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Effect of wastewater as sustainable concrete material on concrete performance: A critical review

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ABSTRACT

A massive amount of water has been consumed to produce concrete. The lack of sufficient water for drinking and other essential processes reduces the quantity of water that should be delivered to the people because of the high water consumption by concrete production. All the waste from commercial buildings, households, institutions, and hospitals are known as wastewater. Generally, the water demand is anticipated to increase considerably in the near future. Energy and industry production are expected to witness essential rises in water demand. The enormous quantities of water and generating large quantities of various wastewater from different treatment processes led to exploring different ideas to overcome these issues. One of these ideas is the utilization of wastewater in the construction industry, particularly in concrete mixtures and curing. In the literature, a lack of sufficient studies is obtainable for concrete production from wastewater. This study reviews the chemical composition and physical properties of wastewater and the durability properties of concrete. The treated wastewater from sewage treatment plants (STP) is utilized acceptably for particular utilization. Using treated effluent (TE) in concrete improves cement paste's setting time and compressive strength more than drinking water. The concrete samples containing wastewater recorded 7%–27% lower porosity than control concrete because of the hydration process of cement with time, in addition to the pozzolan reactions. In terms of rapid chloride penetration examination, the authors detected that the samples containing wastewater recorded higher Coulomb charges than that of the control concrete sample without wastewater at 28 curing days because of the high chloride ions in wastewater than that of tap water. The chloride ion penetration increased due to an increase in the domestic wastewater content. Consequently, there is a critical need to improve various processes to adopt and use wastewater in concrete mixtures. This study recommends using a high volume of wastewater to get sustainable concrete with high performance.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Advances in Construction Materials and Structures.

1. Introduction

Concrete was extensively used as a construction material worldwide [1]. The rapid development and increasing population have resulted in increased concrete utilization in huge quantities [2]. The most disadvantages of concrete production are water and air pollution [3]. The lack of drinking water sources is considered one of the world's greatest difficulties [4]. However, it's expected to increase the water requirement for industrial purposes from 800 billion m3 in 2009 to 1500 billion m3 by 2030 [5]. It's anticipated that water scarcity will happen by 2025, and about 1800 million persons worldwide will suffer [6]. In the construction industry alone, water is also essential, about one trillion cubic

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meters yearly was utilized, and about 500 Liter of water was used to produce 1 m3 of concrete [7].

Moreover, freshwater is used for cleaning, batching plants, aggregating and mixing trucks, and curing concrete samples [8]. Consequently, the concrete industry notably influences environmental pollution by depleting a high amount of fresh-water [9]. There is an urgent need to develop many solutions to reduce the high consumption of these quantities of water used in concrete production processes [10]. One suggested solution is using wastewater for concrete curing and production, which may decrease water needs. Also, the water unsuitable for drinking-purpose was utilized in concrete making [11]. Concrete ready-mix plants consume freshwater and generate wash water, which constitutes a prominent environmental issue [12,13].

Recently, some investigators used various wastewater forms to produce and cure concrete samples. The treated wastewater from sewage treatment plants (STP) is utilized acceptably for particular utilization. Using treated effluent (TE) in concrete improved the cement paste's setting time and compressive strength more than drinking water [14]. Likewise, wastewater (WW) generated from concrete plants can be used in concrete curing and production due to no critical influence on concrete properties [15]. Nevertheless, the utilization of wastewater in curing and mixing concrete samples is vital in decreasing the environmental impacts of dumping this wastewater and reducing the final cost of construction required [10]. The effect of wastewater on the durability properties of concrete cannot be neglected. Concrete durability can resist climate changes, chemical attacks, and abrasion constancy when showing different weather conditions. Even though the concrete is reflected in durability when exposed to aggressive environments, it undergoes corrosion in wastewater generated from plants [16]. Asadollahfardi et al. [17] reported that the treated wastewater (TWW) has a minor effect on the workability and density of concrete. Another study by Liang et al. [18]reported that the fluidity of mortar reduces with an increase in wastewater dosage, the fluidity of mortar reduces by about 4% for each 5% increase in wastewater dosage. The properties of wastewater mainly depend on the source of this water. Thus, the different wastewater has a different effect on concrete properties. The loss in compressive strength value and consistency can be attributed to the sulfuric acid embedded in the metabolism that affects the cement concrete matrix [19,20]. This paper summarized and reviewed the effect of different types of wastewater on the properties of concrete durability. Many investigations are necessary for using wastewater in concrete production. Durability properties are the most significant anxiety for concrete mixtures. It is better to address the resistance against acid and sulfate attacks, carbonation, chloride permeability, and water absorption of concrete made of different types of wastewater.

