Effect of treated wastewater on properties of high strength concrete mixture

By

Mohamed A. E. Halawa[1, *], Saeed Al-Sheikh[2]

[1]Lecturer of Sanitary & Environmental Engineering at Civil Engineering Department, Higher Institute of Engineering at 15th May, Cairo, Egypt. mohamed.34911@yahoo.com Tel.: +20-1116484402.
[2]Lecturer of Structural Engineering at Civil Engineering Department, Higher Institute of Engineering at 15th May, Cairo, Egypt. saeedalsheikh@yahoo.com Tel.: +20-1223443895.
[*]Corresponding Author E-mail: mohamed.34911@yahoo.com

Abstract

Concrete industry in Egypt is consuming enormous amounts of fresh water (FW) for cement hydration and washing aggregate. Increasing of population led to increasing of water consumption, so providing the alternative is an important to save fresh water. In this research, four types of treated wastewater were used for concrete industry. The wastewater samples were collected from Zenien wastewater treatment plant in Giza, Egypt. Primary, biological, tertiary treated wastewater (TTWW) and treated grey water with sediment process only were used, and compare the results with those of concrete mixture using fresh water as a control sample. This paper shows the effect of using treated wastewater to mix the high strength concrete mixture on its properties and compare the results with concrete mixture using FW. In the experimental tests, primary, secondary, tertiary treated wastewater, treated grey water and FW were used as mixing water. The following properties of concrete were tested: compressive, tensile, flexure strength at ages of 3, 7, and 28 days, initial setting time, final setting time and pH value. The use of primary, secondary, TTWW and treated grey water as mixing water increases the final setting time of up to 14%, 6%, 3.5%, and 9.5% respectively compared with FW. The results confirm the possibility of using tertiary treated wastewater in high strength concrete mixture.

Keywords: Treated wastewater; Concrete industry; High strength concrete; Tertiary treated wastewater and Setting time.

1. Introduction

Concrete industry consumes huge amounts of fresh water for cement hydration and washing aggregate; so concrete industry has a serious effect on water shortage. For these reasons, reuse of treated wastewater is an important alternative to save the fresh water [1]. Many studies have experienced for different types of wastewater such as primary, biological, and tertiary TWW. However, using domestic wastewater in concrete industry has been rarely studied in the literature [2]. Using mixture of treated effluents and the fresh water in concrete industry with a percentage of 20% and 80%, respectively, provided that strength reduced compared with specified values in various codes [3]. Using TWW as mixing water in concrete curing is possible according to standard specification in concrete codes [4]. In Tehran, Iran; using effluent TWW from primary and secondary treatment as mixing water to produce concrete samples specified that compressive strength at 28 days was more than 90% of the compressive strength of the control sample of fresh water [5]. Al-Jabri et al. (2011) concluded that concrete strength was prepared by using treated wastewater was similar to the concrete strength using fresh water [6].

Egypt suffers from water shortages due to increasing of population [7]. Approximately 150 liters of water is required for 1 m^3 of concrete [8], so using treated wastewater in the concrete industry can save a lot of fresh water [9]. The fresh water is still being used as mixing water in concrete industry. Nowadays, the fresh water resources are becoming scarce [10]. Untreated wastewater is a hazard to public health, so wastewater treatment is critical for the environment. Wastewater treatment consists of three main stages; the first stage is called primary treatment; suspended matters were removed from sewage effluent. The second stage is called secondary treatment; settleable solids and suspended organic were removed. Tertiary treatment is a third stage of wastewater treatment that can achieve levels of water purification. Grey water is water collected from baths [11].

