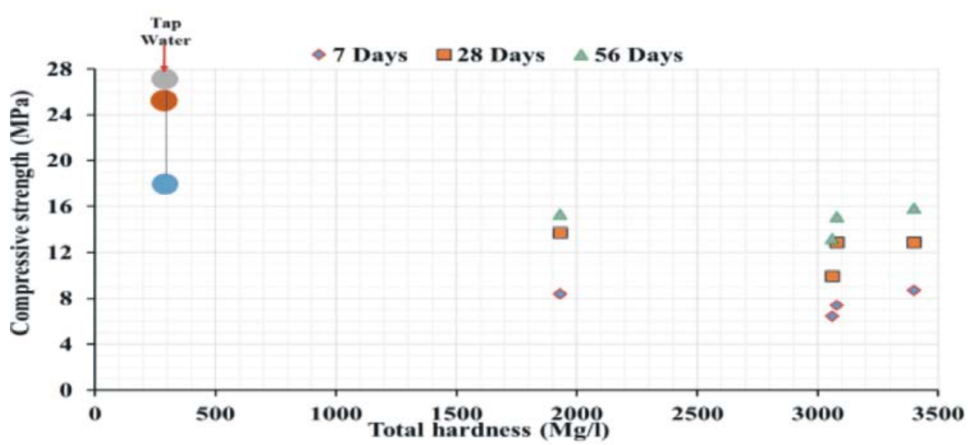

Fig. 19: Effect of Total Hardness on mortar compressive strength

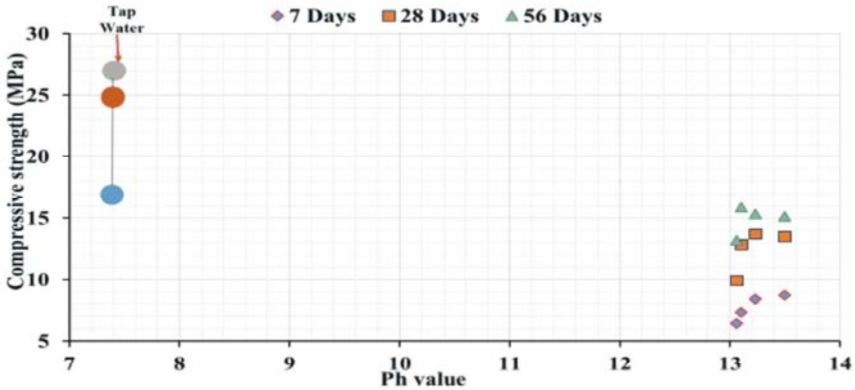

Fig. 20: Effect of pH on mortar compressive strength

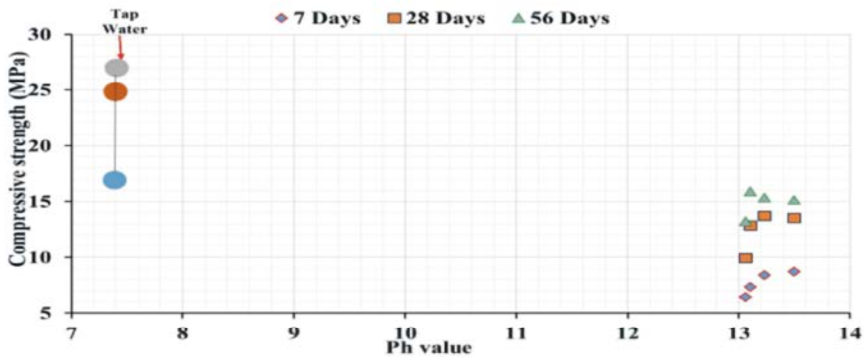

Fig. 21: Effect of Turbidity on mortar compressive strength.

