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SECONDARY TREATED WASTEWATER AS A CONCRETE COMPONENT AND ITS IMPACT ON THE BASIC STRENGTH PROPERTIES OF THE MATERIAL

O.A. AHMAD[1], S.M. AYYAD[2]

In Jordan, the unprecedented proliferation of building projects is anticipated to increase the potable water demand in the construction manufacturing. In the present work, secondary treated wastewater (STW) and potable water (PW) were used in the production of concrete mixes, which were subjected to testing after 3 to 28 days of curing to determine how the, mechanical properties of concrete was affected by the addition of secondary treated wastewater in various proportions (25-100%). Results indicated that the use of 25% and 75% of secondary treated wastewater in concrete production increased the compressive strength to 39 MPa after 28 days of curing. A more noticeable increment was recorded in tensile strength, which was double that achieved with the standard design. Overall, the compressive strength increased by 21.95% when secondary treated wastewater was used, while the expenditure related to water usage was halved. Furthermore, there was consistency between the results obtained from scaling up to actual ready-mix concrete production and the results of the empirical work.

Keywords: Secondary treated wastewater; Tensile strength; Potable water, Mechanical properties of concrete

[1] Prof., DSc., PhD., Eng., Amman Arab University, Faculty of Civil Engineering, Civil Engineering Department; Amman, Jordan Street–Mubis, 11953, Jordan, email: oahmad@aau.edu.jo.

[2] DSc., PhD., Eng., Amman Arab University, Faculty of Civil Engineering, Civil Engineering Department; Amman, Jordan Street–Mubis, 11953, Jordan, , email: samiayyad@aau.edu.jo.

1. INTRODUCTION

To prevent the depletion of finite freshwater resources in the long term, it is necessary to reuse wastewater. In an effort to address extensive water scarcity, this strategy has been implemented in Jordan for irrigation purposes since the 1980s [1]. In 1995, the Water Authority introduced standards for the regulation of treated wastewater reuse for irrigation, thus formally classifying treated wastewater as a resource [2]. In line with the specifications of the Saricimen et al. [2], the treated wastewater produced by the newly established facilities in Jordan is of an extremely high quality. Hence, the uses of treated wastewater could potentially be broadened [3]. The estimate for the volume of treated wastewater produced in 2020 is approximately 262 MCM [4].

Diversification of the uses of treated wastewater and taking advantage of novel water resources to achieve gains both in the water sector and key Jordanian sectors, such as industry and construction, are major goals of the current policy of water demand management [5].

The Jordanian construction industry has grown at a phenomenal pace and has prospered in the last ten years, with large-scale construction projects (e.g. hotels, residential and commercial buildings) being initiated [6]. Furthermore, as the Jordanian population and business sector continue to grow, the Jordanian construction industry is anticipated to maintain its upward trend in the next decade. At present, the processes of concrete production, washing, and wet curing use about 8 MCM of fresh water annually, which is forecasted to rise in direct proportion with the expansion of the construction industry.

The reuse of treated wastewater in construction processes is currently prohibited under [2]. This warrants advocating partial or complete replacement of potable water with treated wastewater in the concrete sector, with anticipated fresh water savings of approximately 8 MCM.

The volume of water used in the concrete sector every year is one billion tons worldwide. Many activities consume massive volumes of fresh water [7-8]. Investigation into replacement of potable water with treated wastewater is warranted by the fact that fresh water sources are used more and more often for the production of concrete employed in various construction operations. Such investigation can hopefully lead to the use of treated wastewater in concrete industrialization [9].

Laboratory analyses of the use of treated wastewater in concrete mixtures have been conducted in a large number of studies. Among the varieties of wastewater that have been analysed are raw sewage [10], treated wastewater [11-12], preliminary, secondary, and tertiary treated wastewater [13], various kinds of wastewater [7], as well as treated effluent [14]. The findings obtained confirmed the practicality of utilizing treated wastewater in concrete production whilst still complying with the standard requirements and construction codes. On the other hand, not much attention has been paid to the use of wastewater in concrete mixtures based on a pilot scale.