2. Experimental Program (Methodology of Work)

2.1 Samples from Zenien wastewater treatment plant (WWTP)

Zenien WWTP is located on the west of the bank of Nile River in Giza Governorate, Egypt. Zenien WWTP is accomplished by 4 basic techniques; physical, mechanical, biological, and chemical. Physical methods of treatment include structures designed to control the flow of wastewater to support the removal of contaminants. Zenien WWTP consists of 12 primary settling tanks, 36 aeration tanks and 12 secondary settling tanks and an odor control system as shown in figure (1). Three samples of treated wastewater were collected from Zenien WWTP in addition to a fourth sample of grey water from the pilot plant model. Sample No. (1), was collected from primary clarifier is called primary TWW (PTWW). The second sample was collected from final clarifier is called secondary TWW (STWW). The third sample signifies treated wastewater after chlorine addition, and the fourth sample of using treated grey water (TGW). Sample No. (3), was collected from tertiary TWW, and final sample No (4) represent treated grey water (TGW). Samples were collected and moved to the laboratory. Collected samples were transported to the laboratory of materials. These samples were analyzed for total suspended solids (TSS), biological oxygen demand (BOD_5) and, finally, chemical oxygen demand (COD).

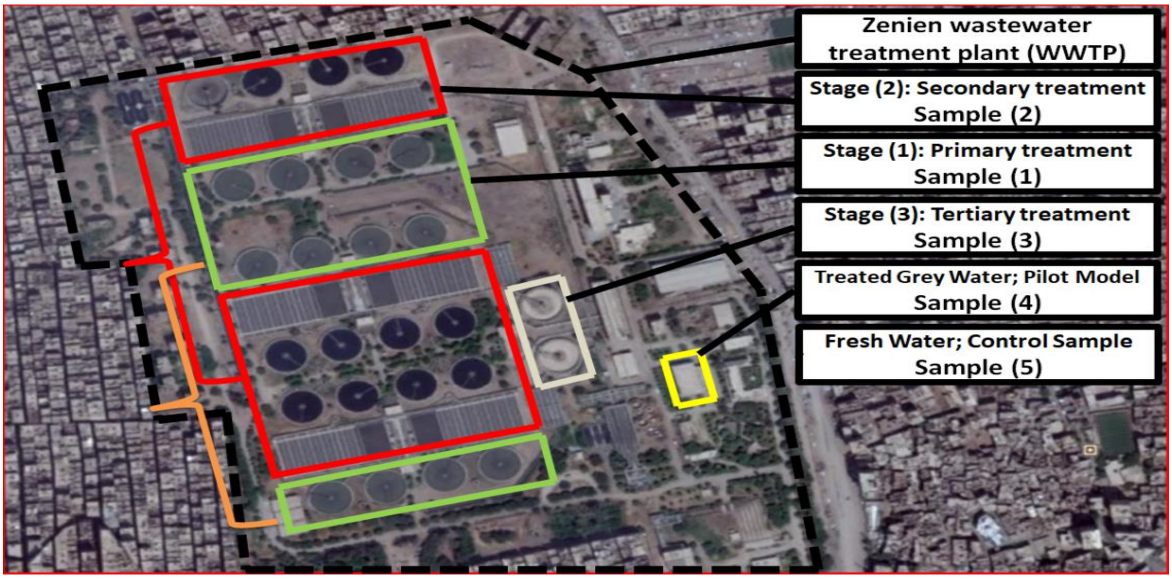

Figure (1): Stages of Zenien wastewater treatment plant (WWTP)

2.2 Properties of materials used in concrete mixes

2.2.1 Mixing water:

The criteria for approval of using TWW in concrete industry are based on physical and chemical testing results. Physical and chemical tests refer to remaining suspended and dissolved matters in treated wastewater which have an effect on setting time and compressive strength. Five types of water samples were used in this study; primary treatment consists of screening and a primary clarifier. Secondary treatment consists of aeration tank and final clarifier. Micro-organisms are grown in an aeration tank and they consume the dissolved organics to be easy for settle in final settling tank. Tertiary treatment aims to remove nitrogen and phosphorous from treated wastewater. Finally, grey water from basin without toilets. Analyzing chemical and physical characteristics of wastewater is considered an important data in the wastewater treatment process, as shown in table (1).