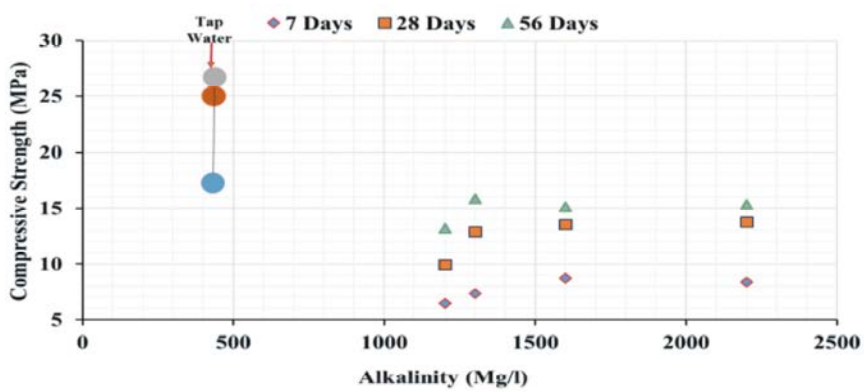

Fig. 22: Effect of Alkalinity on mortar compressive strength

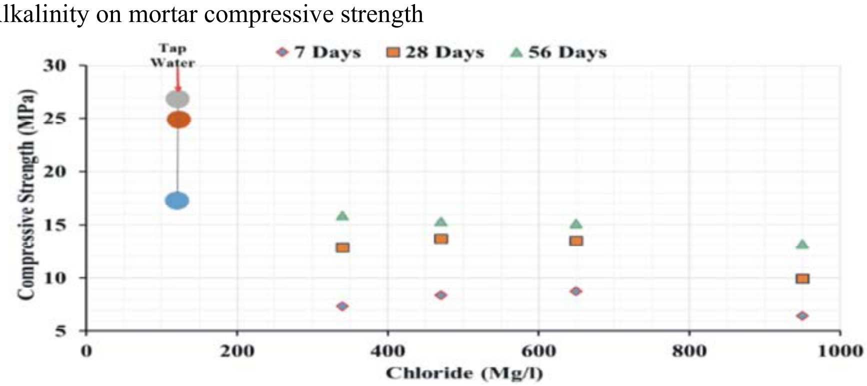

Fig. 23: Effect of Chloride on mortar compressive strength

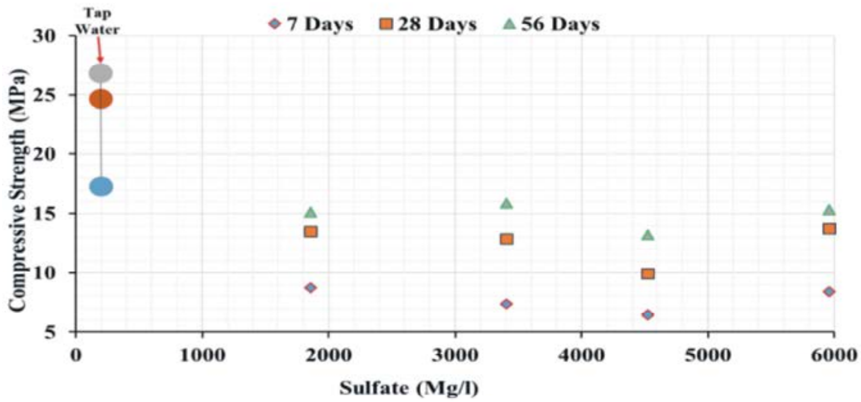

Fig. 24: Effect of Sulfate on mortar compressive strength

CONCLUSIONS

The proposed recycling application of sludge water (SW) showed promising results in special construction applications. Such applications providing economic added value, saving valuable water, protecting the environment and the infrastructure.

- Most of the cement paste specimens needed higher water/cement (w/c) ratio to reach the standard consistency state. Such increment reached 25% for fresh SW samples had alkalinity>1200 mg/l and turbidity>200 N.T.U. On the other hand, filtering or adding $Ca(OH)_2$ to SW reduced such w/c ratio increment.
- Most of the investigated SW samples had minor reduction of initial and final setting times effect (i.e. less than 14%) of cement paste specimens in comparison with tap water (TW). On the other hand, no significant effect was detected due to SW filtration or adding $Ca(OH)_2$.
- No compressive strength reduction was measured when the following proposed limits were respected for all cases of fresh SW (i.e. not treated, filtered and with $Ca(OH)_2$ addition) as mixing water: Alkalinity < 6000 ppm. T.D.S. < 9000 ppm. Total hardness < 4000 ppm. Turbidity < 500 N.T.U.
- When the following more restricted limits were respected, strength enhancement was measured for all cases of fresh SW (i.e. not treated, filtered and with $Ca(OH)_2$ addition) as mixing water: Alkalinity < 6000 ppm. T.D.S. < 3500 ppm. Total hardness < 3000 ppm. Turbidity < 350 N.T.U.

Generally, replacing mortar mixing TW with different investigated states of SW (i.e. fresh, filtered and having $Ca(OH)_2$ additives) had relative flexural/compressive strengths ranged between (0.17 – 0.26) which was close to that using TW (0.20-0.25).

References

1. Low, G.L., K.Y. Ng, C.T. Tam. and R.B.W. Heng, 2007. Use of recycled cement based slurry water for making," Journal -The Institution of Engineers, Vol. 68, No.4, Malaysia, pp 47-55, 2007.
2. Zervaki, M., C. Leptokaridis and S. Tsimas, 2013. Reuse of By-Products froms Ready-Mixed Concrete Plants for the Production of Cement Mortars, J. sustain. Dev. Energy Water Environment. Syst., 1(2): 152-162.
3. Chatveera B. and P. Lertwattanaruk, 2009. Use of ready-mixed concrete plant sludge water in concrete containing an additive or admixture, Journal of Environmental Management 90: 1901–1908,2009, www.elsevier.com/locate/jenvman.
4. Sandrolini F. and E. Franzoni., 2011. Waste wash water recycling in ready-mixed concrete plants, Cement and Concrete Research, pp: 485-489.
5. Sabriani, S. and E.H. Chan, 2010. The effect of waste wash water on concrete properties, Civil engineering and earth resources university Malaysia Pahang, 2010.
6. Chini, S.A. and W.J. Mbwambo, 1996. Environmentally friendly solutions for the disposal of concrete wash water from ready mixed concrete operations, Proceedings of CIB W89, pp: 21-24.
7. Chatveera, B., N. Makul and P. Lertwattanaruk, 2006. Effect of sludge water from ready-mixed concrete plant on properties and durability of concrete, Cement& Concrete Composites, 28: 441-450.