In the empirical work conducted by Manjunatha. M [15] regarding treated wastewater reuse to produce concrete, concrete mixture preparation and curing were undertaken with both potable water and secondary treated wastewater. As stated by the outcomes, secondary treated wastewater was appropriate for use in producing concrete in acceptable amounts. Furthermore, concrete cubes produced with treated wastewater and potable water did not differ significantly. Moreover, in the case of cement mixtures produced with treated wastewater, the IS limit was not exceeded by either the initial or final setting time. The mixtures were suitably workable and displayed an increase in compressive strength after few days of curing age.

The impact of various types of wastewater on certain mechanical properties of concrete was examined by [16-17], who reported that concrete mixtures produced with treated wastewater diminished the compressive strength by only 11% following 28 days of curing.

Kucche et al. [18] reviewed the impact of the mix-up water quality on concrete production. Examining the permissible thresholds of different impurities, that mixing water could contain and the methods of testing applied in various countries, the researcher found that the reaction process and, implicitly, the setting time and mechanical properties were influenced by the addition of non-traditional mixing water in concrete production, causing the concrete to lose its hardness.

In a different study, Olugbenga A. [19] assessed the impact of various types of mixing water of dissimilar origins on concrete strength via a set of tests. It was thus discovered that the concrete compressive strength was substantially influenced by the source of the mixing water. Based on the findings, it was recommended that, in situations where potable water was not widely available, river water should be used instead to produce concrete.

To determine whether treated wastewater was appropriate for use in concrete production in Kuwait [13] analysed a range of types of wasted water. According to the findings, tertiary wastewater could be used in the manufacturing of concrete because it did not affect the properties of concrete negatively.

The possibility of using wastewater to produce concrete was also explored by Rakesh and Dubey [20], who found that the compressive strength of concrete produced with ground water, packed drinking water, wastewater, and other types of water was similar up to (90%) of the compressive strength of concrete produced with traditional water after seven and 28 days of curing. A 20%

scaling down in compressive strength was recorded after seven days of curing in the case of concrete produced with wastewater at a fixed ratio of water to cement of 0.5.

A comparison between concrete produced with wastewater various stages of treatment and concrete produced with fresh water (FW) was undertaken by [21] to determine the impact on compressive strength. The findings revealed that workability was in the range of (slump 25-50 mm). However, concrete produced with wastewater (WW) displayed reduced compressive strength, while concrete produced with treated wastewater (TWW) remained more or less the same after 28 days of curing.

In the empirical explore by Sameer et al. [22], concrete production was undertaken with treated wastewater instead of potable water. This involved using tap water (TW) and two classes of treated wastewater, namely, primary and secondary treated wastewaters. It was concluded that secondary treated wastewater (STW) was suitable for use in the construction sector.

The purpose of the present research is to designate whether it is possible to elevate the use of treated wastewater in the production of concrete mix from the level of the laboratory to the level of pilot production operation. To this end, mortar and concrete mixes are produced with secondary treated wastewater (STW) obtained from wastewater treatment plants.

2. MATERIAL AND METHODS

In Jordan, the main wastewater treatment plants (WTPs) are found in the major cities of Amman and Zarqa. Having been upgraded to mechanical treatment (Activated Sludge), the plants have the daily capacity to treat around 270,000 m^3 of domestic wastewater, with a daily peak of 900,000 m^3. For the purposes of the experiment conducted in this study, STW was sampled from the outflow of the secondary settling tanks of the WTPs. As indicated in (Table 1), the samples were subjected to a range of tests for pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), 5-day Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Phosphorous (T-P), Ammonia (NH_3), and chloride (Cl^-). The tests were carried out in compliance with the standards for water and wastewater analysis [23]. In addition, potable water (PW) was sampled from municipal sources to serve as control within the bench-scale and full-scale experiments.

