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Use of treated domestic wastewater before chlorination to produce and cure concrete

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HIGHLIGHTS

- The data indicate the suitability of treated domestic wastewater for producing concrete.
- Using treated wastewater increases the setting time of cement related to using drinking water.
- A good agreement exist between compressive strength of concrete produced with drinking water and treated waste water.
- The compressive strength of concrete, under rapid freezing and thawing decreased about 10% using treated wastewater instead of using drinking water.

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ABSTRACT

Concrete samples with different amounts of cement and superplasticizer admixture produced with both drinking water and treated wastewater and cured with treated wastewater before chlorination. The 28-day compressive strength of all of the concrete samples was 93–96% of the compressive strength of the control samples. A 28-day tensile strength of all samples was 96–100% of the tensile strength of the control samples and the setting time was increased by 15 min. Concrete samples produced and cured with treated wastewater did not have a significant effect on water absorption, slump and surface electrical resistivity. A one-way analysis of variance (ANOVA) at the 5% significance level indicated no significant difference between concrete samples produced and cured with treated wastewater and control samples at the age of 90 days.

1. Introduction

Nowadays, the problem of water shortages is one of the most significant problems in human societies. The most important reasons for the water crisis are increasing population, improvement of lifestyle, climate change and lack of appropriate water resource management. In these conditions the treatment and reuse of wastewater is one of the most important solutions in the development of water resources management. It may play an important role in the water crisis problem [1]. The recent analyses of water reuse have indicated that the best water reuse projects in terms of economic feasibility and public acceptance are the ones that have replaced drinking water with treated wastewater in irrigation and industrial water. The main benefits of this replacement are the storage and maintenance of water reservoirs and reducing pollution [2]. Municipal wastewater is made of 99.9% water and 0.1% organic and mineral materials that are formed from dissolved and suspended particles. The untreated wastewater is a danger to public health and the environment. Therefore, wastewater treatment is essential before releasing it into the environment [3]. The main uses of treated wastewater are in agriculture, urban consumption, industry, environment, recreation, feeding the ground aquifers and developing drinking water resources.

Concrete is the selected material of the century and plays a significant role in civil engineering and is the most consumed material after water consumed by people [4]. The concrete industry is the largest consumer of water. Water is consumed in producing, curing concrete and washing sand and gravel. Water is also used for washing concrete mixing trucks.

The quality of mixing water plays an important role in concrete characteristics. The impurities in the mixing water may affect the setting time, contraction and the durability of the concrete. Tay and Yip (1987) indicated that water which is not suitable for drinking can still be used in the concrete mix. They compared concrete samples using different percentages (25–100%) of reclaimed wastewater with 100% drinking water. The compressive strengths at the ages of three months and beyond were similar to the

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strengths of concrete made with 100% potable mixing water [5]. Cebeci and Saatci (1989) produced concrete samples using both treated wastewater and distilled water. Their results indicated that treated wastewater was indistinguishable from distilled water when used as mixing water both in the setting time and concrete strength test [6]. Ghazaly and Ng (1992) indicated that rain water, river water, and treated wastewater were suitable for use with cement, but not in the case of raw domestic sewage [7]. Chini Abdol and Muszynsk (1999) described that type 2 wastewater (secondary wastewater from washing) had no statistically important effect on the properties of the setting time or compressive strength of the concrete when used as batch water and/or to saturate coarse aggregate in the production of concrete [8]. Sandrolini and Franzoni (2001) applied concrete wash water in mixing water for concrete and mortar. Their results indicated that a 28-day compressive strength of most samples was higher than 96% of the reference concrete samples [9]. Su et al. (2002) used sludge water in mixer washout operations in a ready-mixed concrete plant to make concrete. All the examined sludge water met ASTM C94 requirements for mixing water for ready-mixed concrete [10]. Al-Ghusain and Terro (2003) examined concrete samples which were made by using four types of water quality, including potable water, preliminary treated wastewater, secondary treated wastewater, and tertiary treated wastewater. Their results indicated that using wastewater for producing fresh concrete increased slump and density. They also reached the conclusion that using tertiary treated wastewater at early ages had a higher strength than concrete samples using potable water [11]. Chatveera et al. (2006) studied the feasibility by using concrete sludge water in concrete mixtures and described that concrete sludge water used in concrete mixtures had a high alkalinity and total solids content exceeding the limits of the ASTM C94 standard, leading to a more porous and weaker matrix. They concluded that when they increased the percentage of concrete sludge water in concrete mixtures, dry shrinkage and weight loss owing to acid attacks were raised while slump and strength were reduced [12]. Nirmalkumar and Sivakumar (2008) used textile wastewater to produce concrete samples. The compressive strength of their samples was acceptable [13]. Chatveera and Lertwattanaruk (2009) studied the practicability of using concrete water from a ready-mixed concrete plant as mixing water in concrete containing either fly ash as an additive or a super plasticizer admixture based on sulfonated naphthalene–formaldehyde condensates. Their results described that increasing the total solids content beyond 5–6% tended to reduce the setting time and compressive strength [14]. Mehrdadi et al. (2009) used the treated wastewater from primary and secondary sedimentation units and effluent from the wastewater plant at Shahrak Ghods in Tehran to produce concrete samples. Their results indicated that the 28-day compressive strength of all the samples was more than 90% of the compressive strength of the control samples that satisfied the ASTM C94 standard [15]. Al-Jabri et al. (2011) tested concrete samples which were made by mixing wastewater and potable water. Their results presented that the strength of concrete mixtures prepared using wastewater was similar to the strength of the concrete using potable water [16]. Tsimas and Zervaki (2011) studied using concrete wash water to produce fresh concrete. Their results illustrated that concrete wash water was suitable for producing fresh concrete samples [17]. Wasserman (2012) studied the compressive strength of concrete mixed and cured using concrete wash water and compared the results with the samples which were mixed and cured using potable water and the results were found to be accurate [18]. Nikhil et al. (2014) used three types of water including drinking water, groundwater and sewage water to produce concrete samples. Their results indicated that the compressive strength of concrete samples at 28 days using drinking water was higher than using wastewater [19]. Asadollahfardi et al. (2015) studied using concrete wash water to produce concrete. Their results indicated that concrete wash water is suitable for producing fresh concrete [20].