8. Tsimas, S. and M. Zervaki, 2011. Reuse of waste water from ready-mixed concrete plants, Chemical Engineering, 22(1): 7-17,2011, www.emeraldinsight.com/1477-7835.htm.
9. Beatrix, K., 2007. Effects of Substances on Concrete and Guide to Protective Treatments, Concrete Technology, Portland Cement Association, ISBN 0-89312-193-2, 2007.
10. Gholamreza, A., A. Mohsen, J. Hamidreza, M. Abdolmohammad and A. Rashin, 2015. Experimental and statistical studies of using wash water from ready-mix concrete trucks and a batching plant in the production of fresh concrete, Construction and Building Materials, 98: 305-314.
11. Nan, S., M. Buquan and L. Fu-Shung, 2002. Effect of wash water and underground water on properties of concrete, Department of Construction Engineering, University of Science and Technology, Cement and Concrete Research, 32: 777-782 15.
12. Colin, L., 2003. Recycled Water in Concrete, National Ready Mixed Concrete Association, Concrete Technology, December 2003.
13. Gholamreza A., M. Asadi, H. Jafari and A. Moradi, 2015. Experimental and statistical studies of using wash water from ready-mix concrete trucks and a batching plant in the production of fresh concrete, Construction and Building Materials, 98: 305-314, 2015, www.elsevier.com/locate/conbuildmat.
14. Sealey, B.J., G.J. Hill and P.S. Phillips, XXXX. Review of Strategy for Recycling and Reuse of Waste Materials, University College Northampton, United Kingdom.
15. Sealey, B.J., P.S. Phillips and G.J. Hill, 2001. Waste management issues for the UK ready-mixed concrete industry, University College Northampton, Avenue Campus, St. Georges Avenue, Northampton NN2 6JD, UK Resources, Conservation and Recycling, 32: 321-331.
16. Standard Methods for water and waste water analysis 22nd Editions
17. ES 4756-1, Cement Part (1) Composition, Specifications and Conformity Criteria for Common Cements.
18. ES 2421-1, Physical and Mechanical Test of Cement-Part (1): Determination of Setting Times and Soundness.
19. Neville, A.M., 2011. Properties of concrete, Fifth Edition.
20. Steinour, H.H., 1952. The reactions and thermochemistry, of cement hydration at ordinary temperature, Proc. 3rd Int., Symp. on the Chemistry of Cement, pp: 261-89, (London, 1952).
21. principle chemistry, Steven Zumble 5th edition 2003.
22. Bernal, J.D., J.W. Jeffery and H.F.W. Taylor, 1952. Crystallographic research on the hydration of Portland cement, A first report on investigations in progress, Mag. Concr. Res., 3(11): 49-54.
23. Day, R.L., 1992. The effect of secondary ettringite formation on the durability of concrete, A literature analyses, research and development bulletin RD108T, Portland cement association, Skokie, Illionios, U.S.A. 1992.
24. Satoshi, O., O. Mitsunori, I. Tsukasa and S. Hisashi, 2016. Succession of Sulfur-Oxidizing Bacteria in the Microbial Community on Corroding Concrete in Sewer Systems" Environmental Microbiology, vol. 73 No. 3: 971-980, 2007. kato Y., Naomachi S. and kato E., "Changes in chloride penetration properties caused by reaction between sulfate ions and cement hydrates," Civil Engineering Department, Faculty of Science and Technology, Tokyo University of Science, pp: 554-561, 2016.
25. Mulwa, M.O., T.J. Karanja and M.J. Wachira, 2016. Effect of sulphate ions in mixing water on cement mortar perfosrmance, IOSR Journal of Applied Chemistry (IOSR-JAC), 9(1): 11-15.
26. Piazza, L.V., M. Politecnico and K. Milan, 2002. Sulphate Attack of Concrete Building Foundations Induced by Sewage Waters, Cement and Concrete Research, El Sevier journal, Vol. 32, No.6, Millan, New Delhi, pp: 843-849.
27. Atkinson, A. and J. Hearne, 1990. Mechanistic Model for the Durability of Concrete Barriers Exposed to the Sulphate Bearing Ground Water, Scientific basis for nuclear waste management, No. 176, U.S.A., pp: 149-151, 1990.
28. Diamond, S., 1996. Delayed Ettringite Formation Processes and Problems, Cement and Concrete Composites, 18: 205-215.
29. Diamond, S., 1996. Delayed Ettringite Formation Processes and Problems, Cement and Concrete Composites, 18: 205-215.