Practical Paper

Water reuse in the production of non-reinforced concrete elements: An alternative for decentralized wastewater management

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ABSTRACT

Replacement of water by treated wastewater in concrete production, totally or in part, could lead to great water economy. Therefore, this experiment evaluated compressive strength from non-reinforced concrete samples produced with a combination of potable water (PW) and treated domestic wastewater (TW) at four different proportions: 0, 50, 75, and 100% of TW in the mixture. Ten samples were prepared for each proportion and the samples were tested for axial compression on the 28th day after concrete preparation. The data were statistically evaluated to analyze the influence of TW in concrete quality. It was possible to note that there was no significant difference between concretes produced using only PW and those produced with 50 and 75% TW, but when only TW was used, the concrete compressive strength increased on average 17.7%, which indicates the good potential of water reuse in the production of non-reinforced concrete elements.

Key words | compressive strength, decentralized system, management, reclamation, reuse, wastewater

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INTRODUCTION

The use of natural resources increases exponentially along with population growth and increasing consumption patterns. Many of these resources are finite and/or irrecoverable.

The construction sector is one of the largest consumers of natural resources and has been blamed for causing environmental problems such as pollution of the enclosing environment (Ding 2008). In this sector, concrete is the most widely used material around the world (Silva & Naik 2010).

Concrete consists of cement, sand, gravel, and water. Cement production causes a great variety of environmental impacts, such as CO_2 and cement kiln dust emission (Van den Heede & De Belie 2012) and high energy consumption. Sand and gravel extraction and processing also have a high impact. The potential environmental impacts that may occur with any type of aggregate operation are noise, dust, and visual changes. Because it is an extractive process, mining of natural aggregates disturbs the environment and creates problems associated with the large holes dug in the ground and the large volume of heavy truck traffic associated with quarry and pit operations, which are often measured as parts of a square mile (Drew *et al.* 2002).

Besides that, the production of concrete requires large amounts of water, which may be burdensome in regions where there is low availability of fresh water (Meyer 2009).

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As water is becoming scarce, it is important to reduce freshwater consumption in all sectors, including the construction industry (Al-Jabri *et al.* 2001). Given the fact that consumption of water depends on the water:cement ratio, the production of 1 m^3 of concrete (with cement:sand:gravel ratio of 1:1.08:1.96 and water:cement ratio 0.44) may consume more than 220 L of water. Water is a valuable natural resource that is essential for all sorts of life. Although it is abundant, its quality is worldwide quickly decreasing due to untreated wastewater release in hydric bodies and other pollutant activities. Water scarcity is a growing problem that already affects a significant part of the world's population.

Al-Ghusain & Terro (2003) evaluated the suitability of using treated domestic wastewater (TW) for mixing concrete by casting samples using tap water, preliminary TW, secondary TW, and tertiary TW. In that study, the strength of concrete made with tertiary TW was higher than that of concrete made with tap water, and tertiary TW was considered suitable for mixing concrete with no adverse effects. Asadollahfardi *et al.* (2016) produced concrete samples with potable water (PW) and TW and cured them with TW before chlorination. There was no significant difference between the compressive strength of the concrete samples made and cured with TW before chlorination and the control samples. Both studies also noted that TW did not affect the results of the slump test.

Thus, replacement of this water by TW or even a combination of both would, at the same time, save PW for other activities and avoid effluent release in water bodies, preventing pollution. Therefore, this experiment analyzed the viability of using TW in non-concrete production.

MATERIAL AND METHODS

Concrete samples studied herein were produced using a cement:sand:gravel ratio of 1:2:3 in mass and a water: cement ratio of 0.45. The water used in it was a mixture of PW and TW in four different proportions (Table 1).

Table 1 | Proportions of PW and TW used in concrete production

Group	Percentage of TW	Percentage of PW
1	0%	100%
2	50%	50%
3	75%	25%
4	100%	0%

Treated wastewater

The domestic wastewater came from a small community in Campinas (Brazil), where it was treated by a septic tank + anaerobic filter + sand filter system (De Oliveira Cruz *et al.* 2013, 2019; Tonon *et al.* 2015). Calcium hypochlorite was added to the effluent for disinfection, in order to make it safe to be manipulated.

The effluent was analyzed for pH, total alkalinity, conductivity, dissolved oxygen, turbidity, total solids, total suspended solids, chemical oxygen demand (COD), total nitrogen, nitrite, nitrate, total phosphorus, total coliforms, and *Escherichia coli*. For the purpose of the reuse in concrete production, the concentrations of chloride, sulfate, lead, and zinc were also determined and compared with the Brazilian regulation on water requirements for concrete production and with characteristics of PW from a water treatment plant in the city of Campinas.

Concrete samples

For each proportion (Table 1), ten cylindrical concrete samples measuring 0.10 m diameter and 0.20 m height (Figure 1) were produced, totaling 40 concrete samples.

The following materials were used in the preparation of the concrete samples: sand (middle grain size – 0.2 to 0.6 mm diameter), gravel (9.5 to 19 mm diameter), high early strength Portland cement, TW, and PW.

