Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (45) No. (2) October. 2023

EFFECT OF USING TREATED WASTEWATER FROM DIFFERENT LOCAL SOURCES ON CEMENT MORTAR PROPERTIES

OMAR K. MAHER[1], MOHAMED A. KHALAF[1], SAYED I. ALI[2], IBRAHIM A-LATIF[1]

1. Department of Structural Engineering, Ain Shams University, Cairo, Egypt
2. Department of Public Works Engineering, Ain Shams University, Cairo, Egypt

ملخص البحث:

العالم حاليا يعاني من أزمة في مياه الشرب, وبما أن صناعة الخرسانة تعد من أكثر الصناعات إستهلاكا للمياه, فقد شرع الباحثون في دراسة تأثير استخدام مياه الصرف المعالجة كبديل للمياه الصالحة للشرب في صناعة المونة والخرسانة. يهدف هذا البحث إلي دراسة التغييرات في خواص مياه الصرف المعالجة بناء على طبيعة مصدر المياه أو درجة المعالجة, حيث تم جمع خمسة عينات من مياه الصرف المعالجة من مناطق مختلفة في أنحاء الجمهورية وتم عمل مجموعة من التحليلات الكيميائية للعينات ومقارنتها بحدود الكود المصري لتصميم وتنفيذ المنشآت الخرسانية والمواصفات القياسية الأمريكية. يهدف هذا البحث أيضا الى دراسة تأثير مياه الصرف المعالجة على خواص المونة, وذلك عن طريق الاختبارات التالية: القوام القياسي للعجينة الأسمنتية - زمن الشك الابتدائي والنهائي - مقاومة الضغط للمونة. أظهرت نتائج الاختبارات وجود أختلافات في خواص مياه الصرف المعالجة بناء على طبيعة مصدر المياه, بالإضافة إلى أن بعض عينات مياه الصرف المعالجة لم تحقق حدود الكود المصري لتصميم وتنفيذ المنشآت الخرسانية والمواصفات القياسية الأمريكية. تم أيضا ملاحظة أن تأثير مياه الصرف المعالجة على زمن الشك الابتدائي والنهائي طفيف, على الجانب الأخر فإن إستخدام مياه الصرف المعالجة أدي إلى خفض مقاومة الضغط للمونة الأسمنتية بشكل كبير, حيث لم تحقق العينات إشتراطات الكود المصري لتصميم وتنفيذ المنشآت الخرسانية والمواصفات القياسية الأمريكية من حيث مقاومة الضغط للمونة الأسمنتية. نتائج البحث توضح أهمية دراسة تأثير مياه الصرف المعالجة على خواص الخرسانة سواء على المدى القصير أو المدى الطويل.

ABSTRACT

The world is currently facing a major crisis in water demand, and since the concrete industry consumes vast amounts of water, researchers started to study the effects of using treated wastewater (TWW) as an alternative to potable water in mortar and concrete. This research studies the variation in the properties of TWW collected from 5 different sources based on either its source or the type of treatment system, it also investigates the effect of TWW on the properties of mortar. Chemical analysis tests were carried out on the TWW samples, and the results were compared to the limits of ASTM C1602 and ECP 203-2020. Subsequently, water consistency, initial setting time, final setting time and mortar compressive strength were studied. The results showed variations in the properties of TWW according to the source of the TWW. Some chemical analysis results exceeded the limits of ASTM C1602 and ECP 203-2020. Although minor effects were noticed in the initial and final setting time, the reduction in mortar compressive strength exceeded 10%

in all the tested mixes. This highlights the importance of investigating the effects of TWW on the properties of concrete, particularly on the long-term properties.

KEYWORDS

Treated wastewater, mortar, setting time, compressive strength, recycling, sustainability, mixing.

1 INTRODUCTION

Fresh water is considered a scarce resource, as most of the water on earth exists in oceans. Ocean water represents 97.6% of the total water and the fresh water only represents 2.4% of the total water [1]. About 68.7% of the fresh water is in the form of ice caps and glaciers, 30.1 % is in the form of ground water, which leaves only 1.2% of the fresh water in rivers, lakes, etc [1].

The scarcity of freshwater is one of the major problems facing the world. According to The Sustainable Development Goals Report [2], by 2030 1.6 billion people will be without safely managed drinking water supplies. Water stress, defined as the ratio between the withdrawn freshwater to the total renewable freshwater resources, is at a critical level in north Africa and central Asia, where the ratio is higher than one, as shown in Fig. 6 [2].