The objective of this study was to determine the feasibility of using treated wastewater before chlorination in wastewater plants as water for producing and curing concrete.

2. Materials and method

For producing concrete samples we used domestic wastewater treatment effluent (before chlorination) from the Khoramabad treatment plant in Lorestan province in Iran. The treatment plant consists of a series of anaerobic and surface aerobic lagoons. All methods of measuring the wastewater were based on the APHA (2005) standard method [21].

One hundred sixty-two concrete cube samples (150 ∗ 150 ∗ 150 mm), 9 concrete cylindrical samples (150 ∗ 300 mm) and 9 concrete cube samples (100 ∗ 100 ∗ 100 mm) were made. We produced concrete samples using 2 different amounts of cement, including 300 and 400 kg of cement per cubic meter and a third group of samples with 350 kg of cement per cubic meter with a super plasticizer admixture included. We measured the water absorption of the concrete at 28 days and the compressive strength at 3, 7, 14, 28, 56 and 90-days on the cube samples (150 ∗ 150 ∗ 150 mm). We also measured the surface electrical resistivity at 90 days on the concrete cube samples (100 ∗ 100 ∗ 100 mm) and also the tensile strength of the cylindrical samples (150 ∗ 300 mm) at 28 days.

We used A300, A350 and A400 to label the concrete samples produced and cured by using drinking water as the control sample. The numbers 300, 350 and 400 indicate the amount of kg of cement per one cubic meter of concrete.

B300, B350 and B400 were used to label the concrete samples produced with drinking water and cured with treated wastewater.

C300, C350 and C400 were used to label the concrete samples produced and cured by using treated wastewater.

Table 1 indicates the mixing design used to produce the concrete samples.

The Doroud Cement Factory, Lorestan (Iran) produced the type two Portland cement which was used for producing the concrete samples. The chemical and physical properties of the cement were tested according to the ASTM-C150 (2004) standard [22].

The aggregate properties used in producing the concrete in this design include:

1. Coarse 12–19 mm.
2. Fine 0–6 mm.

The sieve analysis test of the gravel and sand was based on the ASTM C136 (2004) standard [22], and the fine-grained aggregate gradation was based on the ASTM C33 (2004) standard [23]. We used both drinking water and treated wastewater before chlorination for the setting time test and the Vicat experiment according to the ASTM-C191 (2004) standard [24].

A slump test was performed based on the ASTM C143 (2004) standard [25]. A compressive strength test was performed on the concrete samples according to BS1818 (1983) [26]. We applied the BS 188-122 (2011) for water absorption of concrete [27]. For the primary durability test, we examined concrete water absorption at the age of 28 days, according to BS 1881, part 122 (2011) [27]. We also used a simple non- destructive surface resistivity method according to the FM5-578 (2004) standard [28] instead of a rapid chloride permeability (RCP) to measure the concrete's ability and durability to resist chloride ion penetration (ASTM C1202-129 2012) [29]. Ramazanpour et al. (2011) achieved a high coefficient of determination ($R^2 = 0.\ 89$) between the results of rapid chloride permeability (RCP) and a surface resistivity test for concrete samples in workplaces samples [30]. The special electrical resistance test was conducted at the age of 90 days using an electric current resistance device that produced a direct current of 10 Hz frequency. All the blocks are prepared and maintained at the same temperature, humidity, type of cement, fine aggregate and coarse aggregate conditions in all tests. ASTM 666/C666M (2015) was used to determine the resistance of concrete to rapid freezing and thawing [31]. We carried out two tests, including the resistance of concrete to rapid freezing and thawing according to ASTM C666/C666M (2015) and Scanning Electron Microscopy (SEM) combining with energy-dispersive X-ray spectroscopy (EDX) on the quality of concrete according to ASTM C1723-10, 2010 [32].

3. Results and discussion

Table 2 indicates the results of the wastewater characteristics.

According to the ASTM C94 (2004) [33] standard, three physical and chemical characteristics of water are significant for use in concrete production, including sulfate, chloride and total solid. As indicated in Table 2, the treated domestic wastewater used in our study and the wastewater used by Al-Jabri et al. (2011) both meets