Table 1. Assessment of the quality of the samples of STW and PW

Parameter	STW	PW	Permissible concentration [25,29]
PH	7.5	7.9	6-8
TDS (mg/l)	924	409.6	2000
TSS (mg/l)	11.5	181	2000
Cl^- (mg/l)	257	124.1	500
SO_4 (mg/l)	96.2	22.6	2000
COD (mg/l)	51.9	< 4	500
BOD (mg/l)	854	< 2	-

The chemically inactive granular materials known as aggregates are distributed all through the cement matrix to make concrete more cost-effective as they are less expensive than cement [24]. Concrete mixtures were prepared with various raw materials (e.g. coarse, medium, and fine aggregates, cement), the properties of which were assessed in the laboratory in line with ASTM [25] standards.

Concrete mixtures were produced form a widespread in Jordan limestone (Specific Gravity 2.55) with two types of coarse aggregates and fine aggregates. Fig. 1 and Fig. 2 respectively provide the aggregates employed in the experiment and their gradations.

The concrete mixtures were produced with Ordinary Portland Cement (OPC) procured from the Jordanian Cement Factory Company. (Table 2) lists the chemical properties associated with the employed cement.

The volumetric proportion ranges recommended by ASTM were adopted in the preparation of the standard mixture. The ideal proportions according to the properties of the employed materials were achieved by preparing a large number of trial mixtures. PW was used to prepare the control mixture and additional mixtures were created with STW.

Fig 1. The types of coarse and fine aggregates employed in the experiment

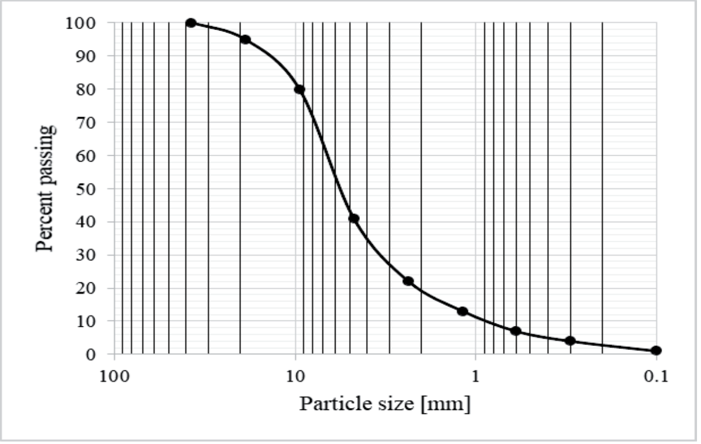

Fig 2. Gradation of aggregates employed in the production of concrete

Table 2. The chemical properties associated with Ordinary Portland Cement (OPC) type II

Oxide composition	%
$3CaO.SiO_2$	54.1%
$2CaO.SiO_2$	16.6%
$3CaO.Al_2O_3$	10.8%
$4CaO.Al_2O_5.Fe_2O_5$	9.1%
Initial setting time (min)	65
Final setting time (min)	315
Compressive Strength N/mm^2	35.0

Although the same amount was used at every stage and the composition of 1 m^3 (kg/dm^3) shown in (Table 3), the proportions in which wastewater was used differed (100%, 75%, 50%, and 25%) shown in (Table 4). The 0.5:1:2:4 mixing ratio of water, cement, fine and coarse aggregate was identical for every mixture A number of 32 (150 x 150-mm) cubes were created and subjected to curing in various proportions in different mixtures. The cubes were subsequently introduced into a basin with treated wastewater. Cylinders 150 mm diameter x 300 mm long were prepared for each mix in order to determine the tensile strength of concrete.