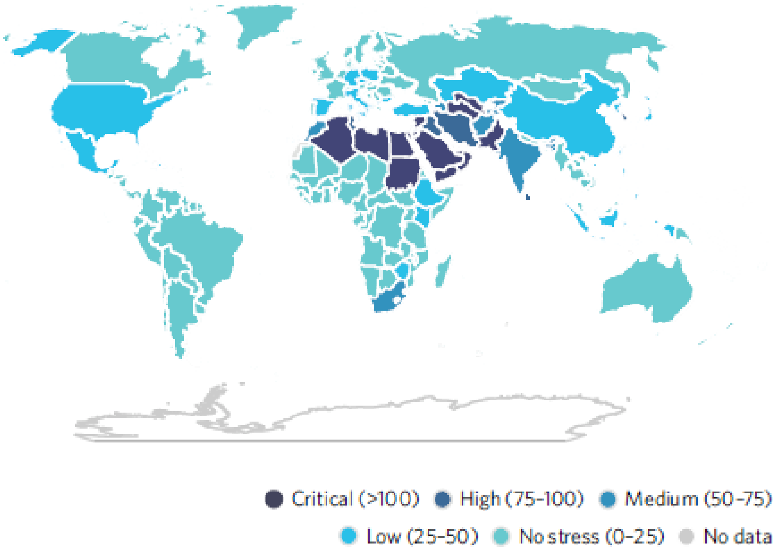

Fig. 6: Level of water stress (2019) [2]

According to the World Water Assessment Program by the United Nations [3], 56% of the total freshwater withdrawals is released as wastewater, while 80% of the released wastewater is discharged into the environment without adequate treatment. The percentage of the wastewater subjected to treatment vary according to the region, in Europe 71% of the domestic and industrial wastewater is treated, while this percentage reaches 51% in the middle east and northern Africa and 20% in Latin America.

Concrete industry is one of the largest industries in the world which consumes vast amounts of fresh water. According to Silva [4], an average of 150 Liters of water is needed to produce 1m^3 of concrete, and if the wasted water that is taken into consideration, the amount of water involved in producing 1m^3 of concrete can reach 500 litres.

Researchers started to study the suitability of using TWW as a partial or full replacement of potable water in concrete and mortar, as this would save enormous amounts of fresh water, which the world is in a persistent need to save every drop. Zahra Bouaich et al. [5] stated that the chemical analysis of TWW complied with the limits of ASTM C94 [6] and ASTM C1602 [7] , while Ahmed et al. [8] used Secondary Treated Wastewater (STWW) and found that the STWW exceeded the allowable limits in Total Dissolved Solids (TDS) and Chloride Content according to BS EN 1008:2002 and ASTM C1602 [7] respectively.

El-Ghorab et al. [9] used Primary Treated Wastewater, Secondary Treated Wastewater and Tertiary Treated Wastewater from the same water treatment plant and found that all of the TWW samples complied with the limits of the Egyptian Code of Practice (ECP 203-2007) [10].

Noruzman et al. [11] used industrial and domestic TWW and found that Total solids in the industrial TWW exceeded the permissible limits and stated that the higher values of Total solids contribute to the increase in compressive strength of concrete. Results showed that the chemical composition of TWW may vary from one region to another in terms of satisfying the limits for using water in mixing of concrete. Al-Joulani [12] suggested the effects of the impurities found in TWW on the properties of Concrete as stated in Table 2.

Table 2: Effect of different impurities on the properties of concrete [12]

Impurity	**Effects**
Alkali carbonate and bicarbonate	Acceleration or retardation of setting time. Reduction of strength
Chloride	Corrosion of steel in concrete
Sulphate	Expansive reactions and deterioration of concrete. Mild effect on corrosion of steel.
Iron salts	Reduction in strength
Miscellaneous inorganic salts (zinc, copper, lead, etc.)	Reduction in strength and large variations in setting time
Organic substances	Reduction in strength and large variations in setting time
Sugar	Severely retards the setting of cement
Silt or suspended particles	Reduction in strength
Oils	Reduction in strength

Peighambarzadeh et al. [13] stated that using TWW increase the initial setting time (IST) and final setting time (FST), as the IST increased from 115 to 177 min and the FST increased from 250 to 280 min. However, the increased values satisfied the limits of ASTM C1602 [7]. Zahra Bouaich et al. [5] found that TWW increased the IST by 3.5% when using CEM I, and explained the increase to the presence of phosphate ions which form poorly soluble compounds overing the anhydrous cement grains, which leads to a delay in the hydration process.