2. Properties of wastewater

All the waste from commercial buildings, households, institutions, and hospitals are known as wastewater. Sewage generated from bathing, toilets, laundry, and kitchens is similarly classified as wastewater. Generally, the water demand is anticipated to increase considerably in the near future. Energy and industry production are expected to witness important rises in water demand. Based on the report published in 2017 by the United Nations World Water Development Report, about 80% of the wastewater was disposed of the landfills and open areas without suitable treatment. About 70% of the wastewater resulting from industrial and municipal in high countries income has been treated annually [21]. In contrast, this percentage decreased significantly for countries with low and medium income to 8% and 38%, respectively [21].

Primarily, sodium chloride (NaCl), calcium chloride (CaCl2), and magnesium chloride (MgCl2) exist in water. Chlorides in treated water were recorded at a higher concentration compared to PW. Mane et al. [22] reported that treated wastewater (TW) is appropriate for concrete curing and mixing in terms of chemical composition. All standards, such as sulfate, TSS, Alkalinity, TS, and Chloride, were according to a recommendation by Indian standards for concrete [23], excluding pH rate. Saxena and Tembhurkar [24] examined the properties of domestic wastewater (DWW) and matched these properties with the standards. Domestic wastewater (DWW) properties were lower than EN 1008 [25] limits but higher than tap water.

3. Durability properties of wastewater concrete

The durability of concrete can be defined as the ability to offer appropriate resistance against climate changes, chemical attacks, and abrasion. Concrete structures should be robust to resist different environmental issues. The resistance against chemical attacks in concrete is a significant property to improve its durability. Generally, concrete samples can resist chemical attacks. The chemical attacks commonly occur due to sulfate or acid attacks on the concrete surface [26]. Kumar and Kumar [27] investigated the influence of chemical attacks such as chloride and sulfate on concrete samples. Results indicated that the weight increased by about 2% due to sulfate attacks using different untreated and treated wastewater. They likewise observed that there is no significant influence of solid sulfate. Sulfate salts commonly connect with hydrated calcium aluminates that produce ettringites. Chini et al. [15] investigated the effect of wastewater on the rapid chloride permeability and its effect on the durability of concrete. Fang et al. [28] stated that treated wastewater concrete performs better than ordinary concrete in density, compressive strength, sorptivity, water absorption, and chloride ion penetration. A recent study by Chen et al. [29] used waste sludge and wastewater for concrete production as 0%, 10%, 20%, and 30% of waste slurry instead of cement and using 0%, 10%, 30%, 50%, 75%, and 100% of wastewater instead of drinking water for concrete mixing. They detected that the concretes made of wastewater has better compressive properties than that of ordinary concrete. In resent study, Guo et al. [30] investigated the effect of wastewater as sustainable construction material on the durability of concrete made of supplementay cementitious materials, namely fly ash (FA) and ground granulated blast slag (GGBS). They concluded that the addition of fly ash and slag into wastewater ash considerably improves the durability and strength properties of wastewater ash cementitious materials due to improve resistance to chloride migration and water absorption.

Abushanab and Alnahhal [31] used wastewater as replacement cement partially to evaluate the concrete performance. They observed that the concrete samples containing wastewater recorded 7%–27% lower porosity compared to control concrete because of occurring the hydration progress of cement with time and pozzolan reactions. In terms of rapid chloride penetration examination, they detected that the samples containing wastewater recorded higher Coulomb charges than the control concrete sample without wastewater at 28 curing days because of the high chloride ions in wastewater than that of tap water. Taherlou et al. [32] observed that using treated waste water (TWW) in self-compacting concrete (SSC) increases the compressive strength more than control concrete with tap drinking water. In addition to that, the SEM photographs show fewer cracks and pores due to the use of the TWW in SCC samples, as shown in Fig. 1. Whereas the treated industrial wastewater named (WW) and tap water with

