Received: 7 July 2022 | Revised: 14 December 2022 | Accepted: 1 February 2023
DOI: 10.1002/suco.202200637

ARTICLE

fib CEB-FIP WILEY

Concrete production with domestic and industrial wastewaters—A literature review

Mohammad Sheikh Hassani[1] | **Jose C. Matos**[1] | **Y.X. Zhang**[2] | **Elisabete Teixeira**[1]

[1]Department of Civil Engineering, University of Minho, ISISE, Guimarães, Portugal

[2]School of Engineering, Design and Built Environment, Western Sydney University, Kingswood, New South Wales, Australia

Correspondence
Mohammad Sheikh Hassani, Department of Civil Engineering, University of Minho, ISISE, Guimarães, Portugal.
Email: id10079@alunos.uminho.pt

Funding information
Fundação para a Ciência e a Tecnologia, Grant/Award Number: 2021.06765.BD; FCT/MCTES through national funds (PIDDAC) under the R&D Unit Institute for Sustainability and Innovation in Structural Engineering (ISISE), Grant/Award Number: UIDB/04029/2020

Abstract

With water scarcity posing an ever-present worldwide crisis, treated wastewater usage as an alternative to fresh water could be a smart choice and contribute to a sustainable construction industry. Numerous studies have been conducted by using treated domestic or industrial wastewater in concrete production, providing a promising solution to the global water shortage and wastewater management. However, the effectiveness of wastewater on the concrete manufacturing in comparison to pure freshwater has been a concern due to its impurities and contaminants. The results derived from previously published studies on concrete manufacturing with wastewater vary as a consequence of considerate different additives, curing age, treatment method, or wastewater quality. This review compiles and compares the previous investigations on physical and mechanical properties, durability characteristics, and morphological assessments of manufactured concrete with treated wastewater, and discusses the reasons for similarities and differences. Research findings and conclusions from the literature are summarized, and future research directions based on the research gaps are also recommended.

KEYWORDS

construction sustainability, durability, green concrete, mechanical properties, sustainable production, wastewater

1 | INTRODUCTION

Water shortage raises growing worldwide concerns, which necessitates heeding and managing water resources accurately.[1,2] Globally, water scarcity is becoming one of the most pressing problems, and 40% of people are expected to experience water shortage in the not-too-distant future.[3–7] Around 4 billion people are currently facing water shortage for at least 1 month each year.[3,8,9] Construction industry is one of the most water consumers and using treated wastewater instead of fresh water can be very promising to save water significantly.[10,11] In fact, to manufacture one cubic meter of conventional concrete, around 500 L of water is needed, and concrete manufacturing worldwide utilizes nearly four trillion liters of fresh water in 1 year.[12]

Discussion on this paper must be submitted within two months of the print publication. The discussion will then be published in print, along with the authors' closure, if any, approximately nine months after the print publication.

Therefore, alternating fresh water with domestic and industrial wastewater is considered a decisive step toward achieving sustainability,[4,10–13] which might be a game-changer and has become popular in some countries in recent years.[14,15]

There have been limitations reported in the standard methods for utilizing wastewater in the production of concrete, and wastewater treatment is needed before being discharged into the environment.[16–20] Since wastewater could pose immense hazards to both human health and the ecosystem,[21–25] it must be treated to have a clean and sustainable water system.[26–29] However, even after a treatment, it could contain impurities, contaminants, and additional components in comparison to pure freshwater,[30,31] which might lead to some mechanical and durability disadvantages and should be investigated precisely.[14,15] Treated wastewater must only be used in concrete when the pros prevail over the cons.[14,15] A comprehensive and in-depth review of published literature since 2015 on the use of domestic or industrial wastewater for concrete manufacturing is presented in this paper to investigate the properties of wastewater concrete profoundly. The research results are analyzed, with findings summarized and future studies recommended.

TABLE 1 Mixing water quality limitations.

Parameter	Acceptable ranges
Chloride (Cl^-, mg/L)	
Grout or prestressed concrete	≤500[32–34]
Reinforced concrete	≤1000[32–34]
Unreinforced concrete	≤4500[32]
Sulfate (SO_4^{2-}, mg/L)	≤2000[32,35–37] ≤3000[33,34]
Alkali (mg/L)	≤1500,[32] ≤600[33,34]
Total solid (mg/L)	≤50,000[33,34]
TSS (mg/L)	≤30[38]
TDS (mg/L)	≤1000[40]
pH	≥4,[32] >5,[35,36] ≥6,[33,34] 6–9[38]
Sugars, phosphates, lead, and zinc (mg/L)	≤100[32]
Nitrates (NO_3^-, mg/L)	≤500[32]
Oils and fats	Must not be visible[32]
Fecal coliform (mg/L)	≤200[38]
COD	–
BOD-weekly (mg/L)	≤30[38]

2 | WATER QUALITY LIMITATIONS IN CONCRETE MIXING

A new and unconventional mixing water must be tested comprehensively before being used in concrete manufacturing to make sure that the water quality meets standards' expectations.[32–38] It is reported that the quality of water could have a direct effect on the properties of concrete.[39] Due to the absence of impurities or contaminants in fresh water, it has been accepted for use in the manufacture of concrete. Table 1 represents some of the most significant limitations of water quality for concrete mixing, which are mentioned in the standards and previous literature.[32–38] According to Table 1, there are three different chloride limitations outlined in the BS EN 1008-02 (2002), ASTM C94-C94M-22a (2022), and ASTM C1602/C1602M-18 (2018) standards.[32–34] Although the lowest content of chloride in mixing water is allocated to grout and prestressed concrete with a maximum amount of 500 mg/L, reinforced and unreinforced concretes' mixing water could contain up to 1000 and 4500 mg/L of chloride, respectively.[32–34] Since corrosion is much more likely to occur if reinforcements are present, maximum allowable amount of chloride in mixing water for concrete production without reinforcement is considered 4.5 times greater than that of reinforced concrete.[32] While ASTM C94-C94M-22a (2022) and ASTM C1602/C1602M-18 (2018) have no limitations for chloride amount in mixing water of unreinforced concrete, maximum of 3000 mg/L is defined for sulfate concentration in all concrete types by the mentioned standards.[33,34] However, some notes indicated that up to 2000 mg/L of sulfate in mixing water is acceptable.[32,35–37]

For concrete manufacturing, mixing water with total solid and alkali content lower than 50,000 and 600 mg/L, respectively, meets ASTM C1602 and ASTM C94 limitations.[33,34] On the contrary, BS EN 1008-02 (2002)[32] has reported that alkali content could be up to 1500 mg/L, which is 2.5 times higher than other standards.[33,34] limitation of pH content is varied between 4 and 9 since it is derived from different standards.[32–36,38] Substances like sugars, phosphates, lead, and zinc are defined to be lower than 100 mg/L and nitrate up to 500 mg/L.[32] Additionally, according to BS EN 1008-2002, oils and fats should be in amounts that are invisible to the naked eye.[32] The Environmental Protection Agency (EPA) has established limits for the BOD (maximum 30 mg/L) and Fecal coliform content (maximum 200 mg/L), but it does not provide a recommendation regarding the maximum tolerable COD content.[38]

3 | STANDARDS ON THE MECHANICAL AND DURABILITY PROPERTIES OF CONCRETE

Researchers have been trying to accentuate the significance of designing and long-term characteristics of concrete to achieve durable eco-friendly concrete. To have green concrete, considering the wasted and recycled materials are tempting whenever the quality of concrete reaches the minimum limitations. By the same token, the properties of fresh and hardened concrete in the laboratory scale must be evaluated to make sure that the quality of structure in the long-term is guaranteed and there are some standard and test methods, which are represented in Table 2. According to Table 2, ACI 211.1-91 represents a suggestion for the minimum and maximum slump test values.[32] The minimum slump of 25 mm is recommended for various concrete constructions under this standard.[41] For pavements, slabs, mass concrete, foundations, and substructure walls, the maximum slump is 75 mm, while beams, reinforced walls, and building columns are specified as having a maximum slump of 100 mm.[41] In the case of replacing conventional materials with new materials, the maximum change in setting time is reported to be 25%.[41] Furthermore, the initial setting time must be more than 1 h, but the final setting time should not exceed 12 h.[41] Furthermore, ASTM C191-19 specifies that the minimum initial and final setting times are 60 and 90 min, respectively.[42] Maximum 10% reduction in compressive strength is acceptable.[33,34,41–43] However, according to BS 3148-1980, which has been withdrawn, it was acceptable to have a decline of up to 20%.[44]