Noruzman et al. [11] used industrial and domestic TWW and found that the setting time decreased when both the industrial and domestic TWW are used, as the setting time decreased from 117 min to 110 and 108 min when using the industrial and domestic TWW respectively. Results showed some contradictions in the effect of using TWW on the IST and FST, and that the % of increase or decrease in the IST and FST may vary according to the components of the TWW.

Zahra Bouaich et al. [5] stated that using TWW cause a slight decrease in the compressive strength of mortar, as the compressive strength decreased from 32,51 MPa to 31,48 MPa. Results show minor effect on the compressive strength of mortar, However, research regarding the effects of using TWW on the compressive strength of mortar is still limited.

This paper aims to investigate the variations between TWW samples, based on the location of the source and the type of treatment. It also aims to study the effect of TWW on the properties of mortar.

2 MATERIALS

Ordinary Portland cement CEM I 42.5 N was used in making the cement pastes and mortar mixes. Sand was collected from a storage in Cairo and was tested to determine its physical and chemical properties as shown in Table 3 and Table 4.

Table 3: Sieve analysis of fine aggregates

Sieve Size (mm)	% Passing
4.75	95.90
2.36	92.40
1.18	78.70
0.6	34.70
0.3	10.20
0.15	3.10

Table 4: Physical and chemical characteristics of fine aggregates

Parameter	Result
Volumetric Weight	1.575
Specific Gravity	2.604
% of Fine Materials	3.2
% of Chlorides by weight	0.0284
% of Sulphates (SO_3^-) by weight	0.1677

3 Mixing water:

In this Study, 6 types of mixing water were collected from different regions across Egypt as following:

1. Potable Water (PW): tape water collected from a source at Ain shams university - Cairo.
2. Treated Wastewater (TWW):
    - TWW1: Collected from a water treatment plant at Cairo – Sokhna Road, where water is subjected to advanced secondary treatment, the treatment process is shown in Fig. 7.
    - TWW2: Collected from a water treatment plant in Suez, where the water undergoes a secondary treatment system (Oxidation ponds), the treatment process is shown in Fig. 8
    - TWW3: Collected from a water treatment plant in Ismailia, where the water undergoes a secondary treatment system (Kruger System), the treatment process is shown in Fig. 9
    - TWW4: Collected from a water treatment plant in Monofeya, where the water undergoes a secondary treatment system (Kruger System), the treatment process is shown in Fig. 9
    - TWW5: Collected from a water treatment plant in Beni Suef, where the water undergoes a secondary treatment system. the treatment process is shown in Fig. 10.