Table (1): Chemical composition and physical properties of treated water

Sample No.	Type of Treatment	Chemical composition and physical properties of treated water						
		pH (Unit)	Temp. (º c)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	TDS (mg/l)	Chloride (mg/l)
Requirements of concrete codes for mixing water (WHO)*		6-8	24-28	< 2000	< 10	< 50	< 1000	< 2000
1	PTWW	7.2	26.9	89	87	180	177	138
2	STWW	7.4	26.6	14	12	29	25	124
3	TTWW	7.2	26.4	1	2	9	2	21
4	TGW	7.6	26.1	31	44	69	54	129
5	FW	7.8	25.4	0	0	1	0	28

*** World health organization (WHO): permissible limits according to ASTM C94 [12].**

2.2.2 Ordinary Portland cement:

Cement used in this study was ordinary Portland cement 53 grade cement (OPC) according to the new Egyptian specifications from Helwan Factory in Cairo, Egypt was used. Its physical properties and chemical analysis are shown in table (2).

2.2.3 Fly ash:

Fly ash is a fine gray powder consisting mostly of spherical, glassy particles that are produced as a byproduct in coal-fired power stations. Table (2) showed physical and chemical properties of used fly ash.

Table (2): Chemical composition and physical properties of Fly Ash

Description	Ordinary Portland cement	Fly ash
	Value	Value
Physical properties:		
1- specific Gravity	3.15	2.68
2- Fineness passing 45μm (%)	90	81.7
Chemical analysis:		
1- Lime (CaO)	60.0 %	36.5 %
2- Silicon Dioxide (S_iO_2)	24.0 %	40.9 %
3- Aluminum Oxide (Al_2O_3)	6.0 %	18.6 %
4- Magnesium Oxide (M_gO)	2.0 %	1.3 %
5- Iron Oxide (Fe_2O_3)	4.0 %	0.85 %
6- Na_2O and K_2O	1.25 %	1.0 %
7- Sulphur trioxide (SO_3)	2.75 %	0.85 %

2.2.4 Aggregate:

Aggregates are considered as a filling material to increase the strength of the concrete. Aggregates consist of fine and coarse aggregate.

2.2.4.1 Coarse aggregate

Crushed dolomite of 19 mm maximum nominal size was used as the coarse aggregate with specific gravity of 2.69; absorption 2.46%, the specific surface area of 2.367 cm^2/gm, fineness modulus 6.9 and crushing value is equal to 17.78 %.

2.2.4.2 Fine aggregate

Local natural sand is used as a fine aggregate with fineness modulus of 2.65, specific gravity is 2.70, absorption of 81%, unit weight is 1.68 t/m^3, and voids ratio 31.7%.

2.2.5 Super-plasticizer:

In order to develop the workability of high strength concrete, Addicrete BVS is a super plasticizer concrete admixture for high range water reduction. This had 3 % from cement weight according to: [ASTM C 494 type G], [EN 934-2] and Egyptian specification requirements [ES 1899]. A commercially available type-high range water reducing super-plasticizer was used.

2.2.6 Silica Fume:

Silica fume used in high strength concrete production and its compacted powder with SiO_2content of 93.6 %. Detailed physical properties and chemical analysis are as shown in table (3).

Table (3): Chemical composition and physical properties of Silica Fume

Description	Value
Physical properties:	
1- specific Gravity	2.23
2- Fineness passing 45µm (%)	92.2
3- Specific surface area (cm^2/gm)	230000
Chemical analysis:	
1- Silicon Dioxide (S_iO_2)	93.6 %
2- Aluminum Oxide (Al_2O_3)	0.50 %
3- Ferrio Oxide (Fe_2O_3)	1.50 %
4- Calcium Oxide (C_aO)	0.90 %
5- Magnesium Oxide (M_gO)	0.60 %
6- Sodium Oxide (Na_2O)`	0.04 %
7- Sulphur trioxide (SO_3)	0.30 %

2.3 Materials, Samples preparation and testing

For the preparation of high strength concrete mixtures for this study, American Concrete Institute (ACI) specifies that, the compressive strength is above 40 MPa ~ 408 kg/cm^2 or 6000 psi ~ 421 kg/cm^2. Five high strength concrete mixtures were prepared with constant mix proportions are shown in table (4). Each sample contains nine concrete cubes (150 * 150 * 150 mm) for compression test, nine concrete cylinders (100 * 200 mm) for tension test and nine concrete reinforced beam samples (150 * 150 * 750 mm) for bending test as shown in figure (2). One hundred thirty-five concrete cube samples of high strength concrete mixtures were prepared for age of concrete (3, 7 and 28 days) for all tests as shown in figure (3).