Furthermore, as detailed in Table 2, ASTM C1202-19 [Rapid Chloride Penetration Test (RCPT)] provides limitations to evaluate the concrete's permeability to chloride ion based on the charge passed ranging from negligible to high.[45] As an alternative to the RCP test, FM 5-578 and AASHTO TP 95 indicate limitations for the electrical resistivity of concrete, where a higher electrical resistivity is indicative of a lower chloride permeability of concrete.[36,46] Furthermore, Podler,[47] Elkey and Sellevold,[48] Song and Saraswathy,[49] ACI 222 R-01,[50] and commercial Wenner Probe Instrument[51,52] Test methods represent limitations for corrosion risk of reinforced concrete. Water absorption and water penetration tests could be conducted according to BS 1881-122 and BS EN 12390-8, respectively.[55,56]

Based on the results of all three durability tests, including water absorption, water penetration depth under pressure, and RCPT, standards are defined to determine concrete's suitability for different environmental conditions.[53,54] Following these two standards, moderate condition is defined as a condition in which the structures are above ground and there is no penetrating risk of chloride ions.[53,54] The term “severe condition” refers to any situation in which structures are above the ground and neighboring shorelines or structures with parts of them in contact with the soil or seawater.[53,54] The last environmental condition is called extremely severe including structures located in aggressive soils,

TABLE 2 Standards' limitations to evaluate the concrete performance.

Physical	Slump[32]	Pavements, slabs, mass concrete, foundations, and substructure walls.	Minimum: 25 mm Maximum: 75 mm				
		Beams, reinforced walls, and building columns.	Minimum: 25 mm Maximum: 100 mm				
	Setting time	Maximum 25% change in using new materials. Initial setting time must be more than 1 h and final setting time less than 12 h.[41] Minimum initial and final setting time are 60 min and 90 min, respectively.[42]					
Mechanical	Compressive strength[33,34,41–43]	Up to 10% reduction is acceptable.					
Durability	Classification		Negligible	Very low	Low	Moderate	High
	Chloride permeability	RCPT[45] (coulombs)	0–100	100–1000	1000–2000	2000–4000	>4000
	Concrete Electrical Resistivity (kΩ-cm)	AASHTO TP95 and FM 5–578.[46]	>254	37–254	21–37	12–21	<12
		Podler.[47]	>100	–	50–100	10–50	<10
		Elkey and Sellevold,[48] Song and Saraswathy,[49] ACI 222 R-01.[50]	>20	–	10–20	5–10	<5
		Wenner instrument.[51,52]	≥100	–	50–100	10–50	≤10
Multiple conditions[53,54]	Classification		Moderate		Serve		Extreme serve
	Water absorption[55]		≤4%		≤3%		≤2%
	Depth of water penetration[56]		≤50 mm		≤30 mm		≤10 mm
	RCPT[45]		≤3000 coulombs		≤3000 coulombs		≤2000 coulombs

underground water, marine zones, or structures used to store water and wastewater.[53,54] Therefore, in determining the appropriateness of a structure for a particular environment, the three mentioned durability results should be taken into account simultaneously.[53,54] The availability of standards, however, does not include codes regarding the permissible limits for chloride, sulfate, and carbon ions diffusion coefficients or the maximum acceptable mass loss under freezing and thawing or sulfate attacks to evaluate the durability properties in using unconventional materials in concrete.

4 | THE EFFECT OF DOMESTIC AND INDUSTRIAL WASTEWATER ON CONCRETE PROPERTIES

4.1 | Physical and chemical characteristics of wastewater used in the literature

Several studies have been conducted to evaluate the effects of various types of wastewater on concrete

TABLE 3 The properties of used wastewaters in the previous studies.

Reference	pH	BOD_5 (mg/L)	COD (mg/L)	TS (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)
Sheikh Hassani et al. (2020)[57,58]	8.1	50	160	420	47	185	15.5
Asadollahfardi et al. (2016)[59]	7.7	30	93	200	55	180	14
Asadollahfardi and Mahdavi (2018)[60]	7.42	8	21	456	15	15	12
Babu et al. (2018) (NEC[1])[61]	7.13	–	–	–	175	22	–
Babu et al. (2018) (MKT[2])[61]	6.93	–	–	–	140	20	–
Babu et al. (2018) (AR[4])[61]	7.16	–	–	–	160	23.5	–
Babu et al. (2018) (PKT[3])[61]	7.05	–	–	–	145	17	–
Khushboo and Salmabanu (2019) (Secondary wastewater)[62]	7.48	20	–	–	270	–	–
Khushboo and Salmabanu (2019) (Tertiary wastewater)[62]	7	14	–	–	258	–	–
Raza et al. (2021) (DS[5])[63]	7.2	311	421	1606	340	755	102
Raza et al. (2021) (FF[6])[63]	2.5	610	1045	5278	1050	950	66
Raza et al. (2021) (TF[7])[63]	7	70	120	405	63	105	2.8
Raza et al. (2021) (SF[8])[63]	7.2	720	950	4201	862	210	32
Raza et al. (2021) (SS[9])[63]	6	1120	1420	560	250	116	10
Kaboosi and Emami (2019) (50% TIWW[10]+ 50% FW[11])[64]	8.1	49.5	175	1237	238	202	–
Kaboosi and Emami (2019) (100% TIWW)[64]	8.5	99	350	1668	340	288	–
Taherlou et al. (2021)[65]	7.3	9	26	7	58	180	10
Arooj et al. (2021) (TW[12])[66]	7.27	43.5	72	1132	175	171	–
Arooj et al. (2021) (PFW[13])[66]	7.26	32	52	1121	166	162	–
Ahmed et al. (2021) (Test1)[67]	8	7	<10	684	–	100	–
Ahmed et al. (2021) (Test2)[67]	7.4	10	10	1884	–	80	–
Ahmed et al. (2021) (Test3)[67]	7.5	<5	24	4800	–	800	–
Abushanab and Alnahhal (2021)[68]	7.8	5	<10	1693	511	8	–
Bouaich et al. (2022)[69]	8.8	53	131	–	10.2	25.8	20.6
Vanitha and Rajan (2022)[70]	7.5	8.5	22.5	22	42	182	13.8
Tanlı et al. (2022)[71]	7.5	2.6	46.9	985	291	106.2	<4.5

Note: *Green colors* show the accepted amounts based on the suggestion of standards methods (Table 2), and *red colors* are the rejected ones. Moreover, since there is no suggestion for COD in the standard methods, the color is considered *black*. [1]Narasaraopeta Engineering College wastewater plant (NEC); [2]PatanKhasim Charitable Trust wastewater plant (PKT); [3]MahmadhKhasim Charitable Trust wastewater plant (MKT); [4]Amara wastewater plant (AR); [5]Domestic sewerage wastewater (DS); [6]Fertilizer factory wastewater (FF); [7]Textile factory wastewater (TF); [8]Factory wastewater (SF); [9]Service station wastewater (SS); [10]Treated industrial wastewater (TIWW); [11]Fresh water (FW); [12]Treated wastewater; [13]Polished filtered wastewater.

curing and manufacturing.[57–72] Table 3 illustrates the physical and chemical characteristics of wastewater used in the previous studies, with green colors denoting the accepted characteristics, and red colors, those that are rejected based on the suggestion of standard methods (Table 2). According to this table, the pH of all wastewaters except one is acceptable, belonging to fertilizer factory wastewater (FF) with a value of 2.5, which is considered to be outside the standards' limitations.[63] The standards report that pH must be ≥4,[32] ≥6,[43] >5,[35,36] and 6–9.[38] Although the U.S. Environmental Protection Agency reported the maximum amount of BOD_5 should be limited to 30 mg/L, several studies have used wastewater in higher amounts than this number.[23,57–59,63,64,66,69] Unfortunately, there is no standard regarding COD limitations. A high level of COD, however, has been reported that can adversely affect the quality of concrete.[59] Therefore, further research is needed. As depicted in Table 3, the other parameters follow standards, but the chloride content of fertilizer factory wastewater (FF) is unacceptably high if it is intended to be used in reinforced concrete.[32–34,63]