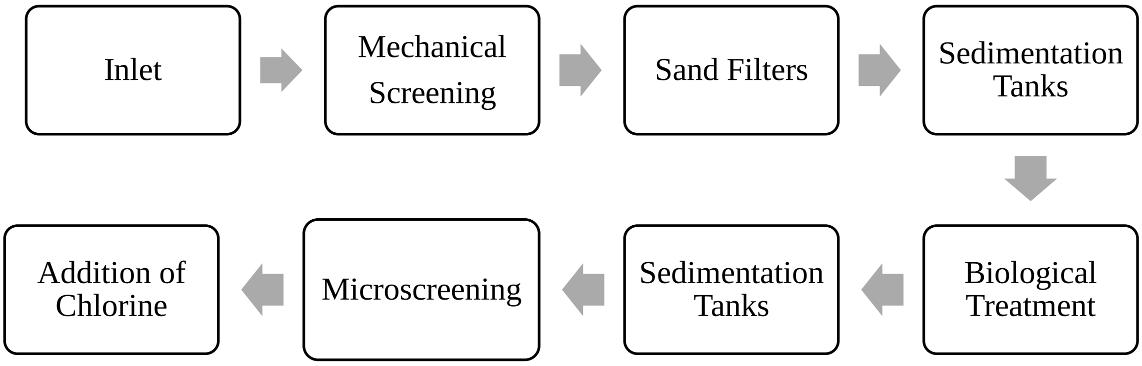

Fig. 7: Advanced Secondary Treatment System

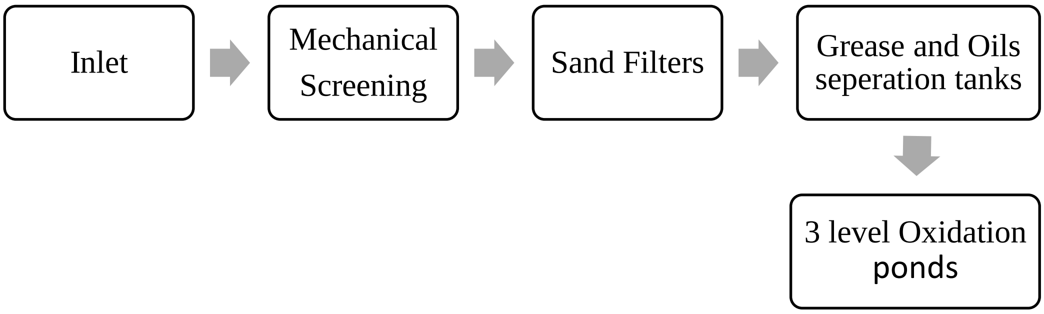

Fig. 8: Oxidation Ponds Treatment System

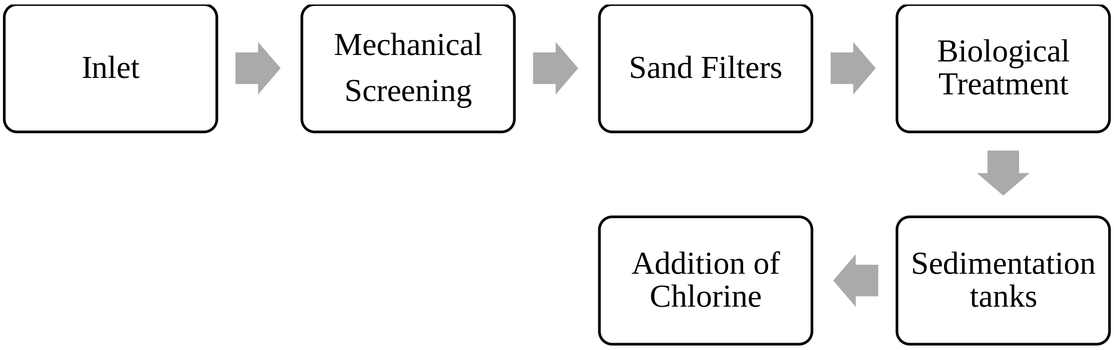

Fig. 9: Kruger Treatment System

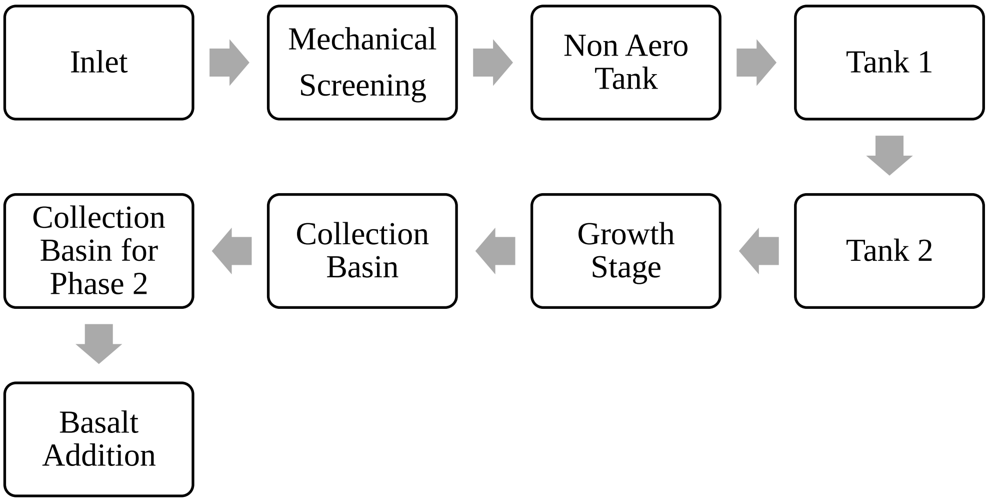

Fig. 10: TWW5 treatment system

4 EXPERIMENTAL PROGRAM

4.1 Chemical Analysis of Mixing Water

Chemical analysis tests were made on the water samples to determine the following:

Carbonates & Bicarbonates, Sodium Sulphide, Organic Matter, Total Dissolved Solids (T.D.S), Total Suspended Solids (T.S.S), Total Solids (T.S), Chemical Oxygen Demand (C.O.D), Sulphates (SO_4), PH, Chloride Content, Sulphates (SO_3), Turbidity.

Results were compared with the limits of ASTM C1602 [7] and ECP 203-2020 [14], and compared between different water types to study the difference between each TWW source according to the region and the method of treatment.