Table 3. The ratio of materials and composition of created mixtures

Mixing ratio of created mixtures	Composition of 1 m^3 (kg/dm^3)
Water = 4.25 –liter.	144
Cement = 8.5 kg.	287
Fine for = 16.4 kg.	548
Aggregates = 34 kg.	1338

Table 4. Group name and the ratio of STW to PW employed in every design

Group Name	STW/L	STW/ kg	PW/L	PW/ kg
A	4.25	144	0	0
B	3.19	108	1.063	36
C	2.125	72	2.125	72
D	1.063	36	3.19	108
E	0	0	4.25	144

The mixtures were produced in line with the ASTM, with a standard mixer being employed in the mixing process. The samples were cast for 24 hours before being removed from the moulds and introduced into a water tank at normal laboratory temperature to be cured for different durations (3, 7, 14, and 28 days). The assessment of the compressive strength was done in compliance with the ASTM [26]. Comparison of the outcomes of the various produced mixtures was based on the samples with different curing durations and the average of two samples at every age. To attain the optimal compressive strength, the ideal grading mix was obtained by selecting the grading of the combined aggregates according to the mix design. The ability of a material to withstand size-diminishing loads is known as compressive strength, which is indicative of the compressive stress at which the material suffers complete failure [28].

3. Results and Discussion

In the context of concrete production, a key aspect is the quality of the mixing water [18]. Mixing water can be sourced either from PW or from non-potable sources of water that are nevertheless suitable to produce concrete [29-30]. As can be seen in (Table 1), the 11.5-mg/L TSS concentration of STW did not exceed the permissible range of suspended particles in mixing water specified by the Portland Cement Association (PCA). Furthermore, the TDS concentration and of STW (924 mg/L) was also below the allowed limit of 2000 mg/L. Likewise, the COD (51.9 mg/L), and the chloride and pH values of STW did not exceed the allowed limit. Thus, taking into account the specifications for water use in concrete production (Table 1), it was concluded that STW was appropriate for use in preparing concrete. The standards implemented in Jordan do not specify any restrictions for dissolved impurities in mix-up water and their potential adverse effect on the properties of concrete.

Fig. 3 presents the compressive strength of concrete produced with STW and PW at curing ages (3, 7, 14, and 28 days) for group A and group E. Following 28 days of curing, the concrete produced with STW exhibited an increase of around 6.3% in compressive strength, but it did not differ significantly from concrete produced with PW. On the other hand, when groups B and E were compared, it was noted that the compressive strength of concrete differed markedly at every curing stage, increasing by 31.5% in concrete produced with STW at the end of curing times.

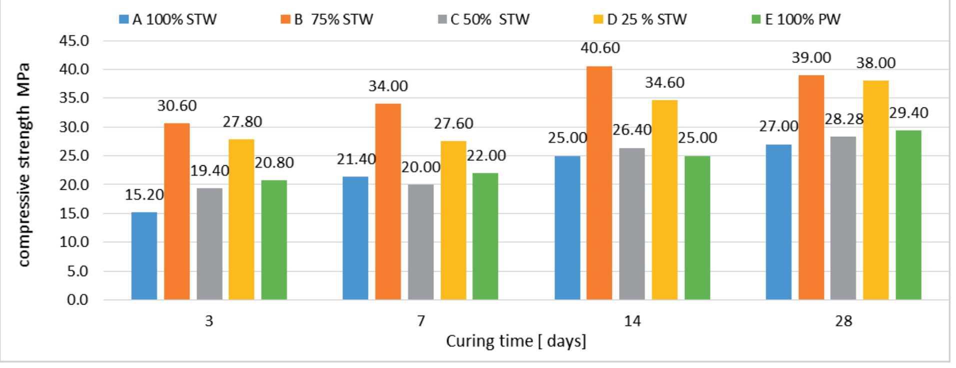

Fig 3. Comparative analysis of the compressive strength of all concrete mixtures produced with SWT