4.2 | Parameters considered in the state-of-art literature for wastewater concrete production

Detailed information regarding the types and percentages of wastewaters, chemical admixtures, water-to-cement ratios, ages, cement types, and tests conducted on concrete manufactured with wastewater is provided in Tables 4 and 5. Apart from one investigation on using domestic and industrial wastewater in self-compacting concrete,[65] all studies used wastewater in normal concrete. Two studies evaluated the effects of combining wastewater with recycled aggregates,[63,67] and one with recycled plastic.[71] Several literatures added chemical admixtures to concrete mix designs, including superplasticizer (SP),[59,64,65] zeolite,[64] municipal solid waste incineration bottom ash (MSWIBA),[65] silica fume,[65,67] limestone powder,[65] calcium chloride ($CaCl_2$),[66] chermite 520 BA,[66] ground granulated blast furnace (GGBF),[67,71] fly ash,[68] calcium nitrite[68] and encapsulated nanoparticles.[69] Water-to-cement ratios (W/C) are varied from 0.35 to 0.5 with ages between 3 and 365 days. Previous studies have utilized either ordinary Portland cement or type two cement. Mechanical properties of fresh and hardened concrete, durability characteristics, and morphological assessments have also been reported in the literature.

4.3 | Physical properties of wastewater concrete

4.3.1 | Slump

In the study by Asadollahfardi et al. (2016), three different water-to-cement ratios (W/C) were investigated.[59] The slump values of freshwater samples decreased from 110, 90, and 117 mm to 99, 82, and 105 mm in wastewater specimens while the W/C ratios were 0.43, 0.5, and 0.6, respectively.[59] However, it was found that there was no difference in slump when wastewater was used instead of fresh water.[59] Taherlou et al. (2021) indicated a higher slump value in using wastewater and superplasticizer in comparison with control samples.[65] In comparison with samples manufactured with fresh water, Abushanab and Alnahhal (2021) found that using 25%, 50%, and 100% of domestic wastewater may increase the slump value by 3.4%, 1.2%, and 5.5%.[68] They stated that suspended solids in wastewater may have contributed to the slight increase.[68] Additionally, the slump value significantly increased when fly ash or calcium nitrite was combined with wastewater, with values ranging from 56% to 115% and 109% to 144%, respectively.[68] A slump reduction of approximately 14% was reported by Vanitha and Rajan (2022) in wastewater concrete samples.[70]

4.3.2 | Setting time

It has been reported in six studies that the setting times of all samples made with wastewater were higher than those for control samples using fresh water,[59–61,68–70] apart from the initial time of Patan Khasim Charitable Trust wastewater (PKTWW) and Amara wastewater (ARWW) in the study of Babu et al. (2018).[61] It is stated that impurities of wastewater might be the reason behind the delay in the hydration process.[59,60] However, Babu et al. (2018)[61] did not mention any particular reason behind lower setting time in the mentioned concrete samples. Based on the ACI 211.1-91,[41] and ASTM C191-19,[42] all the samples have the minimum initial and final setting time and their maximum final setting times comply with the notes. Besides, according to ACI 211.1-91,[41] the difference in setting time when wastewater was used over fresh water, which must be less than 25%, is in line with this note in all samples, excluding the final setting time of samples manufactured with domestic wastewater,[59] PatanKhasim Charitable Trust wastewater,[61] and treated domestic wastewater in combination with fly ash, and calcium nitrate.[68] Figure 1 shows a summary of the setting time results for different kinds of wastewater in concrete manufacturing.

TABLE 4 A summary of the characteristics that have been considered in previous studies (Part 1).

Reference	Wastewater type and proportion (%)	Chemical admixture	W/C	Age (days)	Cement type	Conducted tests
Sheikh Hassani et al. (2020)[57]	Domestic wastewater (100%)	–	0.4, 0.5, and 0.6	28	Portland cement type 2	Chloride ion diffusion coefficient, microstructure analysis.
Sheikh Hassani et al. (2020)[58]	Domestic wastewater (100%)	–	0.4, 0.5, and 0.6	28	Portland cement type 2	Compressive strength, water absorption, water penetration, RCPT, freeze–Thaw cycles, sulfate attack with freeze–Thaw cycles, microstructure analysis.
Asadollahfardi et al. (2016)[59]	Domestic wastewater (100%)	SP 4% (Only in W/C = 0.43)	0.43, 0.5, and 0.6	3, 7, 14, 28, 56, 90	Portland cement type 2	Setting time, slump, compressive and tensile strength, surface electrical resistivity, water absorption, freeze–Thaw cycles, microstructure analysis.
Asadollahfardi and Mahdavi (2018)[60]	Industrial wastewater (100%)	–	0.5	3, 7, 14, 28, 56, 90	Portland cement type 2	Setting time, compressive and tensile strength of mortar and concrete, surface electrical resistivity, water absorption, microstructure analysis.
Babu et al. (2018)[61]	Domestic wastewater (100%)	–	–	3, 7, 28, 90	Ordinary Portland cement	Compressive and flexural strength.
Khushboo and Salmabanu (2019)[62]	Territory and secondary wastewater (100%)	–	0.47	7, 28, 90	Ordinary Portland cement	Workability, compressive and flexural strength, chloride penetration resistance, carbonation resistance, abrasion resistance.
Raza et al. (2021)[63]	Domestic wastewater, fertilizer, textile, and sugar factory and service station wastewater (100%) + recycled aggregates (100%)	–	0.5	7, 28, 90	Ordinary Portland cement	Compressive and tensile strength, water absorption, chloride penetration
Kaboosi and Emami (2019)[64]	Industrial wastewater (100%)	Zeolite (0, 10, 20, 30%), SP (0.8%–1.51%)	0.45	3, 7, 28, 56, 90, 180, 365	Portland cement type 2	Compressive Strength
Taherlou et al. (2021)[65]	Industrial wastewater (100%) in self-compacting concrete	Municipal solid waste incineration bottom ash (MSWIBA; 10%, 15%, 20%), SP (0.7%–1.17%), silica-fume(32 kg/m^3), limestone-powder (175 kg/m^3)	0.5	7, 28, 56, 90	Portland cement type 2	Workability, compressive strength, water absorption, RCPT, microstructure analysis.

TABLE 5 A summary of the characteristics that have been considered in previous studies (Part 2).

Reference	Wastewater type and proportion (%)	Chemical admixture	W/C	Age (days)	Cement type	Conducted tests
Arooj et al. (2021)[66]	Domestic wastewater (100%)	$CaCl_2$ (1, 2%), chermite 520 BA (1, 2%)	0.35	7, 14, 21, 28,	Ordinary Portland cement	Compressive and tensile and flexural strength,
Ahmed et al. (2021)[67]	Domestic wastewater (100%) + recycled aggregates (20%)	GGBS[2] (30%), silica fume (10%)	0.35	28, 90, 150	Portland cement type 2	Compressive and tensile strength, surface electrical resistivity, RCPT, volume resistivity, microstructure analysis.
Abushanab and Alnahhal (2021)[68]	Domestic wastewater (0, 25, 50, 100%)	Fly ash (0, 20, 35%), calcium nitrite (0, 3%), SP 0.2%	0.45	7, 28, 90	Ordinary Portland cement	Workability, slump, compressive and flexural strength, surface electrical resistivity, chloride permeability, porosity. microstructure analysis
Bouaich et al. (2022)[69]	Domestic wastewater (100%)	–	0.5	7, 14, 28, 90	Ordinary Portland cement	Workability, setting time, compressive and tensile strength, porosity, microstructure analysis.
Vanitha and Rajan (2022)[70]	Domestic wastewater (100%)	Encapsulated nanoparticles (not mentioned)	–	7, 28	Ordinary Portland cement	Slump, compressive and flexural strength, carbonation, and chloride attack
Tanlı et al. (2022)[71]	Domestic wastewater (100%) + recycled plastic (30, 40, 50%)	Ground granulated blast furnace (GGBS) (0, 50%)	0.5	1, 7, 14, 28	Ordinary Portland cement	Slump, compressive and flexural strength, thermal properties, density.