4.2 Water Consistency

Water consistency test was carried out on cement paste mix made with PW to determine the amount of water needed to produce cement paste with normal consistency according to ASTM C187 [15]. After determining the amount of water needed for normal consistency, five mixes were made using the five TWW types while maintaining the amount of water needed for normal consistency of the PW mix, and the penetration depth of the normal consistency needle is measured. the different mixes were coded as shown in Table 5.

Table 5: Mixes description

Mix Name	Type of mixing water used
M1	PW
M2	TWW1
M3	TWW2
M4	TWW3
M5	TWW4
M6	TWW5

4.3 Initial and Final Setting Time

Initial setting time (IST) and final setting time (FST) were measured according to ASTM C191 [16], where the amount of water used in this test was determined from the water consistency test. Results were then compared with the limits in specified in ASTM C1602 [7] and ECP 203 -2020 [14].

4.4 Mortar compressive strength

Mortar Compressive strength was measured according to ASTM C109 [17]. as 5x5x5 cm specimens were casted with the predetermined mixing proportions stated in ASTM C109 [17] . Specimens were cured at PW and the compressive strength was measured at 1, 3, 7, 28 days. Results were then compared with the limits in specified in ASTM C1602 [7] and ECP 203 -2020 [14].

5 RESULTS AND DISCUSSION

5.1 Water Tests

Table 6 and Table 7 show the results of water tests. The results showed that all the TWW samples have higher PH value than PW. While Sodium Sulphide showed negligible values in both PW and TWW, Carbonates & Bicarbonates and organic matter showed some variations in the results, however all samples satisfied the limits of ECP 203-2020 [14].

Turbidity and chemical oxygen demand (C.O.D) showed small variations in the results. Although all results of total solids (T.S) satisfied the limits of ASTM C1602 [7], Total dissolved solids (T.D.S) of TWW5 sample exceeded the limits of ECP 203-2020 [14], Furthermore the results of T.D.S in TWW2 and TWW3 samples showed higher values than other samples.

Chloride content showed relatively higher values in TWW2, TWW3 and TWW5 samples, where TWW2 and TWW5 failed to satisfy the requirements of ECP 203-2020 [14]. All samples satisfied the limits of ASTM C1602 [7] regarding SO_4 content as the limit is 3000 mg/l, while TWW3 failed to satisfy the limit of ECP 203-2020 [14] regarding SO_3 content as the limit is 300 mg/l.

Although TWW2 and TWW4 were collected from wastewater treatment plants that works with the same treatment system, the samples showed different results, specially in T.D.S, chlorides, and sulphates.

Table 6: Water tests results 1/2

Test	*Unit*	*Sample*						*Limit*	*Reference*
		PW	*TWW1*	*TWW2*	*TWW3*	*TWW4*	*TWW5*		
PH		7	7.6	7.8	7.7	7.9	7.5	7	ECP 203 - 2020
Sodium Sulphide	mg/l	0.01	0.01	0.01	0.01	0.01	0.4	100	ECP 203 - 2020
Carbonates & Bicarbonates	mg/l	222	260	296	330	270	470	1000	ECP 203 - 2020
Organic Matter	mg/l	5.4	6.1	3.8	3.9	4.1	7.2	200	ECP 203 - 2020
Chemical Oxygen Demand (C.O.D)	mg/l	2.4	3.1	4.3	3.8	5.4	11.6		SMWW-24

Table 7: Water tests results 2/2

Test	**Unit**	**Sample**						**Limit**	**Reference**
		PW	TWW1	TWW2	TWW3	TWW4	TWW5		
Turbidity	mg/l	0.241	0.626	8.76	0.283	0.46	1.18		
Total dissolved solids (T.D.S)	mg/l	221	479	1655	1384	571	2598	2000	ECP 203 - 2020
Total suspended solids (T.S.S)	mg/l	0.6	0.85	0.7	0.64	0.77	4.2		SMWW-24
Total solids (T.S)	mg/l	229	486	1774	1398	587	2644	50000	ASTM C1602
Chlorides	mg/l	24.9	97.6	552	379.9	120.7	983.4	500	ECP 203 - 2020
Sulphates (SO_3)	mg/l	6.8	21.9	257.3	325.8	35.9	55	300	ECP 203 - 2020
Sulphates (SO_4)	mg/l	54.7	74.2	266	194	89.4	258	3000	ASTM C1602

5.2 Water Consistency

Fig. 11 show the results of the water consistency results as a function in the penetration depth with fixed amount of water equals to 180 gm. Results showed that all the TWW mixes had less penetration depth than PW mix, specially in mixes made with TWW2, TWW3 and TWW5.