Table (4): Mix proportions and water-to-cement (w/c) ratios for concrete mixtures

Mix proportions (kg/m^3)						
Cement (kg/m^3)	Silica fume (15%) - kg/m^3	Sand (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (L) - (kg/m^3)	W / C ratio (kg/m^3)	Super-plasticizer (l/m^3) (3%) - (kg/m^3)
475	71.25	450	1200	115	0.25	14.25

Figure (2): Materials, Samples preparation in laboratory

2.4 Laboratory testing program

Three laboratory tests (compressive strength, tensile strength, flexural strength) were prepared. Compressive strength test is a damaging test of concrete in order to determine the strength of the concrete and it plays a very important role to determine the strength difference in concrete cubes using potable water as well as TWW, which are calculated on 7^{th}, 14^{th} and 28^{th} day, respectively. Flexural strength was prepared by using beams were cast by using different types of water. Finally, the results of this experimental work are compared with the recorded values of observation. The setting time test was also made on freshly mixed concrete with different types of mixing water according to ASTM standard C403/C403M-99. Figure (3) illuminates the flowchart of the steps of experimental work.

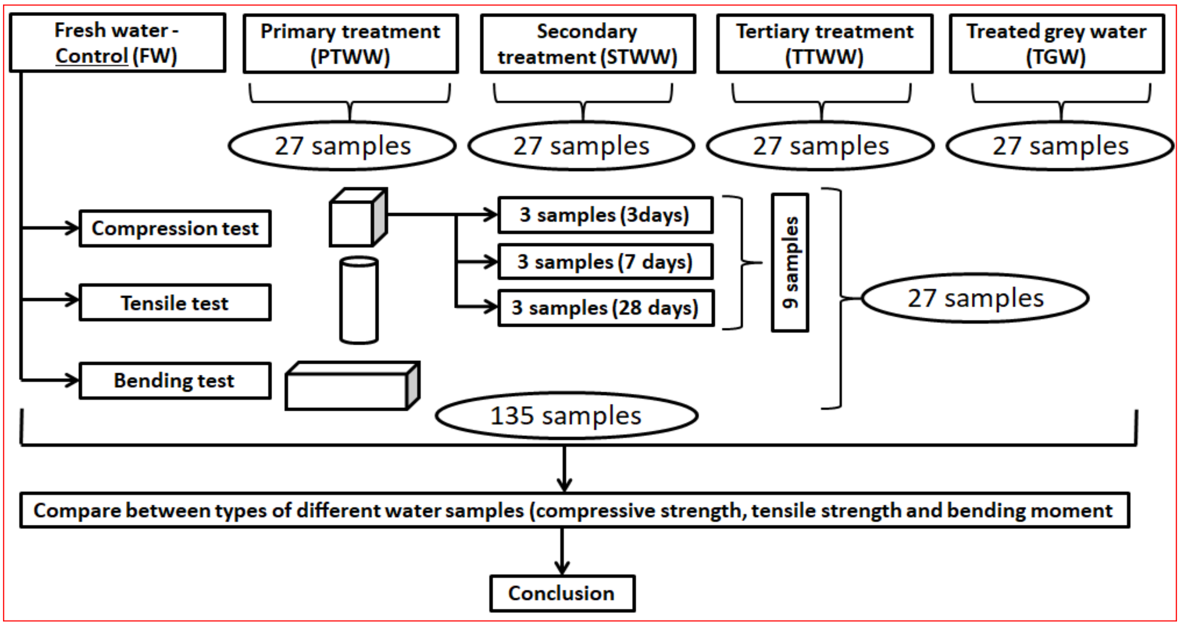

Figure (3): The Work Program Flow Chart

3. Results and discussion

3.1 Compressive strength test results