4.4 | Mechanical properties of hardened wastewater concrete

4.4.1 | Compressive strength

Figure 2 represents the percentage change in compressive strength of wastewater concrete as compared to control samples made with freshwater. The results in Figure 2 show that most types of wastewater, whether they contain additives or not, lowered the compressive strength. However, in some samples, the opposite results were reported.[58–71] As mentioned in the standard methods,[33,34,41–43,73,74] the maximum acceptable reduction of compressive strength is limited to 10%, whereas several wastewater concrete samples have shown a reduction exceeding this limit (Figure 2). While some of these reductions were slightly above 10%, which are considered not acceptable, the use of these treated wastewater resources could be of great value from an environmental perspective to avert the water scarcity disaster, particularly for some areas in which the water is scarce.[20] It has been reported that wastewater impurities could hamper the proper formation of impact hydration products. This could explain the lower compressive strength of the concrete when compared with homogenous freshwater concrete due to their non-uniform structure.[58,59,64–69] Despite no clear explanations were provided in the articles, Figure 2 indicates that some combinations could lead to higher compressive strength.[63–66,69]

As provided in Figure 2, by decreasing the water-to-cement ratio or using 50% wastewater, wastewater

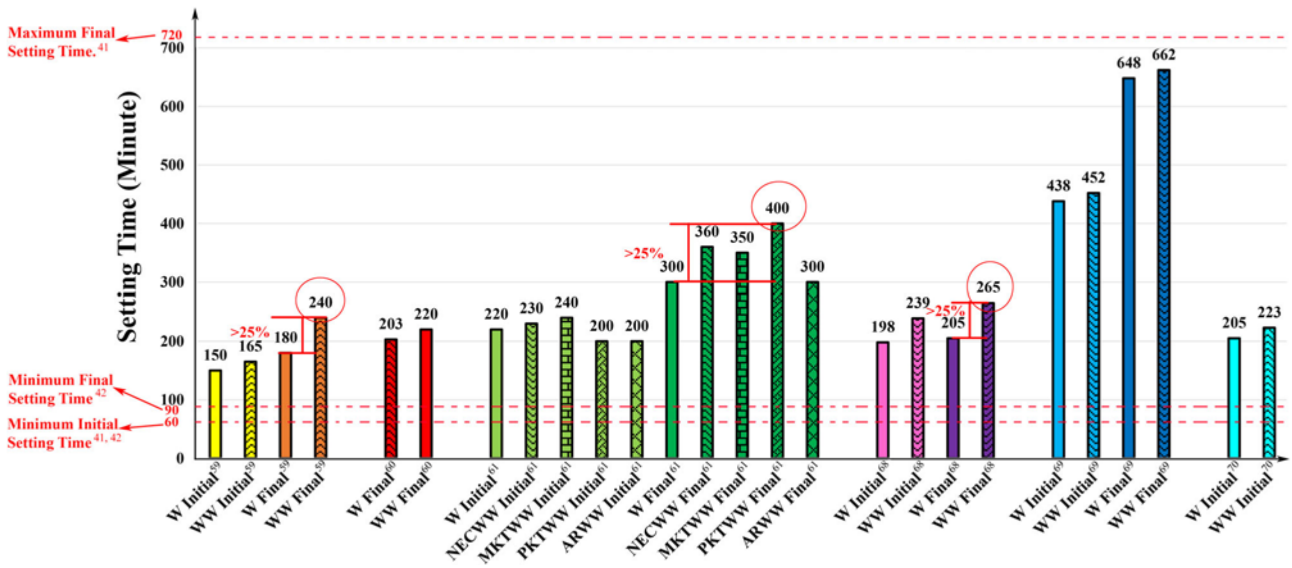

FIGURE 1 Setting time of manufactured concrete samples with freshwater (W), and treated wastewater (WW); adapted from References 59–61,68–70).

concretes perform better in compressive strength than the freshwater concrete. In general, the differences in results might be mostly due to diverse characteristics of wastewater (higher COD results in lower mechanical and durability properties[58,59]), treating methods (using chloride in treating results in chloride attack[59]), maintaining the condition of wastewater (during summertime, high temperature increases biological activities and changes wastewater's characteristics rapidly[14,15]), wastewater's age and duration of concrete manufacturing (aging causes treating and delaying between manufacturing can deference the properties enormously[14,15]) as well as cement type, water to cement ratio and using additives.[58–71] It is challenging to collect, transfer, and maintain the properties of wastewater. These steps must be followed precisely as outlined in the EPA wastewater sampling procedures to minimize the possible changes.[72]

4.4.2 | Tensile and flexural strength

Tensile strength

Asadollahfardi et al. (2016) reported the maximum reductions of 4% in tensile strength of the concrete at the age of 28 days when wastewater was used.[59] In a study conducted by Taherlou et al. (2021), the tensile strength of wastewater concrete decreased by 11%–13% after 90 days.[60] Raza et al. (2021) reported that using primary wastewater (PWW), domestic sewerage wastewater (DS), fertilizer factory wastewater (FF), factory wastewater (SF), and service station wastewater (SS) could result in lowering the tensile strength at the ages of 7, 28, and 90 when compared to the control samples although in using textile factory wastewater (TF) the opposite result was observed.[63] They mentioned that as a result of lower bicarbonate concentrations in TF wastewater samples, compared to other wastewater types, the results were different.[63] Ahmed et al. (2021) demonstrated that, at both 28-day and 150-day ages, the tensile strength of manufactured concrete samples made with wastewater and 100% recycled aggregates was 87%–97% of that of the freshwater concrete samples.[67] However, the presence of bacteria in wastewater was found to result in higher tensile strength of up to 16% in both two studies.[66,69]

Flexural strength

Regarding the flexural strength, all the previous studies claimed that wastewater reduced the flexural strength of the concrete.[61,62,66,68,70,71] Slight reductions were reported in the study of Babu et al. (2018) in using NECWW, PKTWW, MKWW, and ARWW. Wastewater from narasaraopeta engineering college wastewater (NEC) had the lowest reduction, followed by PKT, MK, and AR wastewaters.[61] When tertiary wastewater was used, the flexural strength of concrete at the ages of 28 and 90 days declined by about 7.7% and 13%, respectively. In contrast, these reductions were around 30% and 17.2% in using secondary wastewater.[62] Moreover, curing the samples in secondary wastewater significantly reduced the flexural strength by around 45% and 30% at the ages of 28 and 90 days, respectively.[62] Arooj et al. (2021) reported that wastewater with or without calcium chloride or Chermite 520 BA led to a decline in flexural strength of concrete.[66] Up to 12% decrease in flexural strength of concrete was