Fig. 3 illustrate that there were no marked discrepancies in the compressive strength of concrete in groups C and E at any curing age. After 28 days of curing, concrete produced with STW displayed a minor increase of 5% in compressive strength. On the other hand, Fig. 3 illustrates that there were marked discrepancies between groups D and E in terms of compressive strength at various curing ages. For instance, after 28 days of curing, the compressive strength of concrete produced with STW increased by 28%. The results are similar to those obtained by [31], who concluded that the use of recycled water had no impact on the properties of concrete. Nevertheless, it was suggested that the properties of concrete could be influenced by the type of recycled water used. For instance, wastewater from domestic settings contain distinct pollutants, making it likely that its influence on the properties of concrete would be dissimilar. Meanwhile, Kucche et al. [18] argued that concrete made with wastewater should not have a compressive strength lower than 15% of the standard compressive strength of concrete produced with PW.

The maximum tensile strength of 6.08 N/mm^2 achieved when STW was added in proportion of 75%, but all additions improved the tensile strength to different degrees, and more than the tensile strength of regular concrete produced with PW (Fig. 4). According to the test results, at the end of the curing process, regular concrete was subjected to tensile stress of 3.82 N/mm^2. The most notable increase in tensile strength at any curing periods was achieved when STW was added in a proportion of 25-75%, which is therefore the amount that should be used when preparing concrete.

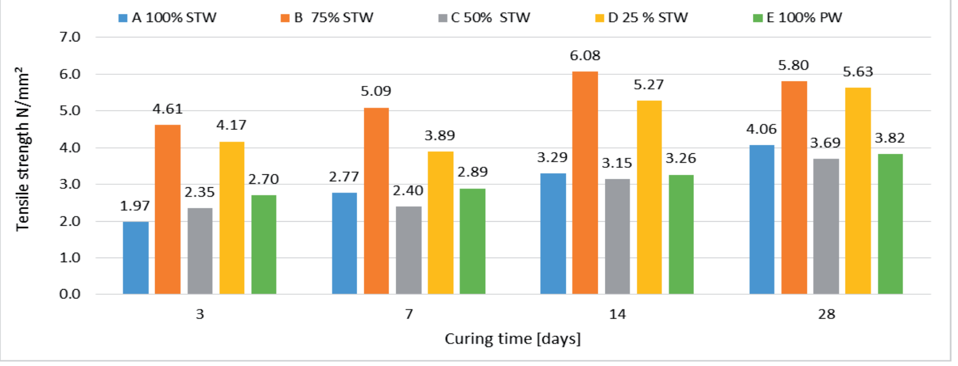

Fig 4. Comparative analysis of the tensile strength of all mixes with STW

When considering STW reuse in concrete industry, the main concerns about the quality of mixing water in this research are related to the effect on concrete and tensile strengths. Fig 5 and Fig 6 are demonstrates the variations of compressive and tensile strengths, which is compatible with the amount of STW additions to the concrete design. The results shows that 25% and 75% replacement of potable water with STW achieved unprecedented results and was the highest of all added ratios by increasing by 20%-25% compared with 100% PW in both compressive and tensile strengths respectively. This increase could be due to filling effect of solid particles, which may have contributed to concrete strength increase.

However, the treated wastewater effluent varies in quality according to type and degree of treatment, and effluent of all types of conventional treatment contains different impurities of different concentrations that may affect the properties of concrete. The result suggested that the organic content present in STW might be acting as a dispersing agent, improving the dispersion of particles. Finally, this study has shown that STW is a potential alternative for PW in the concrete industry.