In this paper, different types of effluent treated wastewater (TWW) were tested in laboratory at different curing time (3, 7, and 28 days). Four types of water were used as a mixing water in the compression test; PTWW, STWW, TTWW, TGW and compared the results with concrete mixture using fresh water (FW) as a control sample. Figure (4) shows the influence of different types of TWW as mixing water at various curing age. The compressive strength of high strength concrete is increased by 3.6 % for tertiary treated wastewater (TTWW) at end of 28 day as compared to fresh water. The compressive strength of high strength concrete by mixing (PTWW, STWW and TGW) was not affected and there were no significant differences in compressive strength.

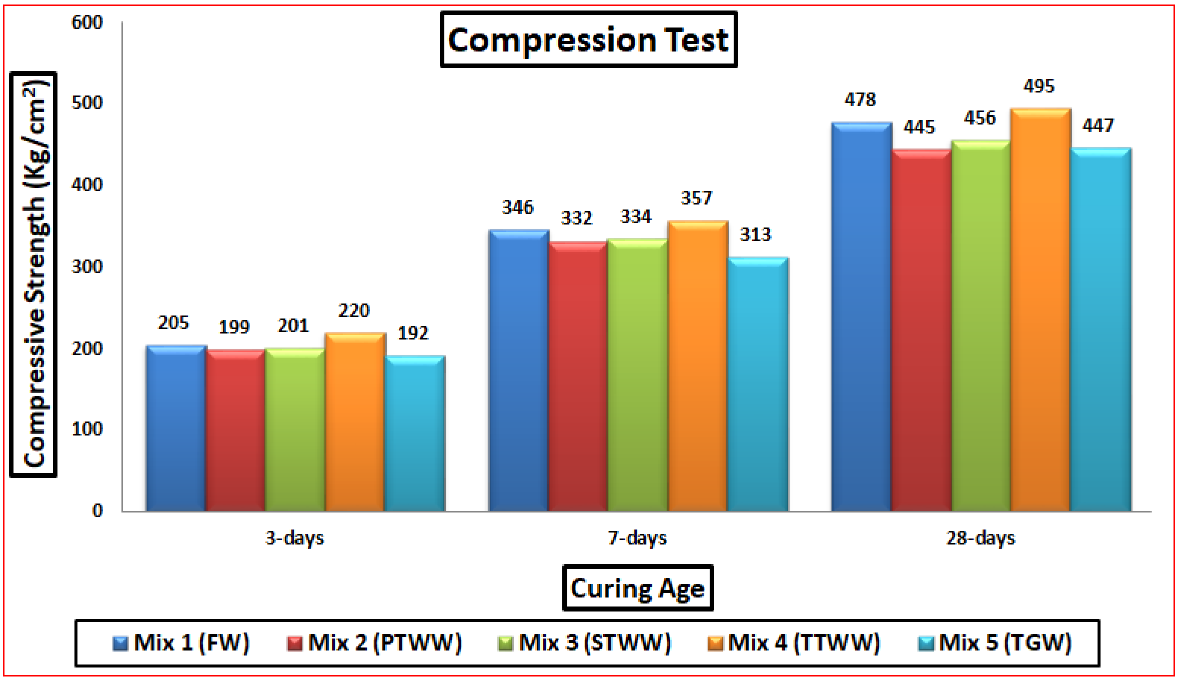

Figure (4): Influence of different types of Treated wastewater on Concrete compressive strength at various curing age

3.2 Tensile strength test results

The same types of water were used as a mixing water in tension test; PTWW, STWW, TTWW, TGW and compare the results with concrete mixture using FW. Figure (5) shows the influence of different types of treated wastewater on concrete tensile strength at various curing ages (3, 7, and 28 days). The tensile strength of high strength concrete is increased by 11.5 % for tertiary treated wastewater (TTWW) at end of 28 days as compared to fresh water. The tensile strength of high strength concrete by mixing (PTWW, STWW and TGW) was less than the tensile strength of high strength concrete which was mixed with fresh water.