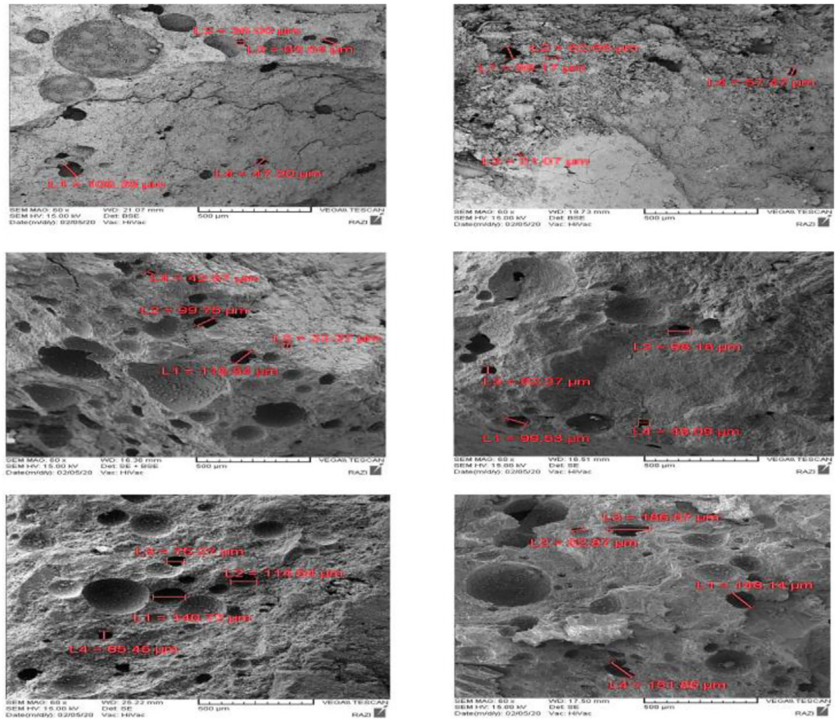

Fig. 1. The SEM photographs for SCC made of wastewater [29].

different replacement of MSWIBA named (W). and municipal solid waste incineration bottom ash named as (MSWIBA).

Chatveera et al. [33] investigated the influence of sludge water with sulfuric acid. The weight of concrete samples was affected for concrete made of sludge water when used to resist acid attacks. Sara et al. [34] studied the effect of using treated wastewater (TWW) and 20% recycled aggregate in 12 concrete mixtures. They concluded that the RCPT presented negligible to low chloride ion permeability for concrete mixtures. Hassani et al. [35] conducted an experimental study to examine a chloride ion penetration of concrete made of domestic wastewater and drinking water. They observed that the chloride ion penetration increased due to increased domestic wastewater content. Meng et al. [36] studied the effect of the carbonation depth of wastewater concrete on the corrosion of dam concrete in China for two years of 2013 and 2019. They recorded the carbonation depth of the concrete dam in three different areas, namely A, T, and S as observed in Fig. 2. The carbonation depth was increased obviously between 2013 and 2019, demonstrating that the carbonation depth increased gradually with time.

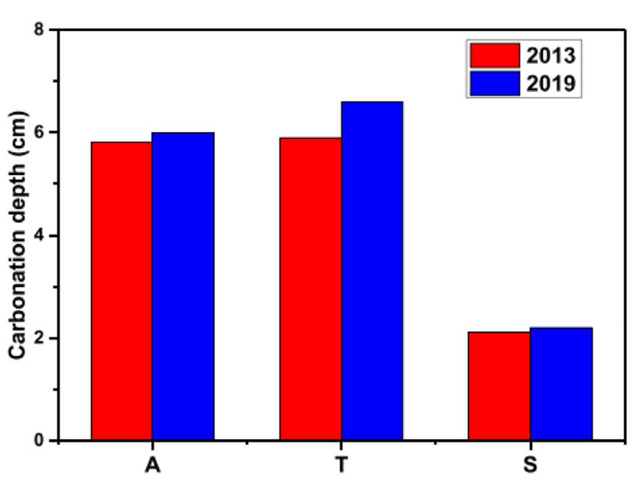

Fig. 2. Carbonation depth of wastewater concrete in three different areas [36].

Water absorption is an important test used to determine the water penetration inside concrete samples when immersed in a water tank, thus finding the concrete durability. Raza et al., [37] conducted an experimental study to evaluate the performance of concrete. The concrete is produced from five different types of wastewater. They observed that the water absorption of concrete made of domestic sewerage wastewater (DSW) was 120% higher than that of control concrete made of potable water (PW), as illustrated in Fig. 3.