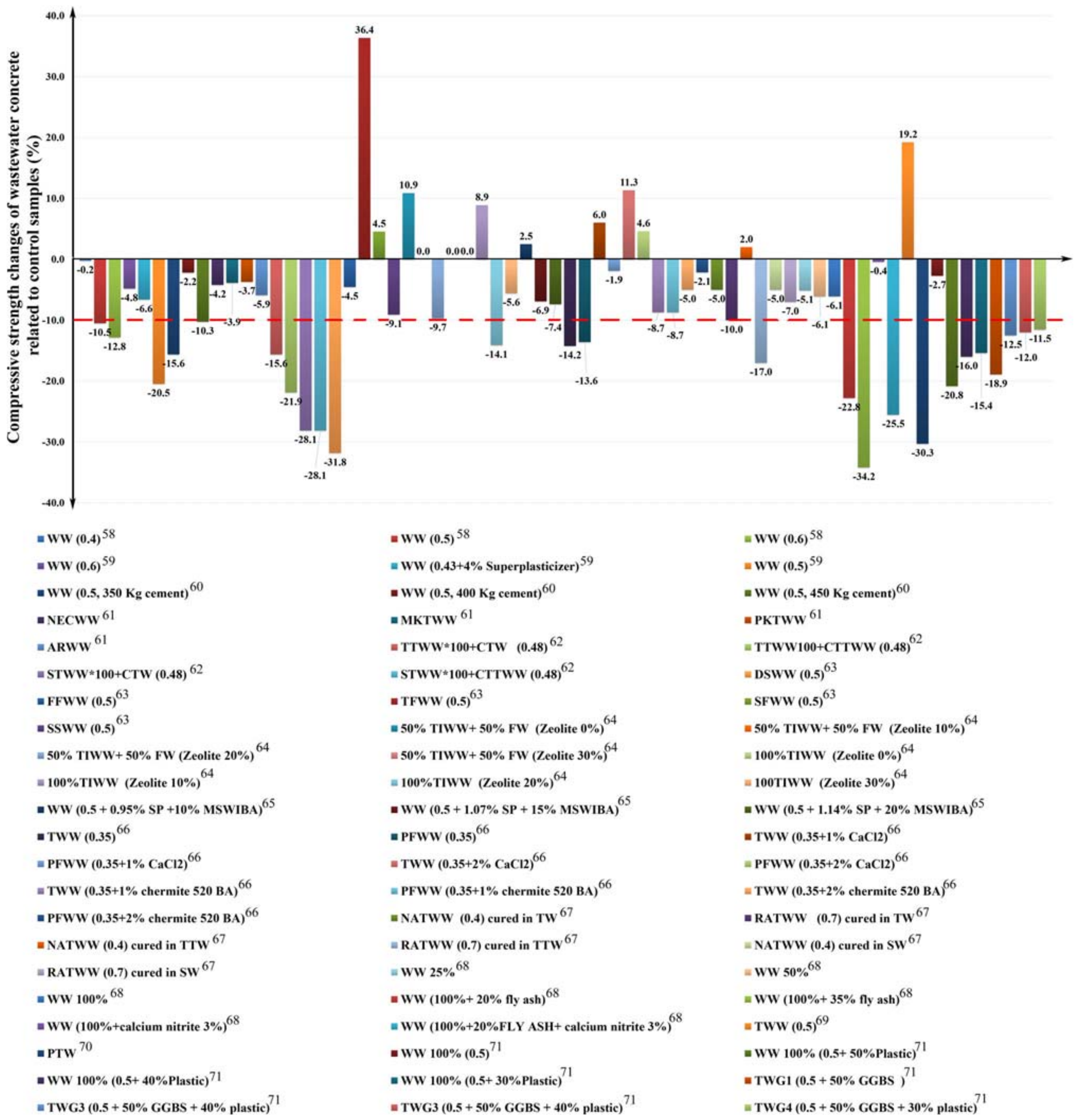

FIGURE 2 Compressive strength changes percentage of wastewater concrete in comparison control samples made of fresh water (adapted from References 58–71).

indicated in an experimental study by Abushanab and Alnahhal (2021).[68] In another study, reductions of around 10% and 15% in flexural strength at the 28-day and 90-day age groups, respectively was reported.[70] Tanlı, et al. (2022) found that around 30%–35% reduction could happen in the flexural strength of concrete when wastewater was combined with recycled plastic.[71] Table 6 summarizes the mechanical properties of fresh and hardened concrete.

4.5 | Durability of wastewater concrete

4.5.1 | Effect of using wastewater on the durability properties of concrete

Long-term durability for green concrete, when using new waste material, must be investigated properly. Researchers have done several investigations on the durability properties of wastewater concrete. Asadollahfardi

TABLE 6 Physical and mechanical results of previous literature in using wastewater.

		Results		
Characteristics	Parameter	Increase	Decrease	No significant effect
Physical properties	Slump	–	Domestic wastewater, especially after adding fly ash or calcium nitrite,[68] domestic wastewater with encapsulated nanoparticles.[70]	Treated wastewater before chlorination,[59] industrial wastewater with SP.[65]
	Setting time	Treated wastewater before chlorination.[59–61,68–70]	–	–
Mechanical properties	Compressive strength	Textile factory and service station wastewaters, especially during early ages.[63] 50% and 100% treated industrial wastewater with 20% zeolite in high cement contents, and 10% in low contents.[64] WW (0.5 + 0.95% SP +10% MSWIBA),[65] Combining treated wastewater with Chermite 520 BA (superplasticizer),[66] TWW (0.35 + 1% $CaCl_2$),[66] PFWW (0.35 + 2% $CaCl_2$),[66] NATWW (0.4) cured in TTW,[72] TWW (0.5).[69]	,[58–71] Increasing COD content,[59] combining treated wastewater with calcium chloride (accelerator), recycled aggregate, recycled plastic, MSWIBA, calcium nitrite.[66–71]	50% TIWW+ 50% FW (Zeolite 10%),[64] 50% TIWW+ 50% FW (Zeolite 30%),[64] TIWW (Zeolite 0%).[64]
	Tensile strength	Simple wastewater, combining treated wastewater with calcium chloride (accelerator) or Chermite 520 BA (superplasticizer) (wastewater bacteria),[66] textile factory wastewater (lower bicarbonate),[63] domestic wastewater (wastewater bacteria).[69]	Treated wastewater before chlorination,[59] industrial wastewater with SP,[60] Sugar factory, service station, and fertilizer factory wastewater,[63] Combining treated wastewater with recycled aggregate.[67]	–
	Flexural strength	–	NECWW, PKTWW, MKWW, and ARWW,[61] territory and secondary wastewater, specially curing in wastewater,[62] Combining treated wastewater with calcium chloride (accelerator) or Chermite 520 BA (superplasticizer)[66,68,70,71]	–

et al. (2016) reported that although chloride ions penetrated slightly deeper into wastewater concrete than that of the control sample using freshwater, the level of penetration was very low.[59] Furthermore, they indicated that the results of water absorption, surface electrical resistivity, and freeze–thaw attack tests in using wastewater and fresh water to manufacture concrete were almost similar.[59] An increase in chloride ion content was reported by Asadollahfardi and Mahdavi (2018) when fresh water was alternated with treated industrial wastewater.[60] However, they mentioned that this concrete can be considered very low permeable based on the result of the water absorption test.[60]

Khushboo and Salmabanu (2019) tested the penetration depth of carbon ions into concrete samples manufactured and cured in freshwater or wastewater at the ages of 7, 14, 21, and 28 days.[62] The carbonation depth of the control samples remained zero at 14 days although reached 2.33 and 3 mm in 21 and 28 days, respectively. For both wastewater concrete cured in freshwater or wastewater at the age of 7 days, the penetration depth of carbon was zero. In the case of wastewater concrete cured in fresh water at 14, 21, and 28 days, it penetrated to the depth of 4.33, 5.33, and 8.66 mm, respectively. Besides, wastewater curing was observed to have a larger negative impact on the carbon penetrating depth than freshwater curing, with around 54, 75, and 67% increases at ages 14, 21, and 28 days, respectively.[62] Furthermore, they indicated that higher water quality resulted in a lower chloride concentration in concrete, and using wastewater increased the chloride ion penetration depth.[62] On the contrary, the abrasion resistance test showed around 2% and 8% improvement in using tertiary wastewater cured in fresh water and wastewater, respectively. Raza et al. (2021) stated that using sugar factory wastewater, service station wastewater, and fertilizer factory wastewater declined split tensile strength, but increased water absorption, mass loss, and chloride penetration.[63] Furthermore, it was reported that textile factory wastewater can significantly increase mass loss and chloride penetration, which both indicate lower durability, whereas it improved compressive strength and split tensile strength.[63]

Sheikh Hassani et al. (2020) conducted an experimental and numerical study on the effect of wastewater on chloride ion diffusion coefficient.[57] It was observed that substituting municipal wastewater for freshwater increased chloride ion concentration and diffusion coefficient of concrete.[57] But, since there are no standards in this regard, it is not possible to determine whether the changes are acceptable or not. Moreover, their results showed that by increasing the water-to-cement ratio, the maximum penetration depth increased, especially in the wastewater concrete samples.[57] In another experimental study, Sheikh Hassani et al. (2020) reported higher water absorption, water penetration, and chloride ion penetration as well as lower compressive strength when wastewater was altered with fresh water. Furthermore, using wastewater can reduce the durability of concrete under freezing and thawing cycles.[58] Additionally, although freezing and thawing cycles combined with sulfate attacks improved the compressive strength in fewer cycles due to the generation of ettringite strings in the voids, this combination doubled the destructive effects in 100 cycles.[58]