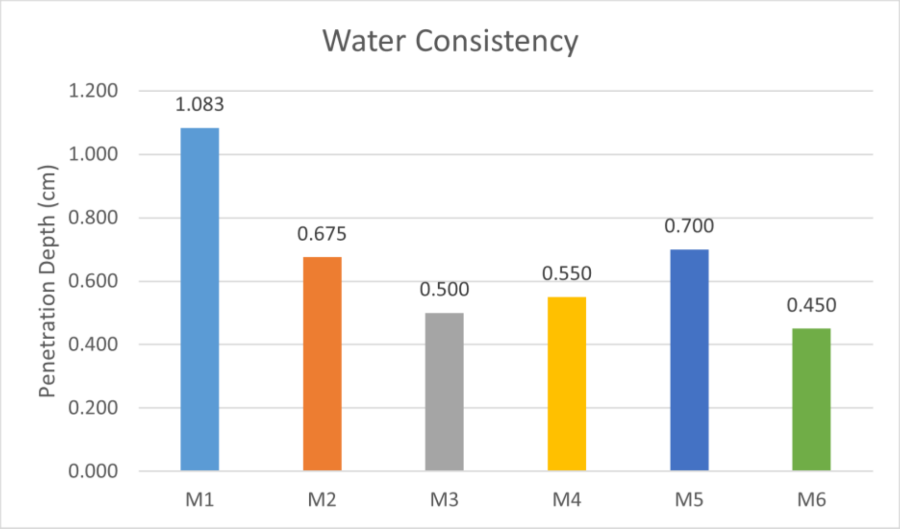

Fig. 11: Water consistency results

5.3 Initial and final setting time

Fig. 12 and Fig. 13 shows the results of initial and final setting time respectively. Although all mixes made with TWW showed less initial and final setting time, However, all mixes satisfied the requirements of both ASTM C1602 [7] and ECP 203-2020 [14] as the maximum reduction in initial and final setting time compared to the control mix were 42 min and 64 min respectively.