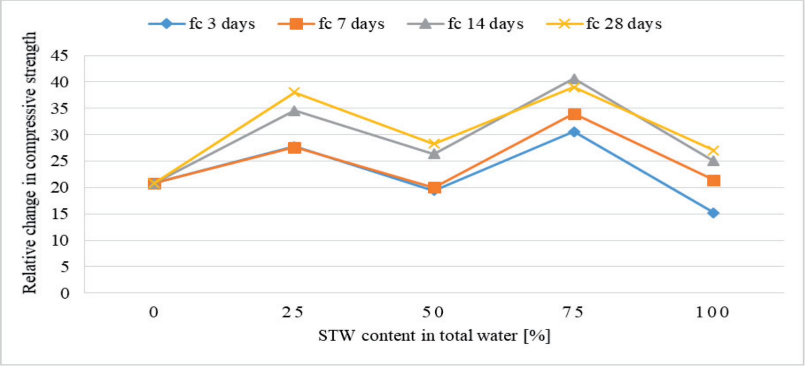

Fig 5. Relative change in compressive strength vs STW content in total amount of water

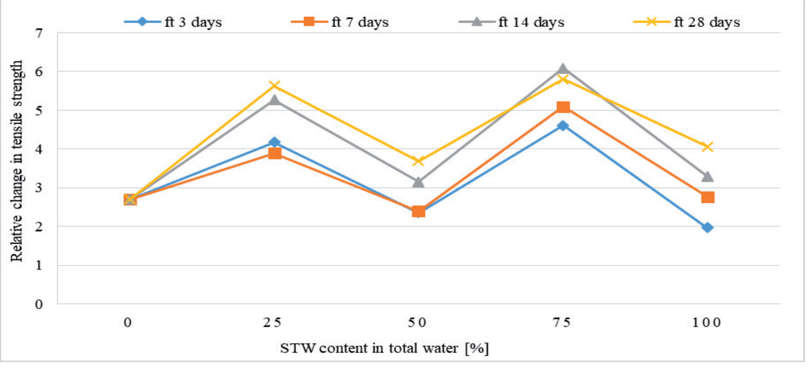

Fig 6. Relative change in tensile strength vs STW content in total amount of water

Limited water resources, especially in an arid climate, are a challenging issue; therefore, water reuse is vital. A huge amount of treated wastewater discharged to the rivers and groundwater daily. The construction industry, especially for producing concrete uses a huge amount of tap water. The sustainability of water resources in a country like Jordan severely suffering from a shortage of drinking water is of great importance and therefore this research highlights the possibility of using various forms of treated wastewater .The reuse of secondary treated water in the concrete industry is beneficial to the environmental as well as economic and sustainability aspects of water resources. Fig. 7 show the economic feasibility of using secondary treated wastewater, as the cost of water drops significantly from 4.255 US dollars /m^3 to about 1 US dollar /m^3 for a suggested 25% portion of used STW.

Fig 7. Economic feasibility of using secondary treated wastewater

4. Conclusion

The present work has undertaken both production of concrete with STW. The outcomes of the water quality assessment confirmed the suitability of STW for use to prepare concrete and mortar provided that the acceptable limits of mixing water were respected. The findings complied with the specifications of the ASTM C 94 [29]. The ASTM C109 supports the suitability of STW for use in producing mortar. Furthermore, this study noted that concrete made with STW displayed an increase of 32% for group B and 28% for group D in terms of compressive strength after 28 days of curing. In terms of flexural strength, group B achieved an increase of 51%, while group D achieved an increase of 48%. The use of STW to produce concrete has also been endorsed by the IS 456-2000. On the other hand, the source of the used water determines the rate at which the compressive strength increases. Given these findings, it can be concluded that STW constitutes a promising alternative for potable water needed to produce concrete. Thus, the authorities should review the existing guidelines regarding wastewater reuse to promote STW as a viable replacement of PW in the production of concrete. The result propose that the organic content present in STW might be playing a role as a dispersing agent, improving the dispersion of particles. In addition, this increase could be due to filling effect of solid particles, which may have contributed to concrete strength increase.

The evidence from this research suggests that this type of water does not significantly affect the strength of concrete prepared with STW. In fact, over the duration of curing, plain concrete produced with STW showed an increase in compressive strength and positive physical and chemical properties. Thus, besides preventing the depletion of natural water resources, the use of STW instead of PW can also improve the strength of the concrete.

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