4.5.2 | Effect of using wastewater on the durability properties of nonconventional concrete

Some researchers have attempted to consider additives and recycled material such as municipal solid waste incinerator bottom ash (MSWIBA),[65] recycled aggregates,[67] calcium nitrite,[68] fly ash,[68] encapsulated nanoparticles,[70] recycled plastic,[71] and granulated blast furnace slag (GBFS)[71] to combine with wastewater in manufacturing green concrete. Taherlou et al. (2021) conducted an experimental study on the properties of self-compacting concrete using treated industrial wastewater and MSWIBA as a replacement of freshwater and aggregates.[65] It was found that mixing MSWIBA into freshwater and wastewater concrete reduced the durability properties. Although MSWIBA demonstrated better performance using wastewater than freshwater, this could be attributed to the higher percentages of superplasticizers in their wastewater concrete mix design than the freshwater concrete.[65] In another study by Ahmed et al. (2021), RCPT and electrical resistivity tests at 90- and 150-day ages showed very low chloride ion penetration in concrete samples manufactured with 100% domestic wastewater and 200% recycled aggregates.[67] At both of the mentioned ages, however, concrete samples manufactured with this combination contained higher chloride contents as compared to control samples.[67] A similar volume resistivity and chloride percentage was also negligible in both control samples manufactured using recycled aggregate concrete combined with fresh water or wastewater.[67]

Abushanab and Alnahhal (2021) conducted experimental tests on evaluating the effect of wastewater with or without calcium nitrite and fly ash.[68] They indicated that using wastewater could improve electrical resistivity by up to 6.5% but on the contrary increase the chloride permeability by around 40%.[68] They mentioned this effect might be the consequence of suspended solids of wastewater.[68] In addition, wastewater combined with calcium nitrite increased both chloride penetration and electrical resistivity by up to 32%.[68] Furthermore, although the combination of 100% wastewater, 20% fly ash, and 3% calcium nitrite improved the electrical resistivity at 7- and 28-day ages, it had a significant negative effect on 90-day age and increased the electrical resistivity by around 32%.[68] They stated that the interaction of wastewater sulfate ion with calcium nitrite might generate ettringite strings and also calcium monosulphoaluminate hydrate and deteriorate the structure of concrete for a long time.[68] Furthermore, adding a maximum of 20% fly ash could decrease the chloride penetration up to around

70%. In combination with wastewater, 20% fly ash without calcium nitrite was reported to be the optimal percentage that could result in better performance in comparison with control samples.[68] Vanitha and Rajan (2022) reported that pretreated wastewater with encapsulated nanoparticles could result in increasing chloride and carbon penetration, losing more weight, and decreasing density while compared to control samples manufactured with fresh water.[70] Tanli et al. (2022) studied the possibility of manufacturing concrete with wastewater in combination with recycled plastic or granulated blast furnace slag (GBFS). The result showed that using 100% wastewater and 30%–50% plastic as a replacement of aggregates declined the compressive and tensile strengths of wastewater concrete by around 30% and 60%.[71] It was also indicated that this combination could reduce the density and thermal conductivity of concrete.[71] Besides, adding GBFS to this combination did not improve the properties.[71]

Figure 3 represents the correlation between compressive strengths and water abortion of concrete samples manufactured with fresh water and wastewater based on the results of previous studies.[58–60,63,65] As shown in Figure 3, by decreasing the compressive strength of concrete, the water absorption increased. The R-squared of freshwater was greater than wastewater, which shows a higher level of correlation. Moreover, the concrete manufactured with freshwater had a steeper slope than that made from wastewater, indicating that the changes in freshwater were more intense than those in wastewater-produced concrete.

4.6 | Microscale analysis of concrete manufactured with wastewater

Evaluating concrete morphology could provide a multitudinous understanding of the interior structure and explicate the behavior of concrete. The mercury intrusion porosimetry test (MIP) was conducted on concrete samples manufactured with fresh water and wastewater to determine the distribution of concrete pores.[58] Figure 4 is the output of the MIP test, which shows the pore size distribution, diameters of pores in nanoscales, and cumulative volume (mm^3/g) for both freshwater concrete (left image) and wastewater concrete (right image).[58]

The left image of Figure 4 represents that the majority of pores in freshwater concrete had diameters between around 10 and 100 nm. Then, the diameter of pores declined rapidly after 100 nm and eventually ended at around 1000 nm. However, there were negligible amounts of pores with a diameter of approximately more than 10,000 nm in freshwater concrete. As shown in the right image of Figure 4, pore diameters of wastewater concrete ranged from around 10 to 10,000 nm with a lower cumulative volume before 100 nm compared to fresh water. In contrast, notable large pores bigger than 100 nm and smaller than around 10,000 nm were

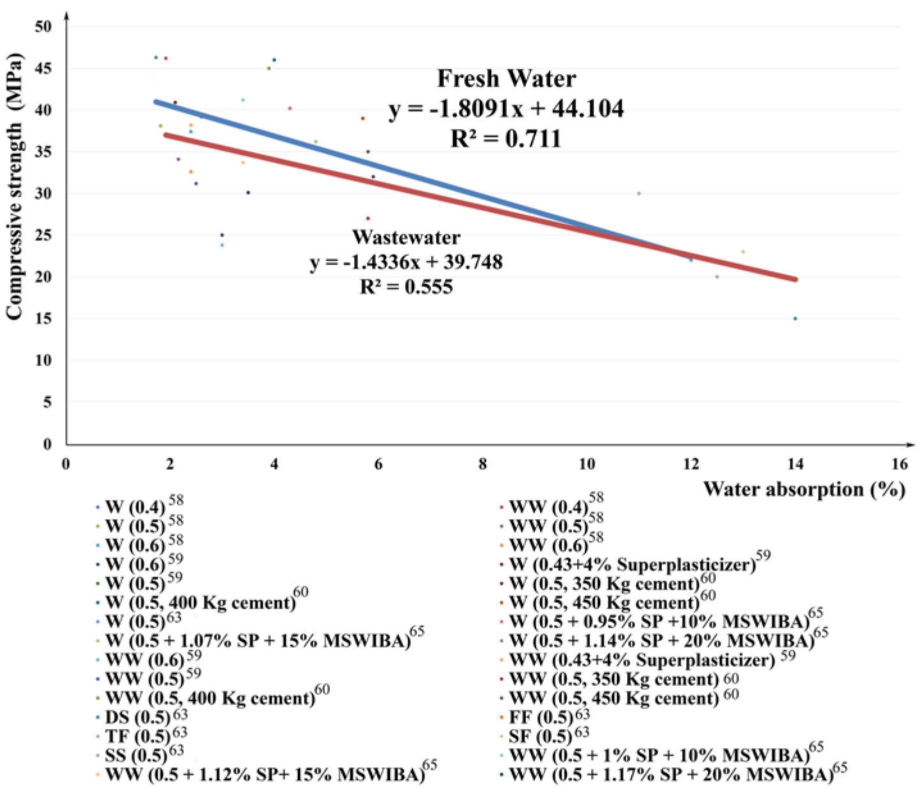

FIGURE 3 The diagram of compressive strength VS water absorption (adapted from references 58–60,63,65).

