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Mechanical Characteristics and Durability of Concrete Made with Treated Domestic Wastewater and Recycled Concrete Aggregates

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Abstract

Massive amounts of fresh water and natural aggregates are annually used for concrete applications, resulting in a rapid depletion of freshwater and natural aggregate resources. This necessitates the need of replacing fresh water and natural aggregates with recyclable materials such as treated wastewater and recycled concrete aggregates (RCA). This study, therefore, investigates the mechanical characteristics and durability of three concrete mixes with different concrete mixing water types (fresh water and TWW) and coarse aggregate types (natural aggregates and RCA). Tests performed were concrete compressive and flexural tensile strengths and electrical resistivity. Test results showed that concrete with TWW recorded 6%, 7.9%, and 5.4% lower compressive strength, flexural tensile strengths, and electrical resistivity than conventional concrete, respectively. Furthermore, the combination of TWW and RCA resulted in improving the compressive strength and electrical resistivity by about 10%, whereas it increased the flexural strength by 9.2% compared to concrete mixes with TWW and natural aggregates.

Keywords

Treated wastewater, Recycled concrete aggregates, Mechanical characteristics, Durability.

1. Introduction

Significant amounts of concrete have been manufactured worldwide due to the rapid growth in the world population, urbanization, and economic development. The annual worldwide production of concrete is about 9 billion tons and is expected to further increase in the coming years, raising questions about the environmental impact and sustainability of concrete ingredients [1]. On a global scale, concrete manufacturing accounts for 10% of the total CO2 emissions in the environment [1]. Moreover, the annual global consumption of fresh water and aggregates are 2 and 48.3 billion tons, respectively [2,3] Accordingly, there is a pressing need to evaluate the feasibility of replacing fresh water and aggregates with recyclable materials in concrete applications.

Numerous studies have addressed the viability of utilizing non-potable water such as treated domestic wastewater (TWW) for concrete applications [3–9]. Studies performed by Shekarchi et al. [5] and Noruzman et al. [6] revealed that TWW showed no significant difference in the fresh properties of concrete. Asadollahfardi et al. [7] observed that the mechanical properties of TWW concrete were comparable with conventional concrete properties at different ages. Shekarchi et al. [5] pointed out that the compressive strength of TWW concrete was 17% higher than that of conventional concrete. Nonetheless, Shekarchi et al. [5] and Arooj et al. [8] found that the compressive strength and electrical resistivity of TWW concrete were about 15% lower than conventional concrete. More recently, Abushanab and Alnahhal [3] pointed out that TWW showed no significant effect on concrete mechanical properties, whereas it significantly increased the chloride permeability by 40%.

Meanwhile, several alternatives to natural aggregates have been proposed for concrete applications. One is the recycled concrete aggregates (RCA), which are produced from construction waste. The annual global construction waste exceeded 3 billion tons in 2018 [10]. Previous studies demonstrated that the residual mortar on RCA influenced the mechanical and durability properties of concrete [1,11–13]. Wang et al. [11] showed that the slump of 50% and 100% RCA concrete decreased by 15% and 25%, respectively, compared to conventional concrete. Andreu and Miren

[14] and Martı´nez-Abella [15] recorded about 5% lower density when natural aggregates were replaced by RCA. Wagih et al. [16] revealed that 100% RCA concrete achieved 15% to 23% lower compressive strength than conventional concrete. In addition, Wang et al. [11] found that 50% and 100% RCA concrete recorded 37% and 45% lower flexural tensile strength than conventional concrete. However, Alnahhal and Aljidda [12] reported that RCA showed no significant effect on the compressive and flexural strength of concrete. Ali et al [13] showed that RCA concrete had higher pores than normal concrete and thus RCA concrete recorded lower durability properties. In a recent study by Ahmed et al. [17], it was shown that combining TWW and RCA had no significant influence on concrete properties.

According to the previous discussion, investigations on the mechanical and durability properties of concrete with TWW and RCA are very limited. Therefore, further studies on the characteristics of TWW-RCA concrete are required to enrich the literature. To this end, this study investigated the compressive strength, flexural strength, and electrical resistivity of TWW-RCA concrete.

2. Materials and Methods

2. 1 Materials

Wash sand and Normal Portland cement type I was used in all concrete mixes. Two types of mixing water were used: fresh water and TWW. TWW used were received from Doha North Sewage Treatment Plant in Qatar. The chemical characteristics of both types of water are presented in Table 1. Compared to fresh water, TWW used had higher chloride, total dissolved solids, and sulphate concentrations. Two coarse aggregates were used: natural coarse aggregates (NCA) and RCA. The aggregate characteristics and gradation are illustrated in Table 2 and Fig. 1, respectively. It can be seen that all RCAs' properties were within Qatar construction specification limits (QCS-14) [18], except for the water absorption, which significantly surpassed the permissible limit.

2. 2 Concrete mixes

Three concrete mixes were prepared and tested. Concrete mix proportions per 1 m^3 are listed in Table 2. The designation of concrete mixes includes two letters. The first letter represents the mixing water type (F and T indicate fresh water and TWW, respectively). The second letter represents the coarse aggregate type (N and R indicate natural and recycled aggregates, respectively). Mix FN was prepared with fresh water and NCA and considered as the control mix. Mix FN was designed as per ASTM C192/C192M-19 standards [19] with a target cylinder compressive strength of 50 MPa. Mixes TN and TR were made entirely with TWW and/or RCA.

Table 38. Chemical characteristics of fresh water and TWW.