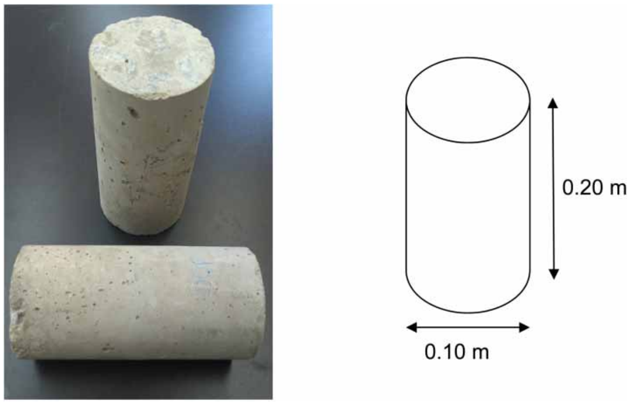

Figure 1 | Cylindrical concrete samples.

For each concrete sample prepared as specified above it was necessary to use 0.60 kg of cement, 1.20 kg of sand, 1.80 kg of gravel and 0.27 kg of PW + TW (approximately 0.27 L).

Prior to sample preparation, sand and gravel were dried in a drying oven for 24 hours to eliminate all humidity. After all the concrete samples were ready, they were placed in a moist chamber for 28 days. The water used in concrete curing contained the same proportion of PW and TW as the one used in sample preparation.

After 28 days, the samples were demolded and then taken to a compression machine, which applied an increasing load until rupture, for determination of compressive strength. The test consisted of a centered compression load applied in a quasi-static manner, with a constant load rate of 0.45 MPa.s^{-1}. The compressive strength for each sample can be determined through Equation (1):

$$\sigma = \frac{F}{A} \tag{1}$$

where: σ is the compressive strength (MPa), F is the rupture load (kN), and A is the surface area of each concrete sample (m^2). Since the average compressive strength was determined after 28 days, as discussed previously, a conventional Portland cement could be used without major concerns.

With these results, it was possible to make statistical evaluations to compare each concrete composition and evaluate the influence of TW use on compressive strength performance. The nonparametric Kruskal–Wallis one-way analysis of variance was used for testing significance. A p value of <0.05 was considered statistically significant.

RESULTS AND DISCUSSION

Table 2 presents the results for the TW analysis after calcium hypochlorite addition, as well as for PW from a water treatment plant in the city of Campinas and the requirements for mixing water for concrete, according to Brazilian regulations (NBR 15900-1 2009). The treated effluent complied with all the requirements, indicating the possibility of its reuse in concrete production.

Table 3 shows the results for compressive strength of concrete produced with 0, 50, 75, and 100% of TW in the water mixture. Samples containing 75 and 100% TW presented no significant difference for compressive strength (32.94 ± 3.34 and 33.79 ± 3.47 MPa, respectively) to those containing only PW (28.72 ± 2.57 MPa) (Figure 2).

Table 2 | Comparison of the water quality parameters used in the evaluation of TW and PW

Parameter	**TW**	**PW**	**Requirements for mixing water for concrete (ABNT 2009[a])**
pH	6.8–7.9	7.2	≥5
Total alkalinity (mg $CaCO_3$ L^{-1})	313.6	21.7	≤2,422[b]
Conductivity (μS cm^{-1})	1,193	54.9	–
Dissolved oxygen (mg O_2 L^{-1})	4.4	8.1	–
Turbidity (uT)	10	0.19	–
Total solids (mg L^{-1})	519	55.2	≤50,000
Chemical oxygen demand (mg L^{-1})	85	–	–
Total N (mg L^{-1})	188	1.10	–
Nitrite (mg NO_2^-N L^{-1})	4.9	<0.005	–
Nitrate (mg NO_3^-N L^{-1})	42.5	0.63	≤500
Total P (mg P L^{-1})	2,74	0.12	≤44[c]
Sulfate (mg SO_4^{2-} L^{-1})	50	3.99	≤2,000
Chloride (mg Cl^- L^{-1})	113	0.36	≤500
Total coliforms (NMP/100 mL)	1.0	0	–
Escherichia coli (NMP/100 mL)	<1.0	0	–
Lead (mg Pb^{2+} L^{-1})	<0.1	<0.1	≤100
Zinc (mg Zn^{2+} L^{-1})	<0.1	<0.1	≤100

[a] This regulation states that TW should not be used for concrete production.
[b] According to ABNT (2009), the alkalis content in mixing water must not exceed 1,500 mg Na_2O L^{-1}, which is equivalent to 2,422 mg $CaCO_3$ L^{-1}.
[c] According to ABNT (2009), the phosphate content in mixing water must not exceed 100 mg P_2O_5 L^{-1}, which is equivalent to 44 mg P L^{-1}.