3.1. Chloride permeability

The chloride permeability is a significant property in determining concrete samples' overall performance and durability. Abushanab and Alnahhal [38] investigated the effect of treated wastewater (TWW) and FA on concrete durability. They concluded that using TWW as a cement replacement leads to increased chloride permeability of concrete. This is mainly attributed to the existence of chloride ions in TWW, which leads to the movement of Coulomb charges. Chloride permeability and concrete porosity were increased by 40% to 77% due to using TWW instead of FW.

Nowadays, most concrete factories adopt wastewater to produce concrete, especially in developed countries like Germany [35]. The use of wastewater not only assistances in using non-potable water in manufacturing concrete but also can be considered a new technique to reduce the high energy and cost consumed to treat wastewater. Hassani et al. [35] investigated the effect of wastewater on the chloride ion penetration of concrete samples prepared from domestic wastewater and drinking water using serious experimental examinations. They adopted three water-cement ratios for three concrete mixtures, namely 0.4 and 0.6. They found that the chloride ion diffusion coefficient and chloride ion percent-

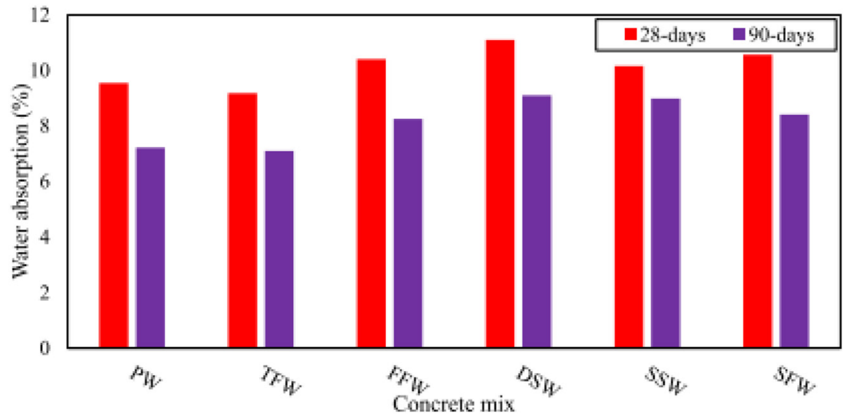

Fig. 3. Water absorption of different concrete mixtures at different curing ages [37].

age increased obviously due to the use of domestic wastewater in concrete mixtures instead of drinking water, as shown in Table 1. They used field emission scanning electron microscopy (FESEM) images and high-resolution scanning electron microscopy (HRSEM) images to assess the morphological variations due to use of wastewater instead of drinking water in the concrete mixtures. Chloride ion proportion of concrete mass (%) at the various depths in samples prepared from the wastewater and drinking water, as shown in Table 1. As shown in the results obtained, in all the depths and water-to-cement ratios, the chloride ion proportion prepared from wastewater CWW (X) was more than drinking water CW(X). The CW (X) represents concrete prepared from normal water, and the CWW (X) represents concrete prepared from wastewater. While (X) is the water-to-cement ratio.

Based on the results obtained from Table 1, the use of drinking water with water-cement-ratio of 0.4, the chloride ion proportion of concrete was zero in the depths of 30–35 mm, whereas the chloride ion proportion reached zero for depths ranging between 35 and 40 mm when used drinking water and wastewater in concrete preparation.

3.2. Water absorption

Water Absorption of concrete is one of the main parameters affecting concrete durability. It can be measured by determining the quantity of water available in the pores' volume of the concrete sample. High water absorption results in negative effects on the concrete durability, such as causing reinforcement corrosion and allowing hurtful chemicals to enter the concrete to react with the concrete components and resulting in the degradation of concrete structures. Raza et al. [37] reported that the water absorption rate was around 120.65% for the concrete mixture prepared from wastewater compared to water absorption of concrete prepared from portable water at 90 days.

As reported before, water absorption is one of the main parameters that should be determined to find out concrete durability. The concrete samples with little absorbency reduce the water entrance and resist durability loss owing to freezing and thawing state. They observed that water absorption was reduced as the curing age increased for all the concrete mixtures. Shekharchi et al. [39] observed that using wastewater in the concrete mixtures leads to absorbing further water than concrete prepared with drinking water. Raza et al. [40] stated that the water absorption at 28 and 90 days exhibited by the portable water was 11.93% and 9.03%, respectively, showing the reduction in water absorption with curing age. The results obtained concluded that the water absorption of concrete samples prepared from the textile factory has a lower rate than that of prepared from the portable water.