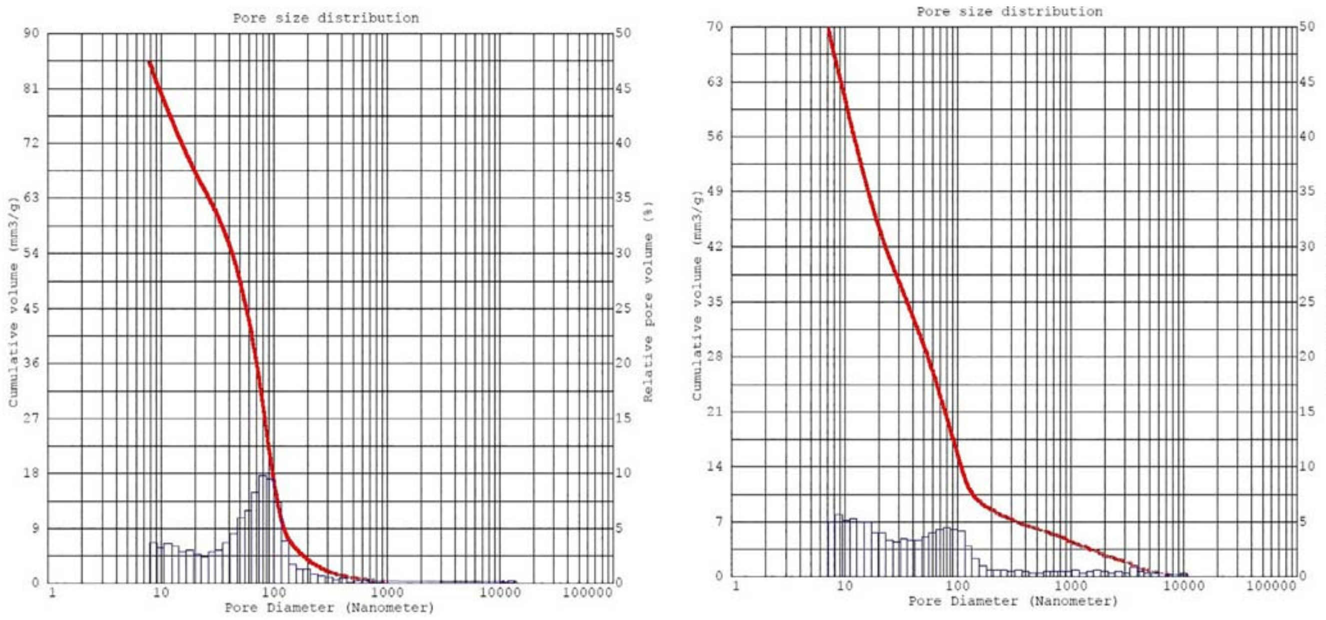

FIGURE 4 Pore size distribution, diameters of pores in nano scales, and also cumulative volume (mm^3/g) for both freshwater concrete (left image) and wastewater concrete (right image).[58]

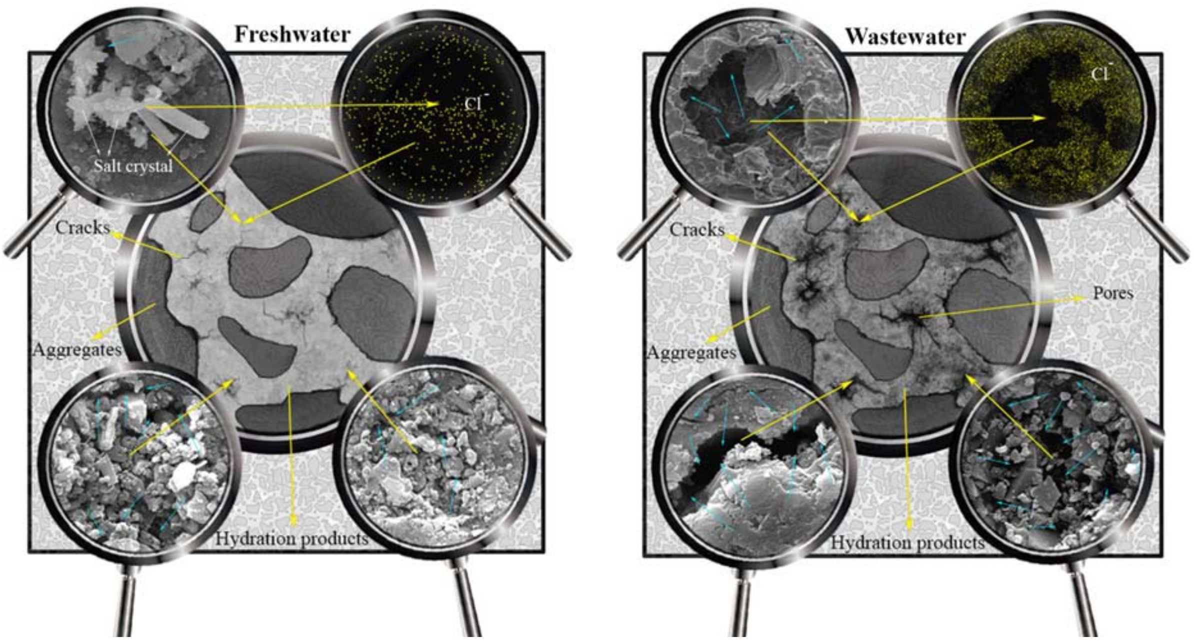

FIGURE 5 SEM images and EDX mapping analysis of fresh water and wastewater concrete samples in water to cement ratio of 0.4 (adapted from References 57,58).

observable in wastewater concrete, which could be claimed as a reason for the higher permeability of this concrete. Abushanab and Alnahhal (2021) used a combination of treated sewage, calcium nitrite, fly ash, and superplasticizer to manufacture concrete samples and it was mentioned that wastewater concrete had markedly higher permeability than that of control samples.[68] Bouaich et al. (2022)[69] and Tanli et al. (2022)[71] also reported similar results. They indicated that using domestic wastewater with or without recycled plastic could reduce the density of concrete.

4.6.1 | Morphology of concrete in using wastewater and after chloride attack

Figure 5 represents the SEM images and EDX mapping analysis of concrete samples manufactured with fresh

TABLE 7 Permeability and durability results of previous literature in using wastewater.

		Results		
	Parameter	**Increase**	**Decrease**	**No significant effect**
Permeability and durability characteristics	Water absorption	Treated sewage,[58] industrial wastewater,[60] sugar factory, service station, and fertilizer factory wastewater,[63] treated industrial wastewater with MSWIBA.[65]	–	Treated wastewater before chlorination.[59]
	Water penetration	Treated sewage.[58]	–	–
	Density		Treated municipal wastewater,[57] sewage,[58] treated wastewater before chlorination,[59] treated wastewater with and without calcium nitrite,[68] domestic wastewater with or without recycled plastic.[71]	Domestic wastewater.[69]
	Mass loss	Textile factory, sugar factory, service station, and fertilizer factory wastewater.[63]	–	–
	RCPT (chloride content and penetration)	Treated municipal wastewater,[57] treated sewage,[58] treated industrial wastewater,[60] secondary or tertiary treated wastewater,[62] textile factory wastewater,[63] sugar factory, service station, and fertilizer factory wastewater,[63] treated industrial wastewater and MSWIBA,[65] combining treated wastewater with recycled aggregate,[67] treated sewage with and without calcium nitrite,[68] wastewater with encapsulated nanoparticles.[70]	Increasing water quality,[62] treated wastewater with 20% fly ash.[68]	–
	Chloride diffusion coefficient	Treated municipal wastewater.[57]	–	–
	Surface electrical resistivity	Treated wastewater before chlorination in combination with superplasticizer.[59]	Treated industrial wastewater and MSWIBA,[65] treated wastewater with 20% fly ash with 3% calcium nitrite.[68]	Treated wastewater before chlorination.[59]
	Carbon penetration	Secondary or tertiary treated wastewater,[62] pretreated wastewater.[70]	–	–

TABLE 7 (Continued)

	Results		
Parameter	Increase	Decrease	No significant effect
Freeze and thaw attack	–	Compressive strength of treated sewage.[58]	Treated wastewater before chlorination.[59]
Freeze and thaw cycles with sulfate attack	In early ages: Compressive strength of treated sewage.[58]	In older ages: Compressive strength of treated sewage.[58]	–

water and wastewater.[57,58] In using fresh water, calcium hydroxide crystals and calcium silicate hydrate gels were formed uniformly and abundantly, which caused a compacted and homogenous structure with small pores and cracks.[57–60,65,68] On the contrary, concrete samples manufactured with wastewater had frail hydration products, spacious cracks, and substantial pores.[57–60,65,68] The higher permeability of the wastewater concrete might be because of the wastewater's impurities, which generate porous structures and avoid completing the formation of hydration products.[57–60,65,68] The first row of Figure 5 shows the FESEM images and EDX mapping analysis after a long-term chloride test (3% NaCl in 90 days) on the concrete samples. As shown in Figure 5, the chloride ion contents (yellow points) of concrete manufactured with fresh water were noticeably lower than those of manufactured samples with wastewater. The main reason for this seems to stem from the higher permeability of wastewater concrete samples, which resulted in absorbing and sedimenting more chloride ions into deeper interior porous zones and cracks of concrete.[57] The summary of durability properties of wastewater concrete is presented in Table 7.