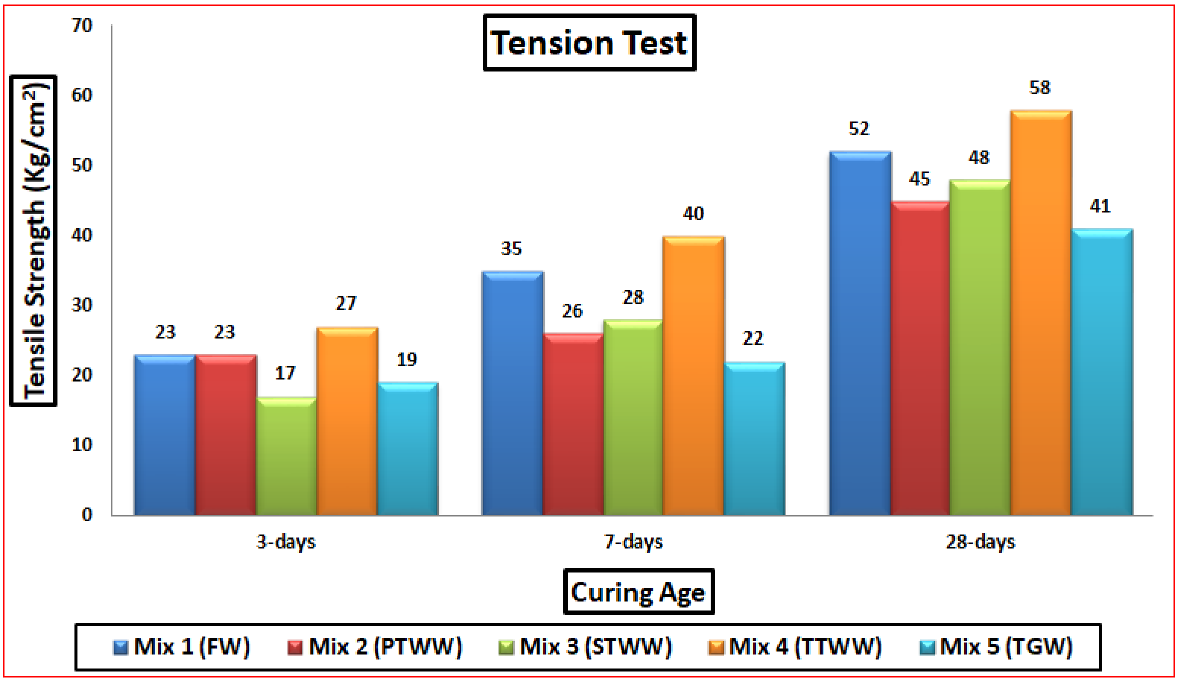

Figure (5): Influence of different types of Treated wastewater on Concrete tensile strength at various curing age

3.3 Flexural strength test results

The flexure strength of high strength concrete was recorded at maximum strength with tertiary treated wastewater by 6.1 % at end of 28 days as compared to fresh water. Figure (6) shows the effect of different types of treated wastewater on the concrete industry for 3 days, 7 days and 28 days. The flexure strength of high strength concrete by mixing (PTWW, STWW and TGW) was less than the flexure strength of high strength concrete which was mixed with fresh water.