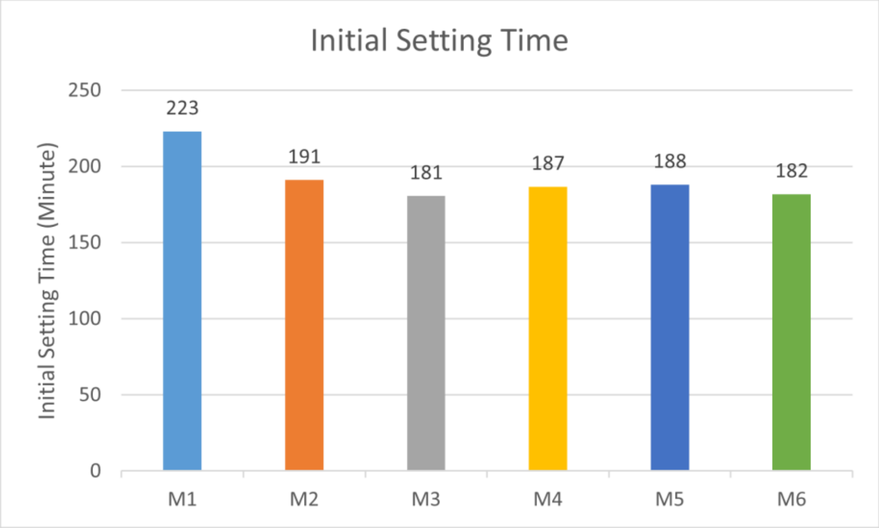

Fig. 12: Initial setting time results

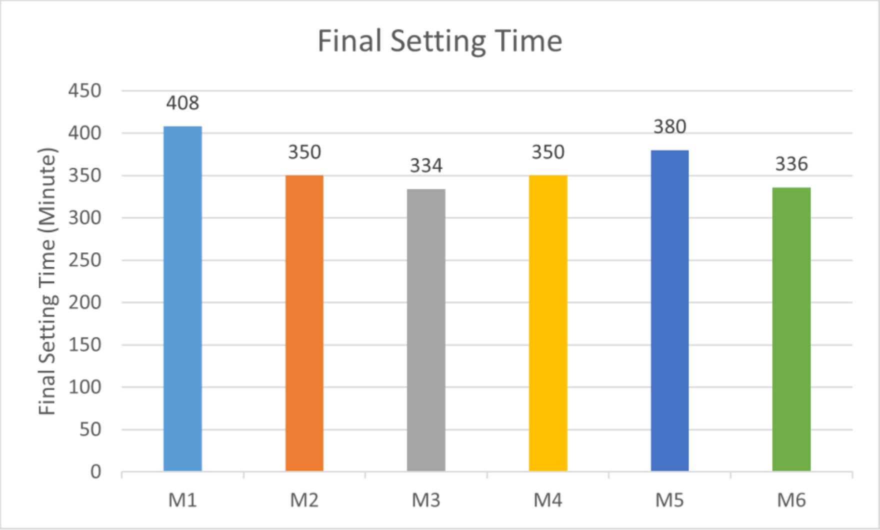

Fig. 13: Final setting time results

5.4 Mortar Compressive Strength:

Table 8 show the compressive strength of the mortar mixes at age 1,3,7,28 days. All TWW mixes failed to satisfy the requirements of either ASTM C1602 [7] or ECP 203-2020 [14] , as the compressive strength of TWW mixes at 7 days was less than 90% of the compressive strength of the control sample M1 as shown in Fig. 14. The reduction in compressive strength at 7 days ranged from 18.56% to 42.71%.

At 28 days, the results of all the TWW mixes were lower than the control mix M1, as the reduction in compressive strength ranged from 13.63% to 38.28%. M2, M3 and M6 showed approximately similar compressive strength as shown in Fig. 15.

Table 8: Compressive strength of mortar (MPa)

Age (days)	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**
1	12.73	12.23	8.36	11.57	10.58	9.24
3	17.74	15.58	16.71	14.79	15.91	14.64
7	26.70	21.74	18.06	15.30	17.07	19.82
28	29.67	23.94	24.79	21.23	18.31	25.63

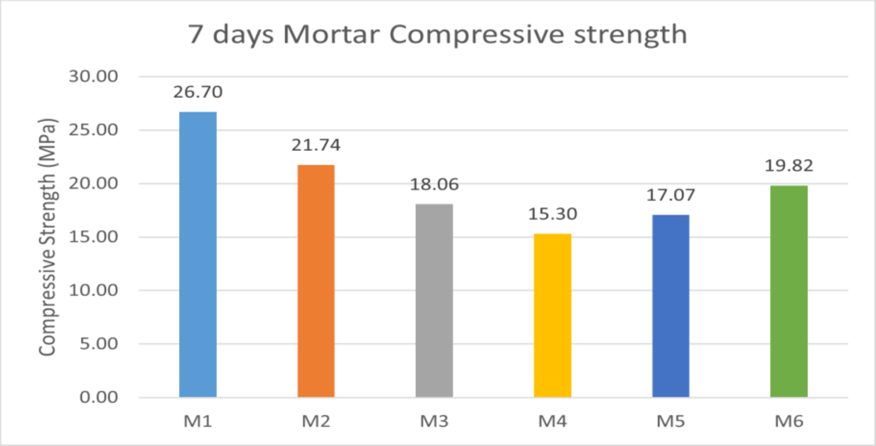

Fig. 14: 7 days mortar compressive strength

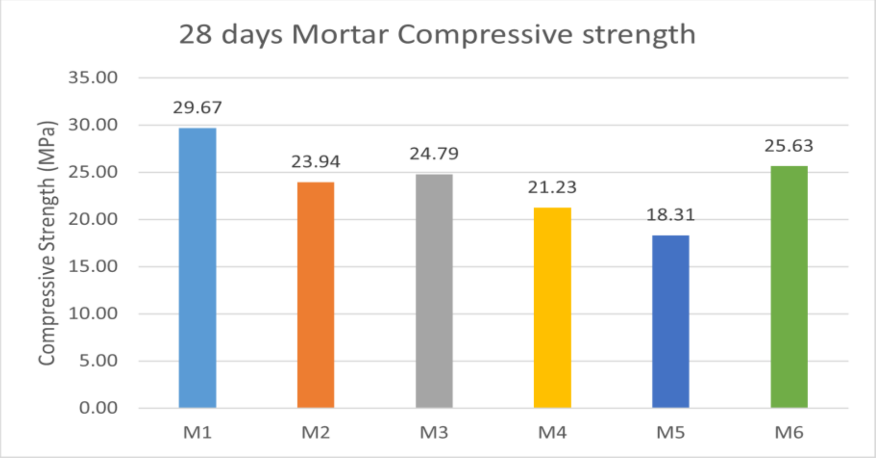

Fig. 15: 28 days mortar compressive strength

6 CONCLUSIONS

This study aimed to investigate the differences in the TWW properties according to the source or the treatment system, furthermore it aimed to study the effects of TWW on cement mortar properties.