When only TW was used, the concrete compressive strength increased on average 17.7%. However, statistically, it is only possible to affirm that the sample that contained 50% of PW had a worse performance than that of the sample that contained 75% and 100% of TW (Figure 2). Even when 100% PW was used, the average compressive strength was lower than that obtained when 75 and 100% TW were used, although this difference was not statistically significant. Thus, in general, it can be stated that the use of treated wastewater does not result in loss or gain of concrete compressive strength. Therefore, there would be no problem in replacing PW by TW in the production of concrete, according to the results obtained here.

Table 3 | Compressive strength of concrete for different percentages of TW in the water mixture

	Compressive strength (MPa)			
	Percentage of TW			
Sample	**0%**	**50%**	**75%**	**100%**
1	29.47	26.72	32.71	28.97
2	28.72	31.22	39.96	28.97
3	27.47	26.72	31.22	32.96
4	31.47	25.47	27.97	34.96
5	28.72	25.97	37.21	33.21
6	26.22	23.22	31.22	38.21
7	23.72	27.72	32.46	30.22
8	32.96	28.47	31.71	36.71
9	28.97	26.72	32.21	36.46
10	29.47	26.47	32.71	37.21
Average (MPa)[a]	28.72 *ab*	26.87 *b*	32.94 *a*	33.79 *a*

[a] The different letters in each column indicate significant difference ($p < 0.05$).

Similar results can be found in the literature. Tay & Yip (1987) studied cubic concrete samples produced with 25 to 100% wastewater from an industrial treatment plant in the water mixture and observed that strength resistance showed either no significant difference or a slight increase, when compared to control samples. They also carried out studies on effects of wastewater use for concrete curing and concluded that the compressive strengths of concrete cubes cured with 100% wastewater were greater than those of cubes cured with PW. Ismail & Al-Hashmi (2011) produced concrete samples using polyvinyl acetate wastewater and observed that strength values for these samples were similar or slightly higher than those for the control samples. None of the authors presented a justification for improving performance using wastewater.

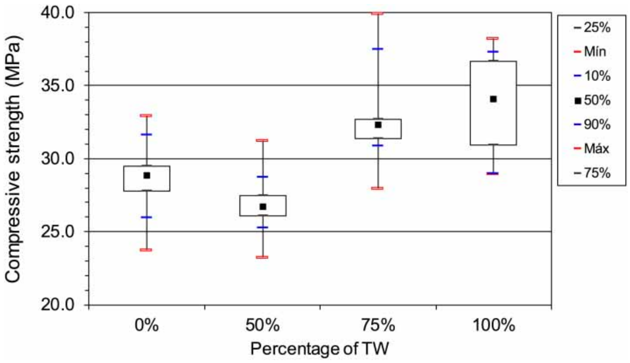

Figure 2 | Statistical analysis for compressive strength averages.

Silva & Naik (2010) produced mortar cubes with either only wastewater from a sewage treatment plant or PW, and obtained similar compressive strength values for both.

Opposite results were found by El-Nawawy & Ahmad (1991), who investigated concrete produced with treated effluent from a local municipal sewage treatment plant in Qatar and observed that compressive strength for mortar and concrete samples decreased with an increase in the proportion of treated effluent in the mixing water. He concluded that treated effluent should not be greater than 20% of the mixing water, otherwise, compressive strengths would not be within the prescribed limits. However, in this specific case, the wastewater did not comply with the limits for concrete mixing water.

Noruzman *et al.* (2012) produced concrete samples using treated effluent from heavy industry, palm-oil mill, and domestic sewage. The heavy industry treated effluent showed better results for compressive strength than the control samples, but the other two had poor performance, showing a 14-day strength below 90% of the control samples' strength.

It is worth highlighting that the TW used in this study was obtained from a decentralized wastewater treatment system, which is a necessary sanitation solution for rural and/or isolated areas where there is no access to a conventional wastewater collection and treatment system. Furthermore, universities *campi* or isolated commercial, industrial, and agricultural facilities may use decentralized systems and the water reclaimed can be utilized in the vicinity (Gikas & Tchobanoglous 2009). In the specific case of this work, the treatment consisted of septic tank + anaerobic filter + sand filter, installed in a small community.

Since the results obtained in this research indicate the feasibility of TW reuse for the production of non-reinforced concrete elements, one possible outcome is the boost of local wastewater treatment plants as suppliers for small civil construction industries. The use of the wastewater at the same place it is generated could lead to a more sustainable industry, with greater water economy, less hydric pollution and, at the same time, lower expenses of water transportation, resulting in lower production costs, which is an additional benefit of this alternative.

CONCLUSIONS

The analyses of the effluent after treatment by an alternative system, which was composed of septic tank followed by anaerobic filter and sand filter, showed its quality complies with Brazilian regulation requirements for concrete production, indicating this option is a feasible solution for wastewater management. Furthermore, the concentration of alkalis in TW was much lower than indicated in Brazilian regulations to prevent alkali–aggregate reaction (NBR 15900-1 2009).

Regarding the compressive strength, samples produced with a mixture of PW and TW showed similar values to the samples produced only with PW. When only TW was used, concrete compressive strength increased on average 17.7%, which indicates the great potential of water reuse in the production of non-reinforced concrete elements.

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