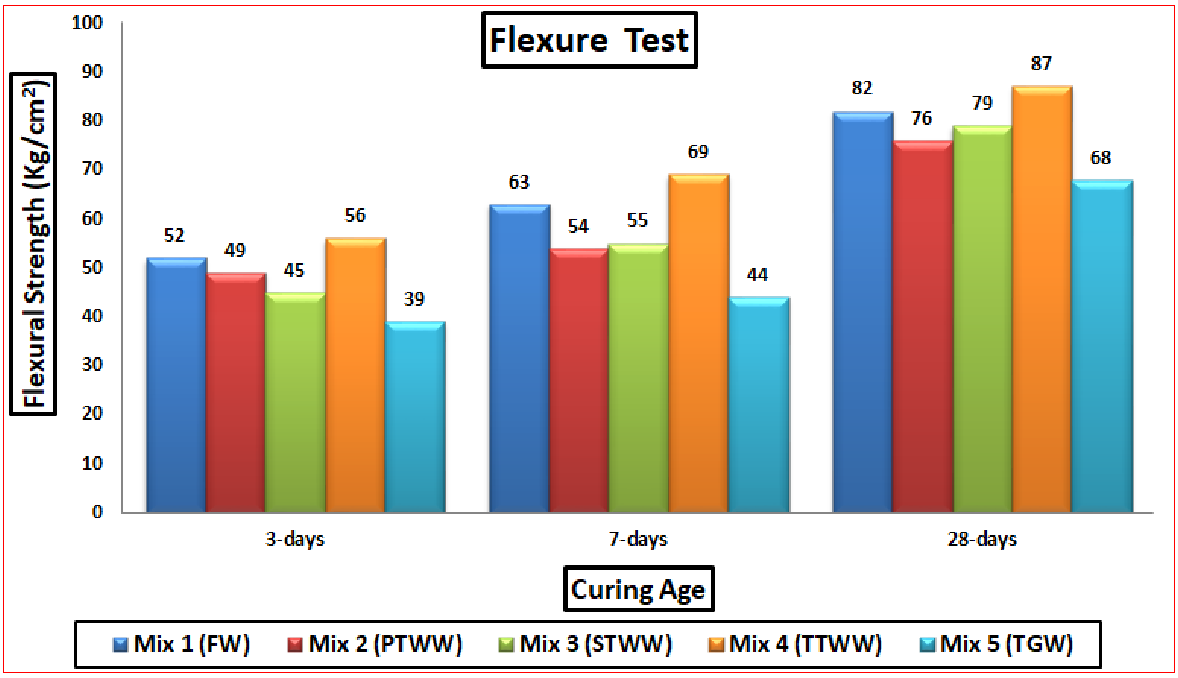

Figure (6): Influence of different types of Treated wastewater on Concrete bending moment at various curing age

3.4 Setting time test results

The effect of different types of mixing water on initial and final setting times is shown in figure (7). Concrete made with treated wastewater exhibited longer setting times because of the presence of organic matter in the water as indicated by the higher COD concentration in PTWW as shown in table (1). Figure (7) show that initial setting time of concrete is increased by 24%, 5.5%, 2%, and 15% for PTWW, STWW, TTWW and TGW, respectively as compared to fresh water. The initial setting time of concrete for TTWW is very close to the same as the initial setting time of the fresh water. The final setting time was delayed by 14%, 6%, 3.5%, and 9.5% for concrete made with PTWW, STWW, TTWW and TGW, respectively, as compared to concrete made with fresh water as shown in figure (7).