Based on the results obtained in this study, the following were concluded:

- The properties of the TWW samples vary according to its source, as TWW collected from sources in upper Egypt and in coastal areas showed higher values of T.D.S, Chlorides and Sulphates than TWW collected from Cairo or Monofeya.
- TWW may exceed the limits of ECP 203-2020 [14] in some cases.
- The value of T.D.S, chlorides and sulphates do not depend on the type of treatment system as much as it depends on the nature of the source which the wastewater is collected from.

- Although TWW showed negative effects on the initial and final setting time, the results are accepted according to both ASTM C1602 [7] and ECP 203-2020 [14].
- TWW have major negative effects on the compressive strength of cement mortar, as all the TWW mixes failed to satisfy the limits of either ASTM C1602 [7] or ECP 203-2020 [14].
-

7 FUTURE RECOMMENDATIONS

Further studies are needed to determine the effect of TWW on the properties of concrete, specially on the long-term properties.

REFERENCES

[1] T. M. Agwe, P. Tibenderana, M. N. Twesigye-Omwe, J. W. Mbujje, and S. T. Abdulkadir, “Concrete Production and Curing with Recycled Wastewater: A Review on the Current State of Knowledge and Practice,” *Advances in Civil Engineering*, vol. 2022. Hindawi Limited, 2022. doi: 10.1155/2022/7193994.

[2] “The Sustainable Development Goals Report.”

[3] World Water Assessment Programme (United Nations), *Wastewater : the untapped resource : the United Nations world water development report 2017*.

[4] M. R. Silva, “Sustainable use of resources-Recycling of sewage treatment plant water in concrete Sensor for Detection of Particles in Water View project Technology for removal of phosphorus from water View project,” 2014. [Online]. Available: https://www.researchgate.net/publication/242651115

[5] F. Zahra Bouaich *et al.*, “Mortar mixing using treated wastewater feasibility,” *Constr Build Mater*, vol. 352, Oct. 2022, doi: 10.1016/j.conbuildmat.2022.128983.

[6] “ASTM C94/C94M − 17a Standard Specification for Ready-Mixed Concrete 1”, doi: 10.1520/C0094_C0094M-17A.

[7] “ASTM C 1602 Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete 1”, doi: 10.1520/C1602_C1602M-12.

[8] S. Ahmed, Y. Alhoubi, N. Elmesalami, S. Yehia, and F. Abed, “Effect of recycled aggregates and treated wastewater on concrete subjected to different exposure conditions,” *Constr Build Mater*, vol. 266, Jan. 2021, doi: 10.1016/j.conbuildmat.2020.120930.

[9] H. El-Ghorab, M. El-Hossieny, and M. Kohail, “Effect of Using Treated Wastewater in Mixing and Curing of Concrete on its Compressive Strength.”

[10] “ECP 203-2007 ”.

[11] A. H. Noruzman, B. Muhammad, M. Ismail, and Z. Abdul-Majid, “Characteristics of treated effluents and their potential applications for producing concrete,” *J Environ Manage*, vol. 110, pp. 27–32, Nov. 2012, doi: 10.1016/j.jenvman.2012.05.019.

[12] N. M. A. Al-Joulani, “Effect of using tertiary treated wastewater from nablus wastewater treatment plant (NWWTP), on some properties of concrete,” *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 11, pp. 2460–2466, Sep. 2019, doi: 10.35940/ijitee.K1709.0981119.

[13] F. S. Peighambarzadeh, G. Asadollahfardi, and J. Akbardoost, “The effects of using treated wastewater on the fracture toughness of the concrete,” *Australian Journal of Civil Engineering*, vol. 18, no. 1, pp. 56–64, Jan. 2020, doi: 10.1080/14488353.2020.1712933.

[14] “ECP203-2020”.

[15] “ASTM C 187 − 16 Standard Test Method for Amount of Water Required for Normal Consistency of Hydraulic Cement Paste 1”, doi: 10.1520/C0187-16.

[16] “ASTM C 191 - 13 Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle”.

[17] “ASTM C 109 Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens) 1”, doi: 10.1520/C0109_C0109M-16A.

3