3.3. Corrosion reisistance

The chemical materials' existence in wastewater is one of the main reasons for the corrosion of wastewater pipelines. Wang et al., [41] studied the corrosion of concrete samples exposed to sewer environments, comprising chemical tests using mineral sulphate and acids solutions. As well as, Roghanian and Banthia [42] investigated the effect of chemical materials' existence in wastewater on the biogenic corrosion in concrete in wastewater pipes. They observed that preventing concrete bio-corrosion normally needs the application of a corrosion-resistant or modify concrete mix in order to make a protective layer between corrosive solutions and the concrete surface. Another study by De Belie et al. [43]conducted a new study about the effect of chemical materials of wastewater on the corrosion of pipeline concrete using simulating biogenic sulfuric acid corrosion in sewerage systems. They concluded that the concrete made of limestone aggregate had a lower degradation depth than concrete with inert aggregate.

3.4. Resistance against acid attack

The resistance to acid attacks is a very important property in concrete that should enhance it to save the concrete structures

Table 1
Chloride ion proportion of concrete for various w/c and various [35].

Concrete sample	Chloride ion proportion for concrete mass							
	0–5 (mm)	5–10 (mm)	10–15 (mm)	15–20 (mm)	20–25 (mm)	25–30 (mm)	30–35 (mm)	35–40 (mm)
CW(0.4)	3.1	1.97	1.21	0.72	0.35	0.11	0	0
CWW(0.4)	3.8	2.54	1.67	1.08	0.65	0.35	0.15	0
CW(0.5)	3.7	2.46	1.64	1.05	0.63	0.34	0.15	0
CWW(0.5)	4.2	2.98	2.07	1.41	0.91	0.53	0.24	0.12
CW(0.6)	4.36	3.2	2.28	1.51	0.93	0.52	0.2	0
CWW(0.6)	4.75	3.58	2.67	1.89	1.23	0.72	0.33	0.16

from deterioration due to exposure to different environmental acids. Concrete is tremendously exposed to acid attacks because of its alkaline nature. Most of the wastewater infrastructure deterioration was due to the high acid attacks. Consequently, numerous researchers focus on enhancing and improving the resistance against acid attacks. HCL and H_2SO_4 are the most aggressive and destructive acids that cause deterioration in concrete structures. Raza et al. [37] conducted an experimental study to determine the effect of wastewater on concrete durability by testing the acid attack. They immersed the concrete samples in a 4% H_2SO_4 solution. They observed that the deterioration of the concrete samples prepared from the wastewater was detected to be the highest. Chatveera et al. [33] stated that sludge water and sulphuric acid significantly impact the deterioration of concrete structures. Weight loss was continuously identified in the development of hardened concrete. A gypsum layer or calcium sulfate created from the reactions of H2SO4 and Ca(OH)2 from concrete leads to reduced bonding among layers, thus resulting in deterioration [44]. Raza et al. [40] stated that the deterioration of concrete prepared from mixing textile factory wastewater is faster than that of the concrete mixed with potable water. The wastewater with a low pH value has a higher losing mass. Then the water with a high PH. Hereafter, concrete collapse is fundamentally influenced by mixing wastewater and the pH values of acids [45].

4. Conclusions

This paper reviews the previous studies that addressed the effect of wastewater on durability properties. Using wastewater can be a new trend in reducing the harmful effect on the environment and reducing the cost required for providing adequate water for concrete production. Therefore, the upcoming potentials are optimistic for wastewater requests in concrete production. From the results obtained in the abovementioned studies, the following conclusions were drawn-.

1. The acid attacks harm the concrete's durability, and solid particles do not influence the concrete's durability unless they come in contact with other chemicals to produce new ettringite.
2. The water absorption of concrete made of wastewater has a higher rate than the control concrete.
3. The chloride permeability increased due to the increased proportions the wastewater in concrete mixtures.
4. This study recommends using a high quantity of treated wastewater in concrete production. Other tests are required to determine wastewater concrete durability, such as corrosion of steel bars and permeability of chemical materials.

CRediT authorship contribution statement

Hussein M. Hamada: Conceptualization, Methodology. **Khamees N Abdulhaleem:** Data curation, Software. **Ali Majdi:** Visualization, Investigation. **Mohammed S. Al Jawahery:** Software, Validation. **Blessen Skariah Thomas:** Supervision. **Salim T. Yousif:** Writing – review & editing.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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