Characteristic	Unit	Fresh water	TWW
pH	-	8.1	7.8
Chloride (Cl^-)	mg/l	14.1	511
Phosphate	mg/l	<0.03	9.19
TDS	mg/l	90	1690
Sulfate ($SO4^{-2}$)	mg/l	6	490

Note: TDS= total dissolved solids.

Table 39. Sand and coarse aggregate properties.

Property	NCA	RCA	(QCS-2014) Limit [18]
Bulk Dry Specific Gravity (%)	2.89	2.47	-
Bulk SSD Specific Gravity (%)	2.91	2.55	-
Bulk Apparent Specific Gravity (%)	2.95	2.70	-
Water Absorption (%)	0.72	3.51	2
Elongation Index (%)	24.0	8.00	35

Los Angeles Abrasion (%)	8.10	27.84	30
Soundness (%)	2.17	12.6	15
Water Absorption (%)	2.89	2.47	-

Note: SSD = saturated surface dry and APP = apparent.

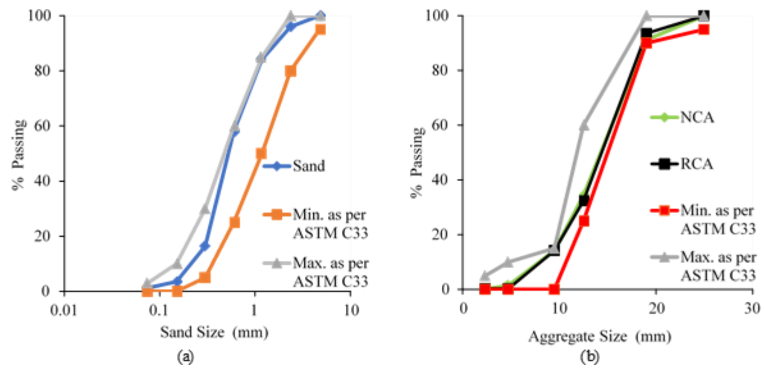

Fig. 46. Gradation of sand and coarse aggregates.

Table 40. Concrete mix proportions (kg/m^3).

Mix	Fresh water	TWW	Cement	NCA	RCA	Sand
FN	156	0	349	1075	0	708
TN	0	156	349	1075	0	708
TR	0	156	349	0	942	708

2. 3 Methods

Concrete compressive strength was evaluated at 28 days using three cylinders of 100 × 200 mm from each batch according to ASTM C39/C39M-20 [20]. In addition, concrete flexural tensile strength was evaluated using three prisms with dimensions of 100×100×500 mm according to ASTM C78/C78M-18 provisions [21]. Moreover, concrete electrical resistivity was tested at 28 days using three cylinders of 100 × 200 mm from each batch according to AASHTO TP 95 standards [22].

3. Results and Discussion

3.1 Effect of TWW

Table 4 presents the compressive strength, flexural tensile strength, and electrical resistivity results for all concrete mixes. It could be seen that the complete replacement of fresh water with TWW in mix TN slightly decreased the compressive strength by 6%. The presented results also indicated that the flexural tensile strength of mix TN decreased by 7.9% at 28 days in comparison with mix FN. That was because TWW contains higher amounts of suspended solids and dissolved oxygen than fresh water, which, in turn, increased concrete pores and decreased the bond between cement and aggregates. The drop in the mechanical properties of TWW concrete could also be related to the high concentration of phosphate in TWW, which alerted the interface layers in concrete and delayed the hydration of cement. The results of Asadollahfardi et al. [7] also confirmed that mixing concrete with TWW slightly decreased the mechanical properties of concrete.

Moreover, it could be seen that TWW slightly decreased the electrical resistivity of mix TN by 5.4% compared to mix FN. This reduction could be attributed to the suspended solid in TWW, which increased concrete internal pores. Furthermore, TWW is composed of higher concentration of iron than fresh water. Thus, the movement of electrons in TWW was promoted in TWW concrete compared to that in freshwater concrete.

3.1 Effect of RCA

It was observed that replacing NCA with RCA in mix TR resulted in a 10% lower compressive strength as compared with that of mix TN. That was due to the residual mortar on RCA, which affected the internal cracks and pores of concrete and decreased concrete bond with aggregates and, in turn, decreased concrete capacity under compression. Nonetheless, it was observed that TWW-RCA prism TR exhibited 9.2% higher flexural strength than prism TN and approximate similar flexural strength to prism FO. This is probably attributed to the chemical reaction between sulfate in TWW and calcium in RCA, which produced calcium monosulphoaluminate hydrate and, in turn, improved the cohesion of the ITZ layers between the old and new mortars. Likewise, the results showed that mix TR achieved about 11% lower electrical resistivity than mix TN, owing to the residual mortar on RCA, which alerted the internal cracks and pores of concrete. The results are in good agreement with Abushanab and Alnahhal [3] and Ahmed et al. [17].

Table 41. Compressive strength, flexural tensile strength, and electrical resistivity results at 28 days.

Mix	Compressive strength (MPa)	Flexural tensile strength (MPa)	Electrical resistivity (kΩ·cm)
FN	50.9	5.32	18.5
TN	47.8	4.90	17.5
TR	42.9	5.35	15.6

4. Conclusions

This study evaluated the compressive and tensile strengths and electrical resistivity of three concrete mixes made with different concrete mixing water types (fresh water and TWW) and different coarse aggregate types (natural aggregates and RCA). The following conclusions could be drawn:

- The use of TWW in concrete slightly decreased the mechanical characteristics and durability of concrete.
- The compressive strength and electrical resistivity of TWW-RCA concrete decreased by 10% and 11%, respectively, whereas the flexural tensile strength increased by 9.2% compared with TWW-NCA concrete.
- Both TWW and RCA affected the internal cracks and pores of concrete.

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