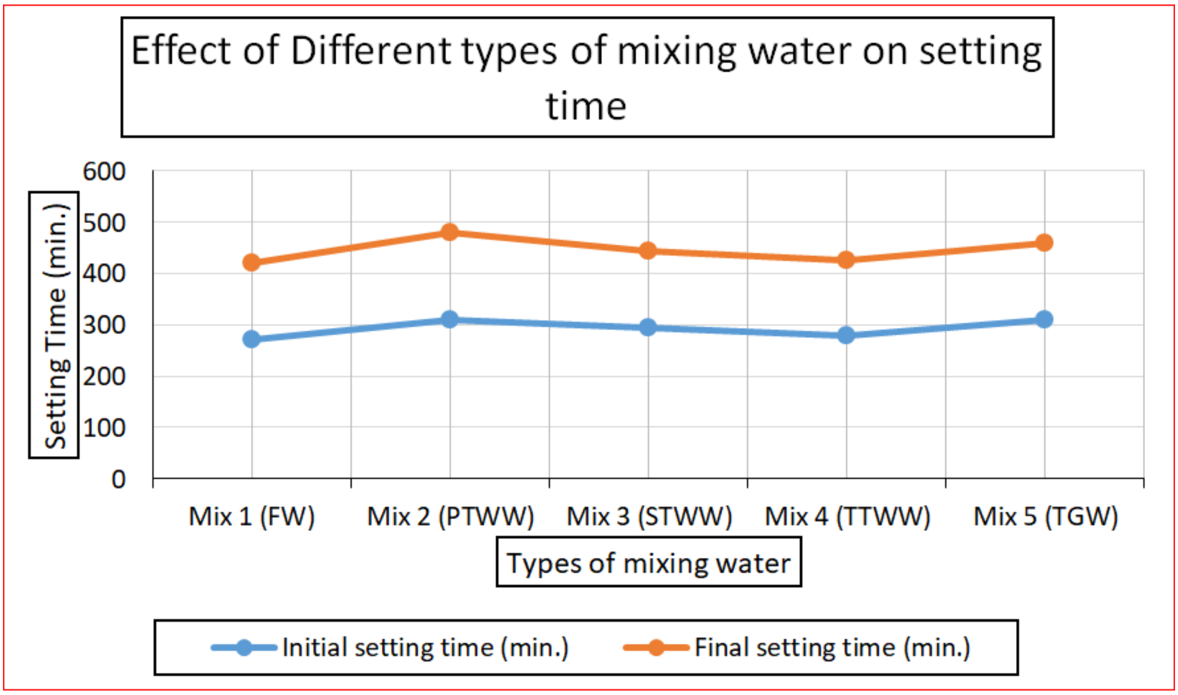

Figure (7): Effect of Different types of mixing water on setting time

4. Conclusions

The analytical results of the quality of treated wastewater tested from Zenien WWTP as mixing water in high strength concrete and the allowable limits of mixing water for concrete show that using of treated wastewater is suitable for concrete production. The experiment concluded that;

1. In case of using treated wastewater as mixing water in concrete, compressive, tensile, and flexure strength have not harmful effects after 28 days. In contrast using TTWW improves the strength of concrete.
2. In the compression test, different types of treated wastewater (PTWW, STWW and TGW) gave strength less than the strength was mixed with fresh water at 28-day by (-7.4%, -4.8% & -6.9%).
3. The 28-day compressive strength of cubes that used TTWW was higher than the compressive strength of the control samples by 3.6 %.
4. In the tension test, different types of treated wastewater (PTWW, STWW and TGW) gave strength less than the strength was mixed with fresh water at 28-day by (-15.6%, -8.3% & -26.8%).
5. The 28-day tensile strength of cubes that used TTWW was higher than the compressive strength of the control samples by 11.5 %.
6. In the flexure test, different types of treated wastewater (PTWW, STWW and TGW) gave strength less than the strength was mixed with fresh water at 28-day by (-7.9%, -3.8% & -20.6%).

7. In the flexure strength for beam samples that were cured using TTWW was higher than the ones using fresh water at 28-day by 6.1 %.
8. Using TTWW in concrete mixture reached the maximum strength values faster than FW as mixing water.
9. Setting time of concrete is affected by the type of mixing water because of the presence of organic matter in the water. The higher the COD content in mixing water, the slower the final setting time.
10. Finally, using TTWW in concrete mixture reached the maximum strength values faster than FW as mixing water.
11. In conclusion, TTWW is potential alternative for FW in the concrete production industry. Based on this study, the authors recommended that it is permissible to use TTWW instead of FW in high strength concrete, as it gives acceptable strength efficiency and acceptable setting time.

The authors also recommended that other experiments for concrete cubes should be carried out on different types of wastewater such as; (Inorganic and organic compounds, harmful substances content, salts, and sustainability problems; freezing and heat resistant when concrete is exposed to temperatures above 100°c) to give a final recommendation whether or not to use TTWW instead of FW in high strength concrete.

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