5 | CONCLUSION

Reusing treated wastewater has established itself as a leading idea in civil and environmental engineering to compensate for the lack of available freshwater worldwide. A comprehensive review on using domestic and industrial wastewater instead of fresh water to manufacture concrete has been done in this current study. The following finding and conclusions could be drawn from the review of the most recently published articles in this domain.

1. Replacing wastewater with fresh water in manufacturing concrete revealed advantages in many aspects, but still, lots of steps should be taken to find its real potential and put it into effect. The initial characteristics of wastewater and maintaining its quality during collecting, transferring, and manufacturing might have an overwhelming effect on concrete quality.
2. In general, the impurities, contaminants, and additional components in the treated wastewater are the main reasons for the differences in mechanical, durability, and morphological properties of the wastewater concrete. Physical and chemical tests should be conducted on a new mixing water before using it in concrete manufacturing to ensure that these kinds of water can be considered suitable for manufacturing concrete.
3. It is mostly reported that the heterogeneous interior structure of manufactured concrete with wastewater results in lowering compressive, tensile, and flexural strengths and declining durability by increasing water absorption, water penetration, and chloride, sulfate, and carbon ions penetration. These slight reductions are mainly acceptable and consistent with the related standards.
4. Although there is no limitation for some of the durability properties to ascertain the performance of this concrete in long term, using treated wastewater with lower impurities and considering filler additives might be worthy suggestions to compensate for the porous problem of wastewater concrete.
5. There is a possibility that impure water could be operative if the water quality is slightly below the standards, especially in plain concrete with low water-to-cement ratios, or while it is mixed with appropriate additives. However, a comprehensive study of long-term properties is required.

The following future research is suggested:

1. The use of wastewater in reinforced concrete has never been examined and investigations in this field could bring several important results. Since wastewater has several contaminants and ions, its effect on the

corrosion of rebars as an interior threat must be investigated profoundly.
2. The modeling of durability properties needs to be studied comprehensively to predict the unexpected limitations in the long-term.
3. The effect of an earthquake on wastewater concrete might be so challenging since nobody has ever tried it before and could be attempting to put the idea of having environmentally friendly green concrete into operation level after optimizing it.

ACKNOWLEDGMENTS

This work was partly financed by FCT/MCTES through national funds (PIDDAC) under the R&D Unit Institute for Sustainability and Innovation in Structural Engineering (ISISE), under reference UIDB/04029/2020. This work is financed by national funds through FCT-Foundation for Science and Technology, under grant agreement [2021.06765.BD] attributed to the first author.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

ORCID

Mohammad Sheikh Hassani https://orcid.org/0000-0003-0985-3504
Jose C. Matos https://orcid.org/0000-0002-1536-2149
Y.X. Zhang https://orcid.org/0000-0003-1912-8277
Elisabete Teixeira https://orcid.org/0000-0003-1435-0733

REFERENCES

1. US EPA. Progress cleaning the air and improving People's health. Washington, DC: EPA; 2020 [cited 20 April, 2021]. Available from: https://www.epa.gov/clean-air-act-overview/progress-cleaning-air-and-improving-peoples-health
2. US EPA. Regulatory information by business sector. Washington, DC: EPA; 2020 [cited 20 April, 2021]. Available from: https://www.epa.gov/regulatory-information-sector
3. Orimoloye IR, Belle JA, Olusola AO, Busayo ET, Ololade OO. Spatial assessment of drought disasters, vulnerability, severity and water shortages: a potential drought disaster mitigation strategy. Nat Hazards. 2021;105(3):2735–54.
4. Mishra BK, Kumar P, Saraswat C, Chakraborty S, Gautam A. Water security in a changing environment: concept, challenges and solutions. Water. 2021;13(4):490.
5. van Vliet MTH, Jones ER, Florke M, Franssen WHP, Hanasaki N, Wada Y, et al. Global water scarcity including surface water quality and expansions of clean water technologies. Environ Res Lett. 2021;16(2):024020.
6. Farhadkhani M, Nikaeen M, Yadegarfar G, Hatamzadeh M, Pourmohammadbagher H, Sahbaei Z, et al. Effects of irrigation with secondary treated wastewater on physicochemical and microbial properties of soil and produce safety in a semi-arid area. Water Res. 2018;144:356–64.
7. Fattah KP, Al-Tamimi AK, Hamweyah W, Iqbal F. Evaluation of sustainable concrete produced with desalinated reject brine. Int J Sustain Built Environ. 2017;6(1):183–90.
8. Li H, Cohen A, Li Z, Lv S, He Z, Wang L, et al. Intermittent water supply management, household adaptation, and fresh water quality: a comparative study in two Chinese provinces. Water. 2020;12(5):1–18.
9. Loubser C, Chimbanga BM, Jacobs H. Intermittent water supply: a South African perspective. Water. 2021;47(1):1–9.
10. Coffetti D, Crotti E, Gazzaniga G, Carrara M, Pastore T, Coppola L. Pathways towards sustainable concrete. Cem Concr Res. 2022;154:106718.
11. Miller SA, Horvath A, Monteiro PJM. Impacts of booming concrete production on water resources worldwide. Nat Sustain. 2018;1:69–76.
12. Tang SW, Yao Y, Andrade C, Li ZJ. Recent durability studies on concrete structure. Cem Concr Res. 2015;78:143–54.
13. Prochazka P, Honig V, Maitah M, Pljucarska I, Kleindienst J. Evaluation of water scarcity in selected countries of the Middle East. Water. 2018;10(10):1482.
14. Venkatesan G, Kumar A, Perumal P. Fresh and hardened properties of five non-potable water mixed and cured concrete: a comprehensive review. Construct Build Mater. 2021;309:125089.
15. Varshney H, AhmadKhan R, KhaleelKhan I. Sustainable use of different wastewater in concrete construction: a review. J Build Eng. 2021;41:102411.
16. Erickson JJ, Smith CD, Goodridge A, Nelson KL. Water quality effects of intermittent water supply in Arraij'an, Panama. Water Resour. 2017;114:338–50.
17. Kumpel E, Nelson KL. Intermittent water supply: prevalence, practice, and microbial water quality. Environ Sci Technol. 2016;50(2):542–53.
18. Farmani R, Dalton J, Charalambous B, Lawson E, Bunney S, Cotterill S. Intermittent water supply systems and their resilience to COVID-19: IWA IWS SG survey. J Water Supply Res Technol. 2021;70(4):507–20.
19. Salehi M. Global water shortage and fresh water safety; Today's concern and tomorrow's crisis. Environ Int. 2022;158:106936.
20. WHO & UNICEF. Progress on fresh water, sanitation and hygiene: 2000–2017: special focus on inequalities. New York, NY: UNICEF; 2019 Available from: https://data.unicef.org/resources/progress-drinking-water-sanitation-hygiene-2019/
21. Aghalari Z, Dahms HU, Sillanpaa M, Sosa-Hernandez JE, Parra-Saldívar R. Effectiveness of wastewater treatment systems in removing microbial agents: a systematic review. Glob Health. 2020;16(1):13.
22. Jafarinejad S. A framework for the design of the future energy-efficient, cost-effective, reliable, resilient, and sustainable full-scale wastewater treatment plants. Curr Opin Environ Sci Health. 2020;13:91–100.
23. Mallik A, Arefin MA, Shahadat MMZ. Design and feasibility analysis of a low-cost water treatment plant for rural regions of Bangladesh. AIMS Agric Food. 2018;3(3):181–204.

24. Zhang QH, Yang WN, Ngo HH, Guo WS, Jin PK, Dzakpasu M, et al. Current status of urban wastewater treatment plants in China. Environ Int. 2016;92–93:11–22.
25. Abbasi N, Ahmadi b M, Naseri M. Quality and cost analysis of a wastewater treatment plant using GPS-X and CapdetWorks simulation programs. J Environ Manage. 2021;284:111993.
26. Foladori P, Cutrupi F, Cadonna M, Manara S. Coronaviruses and SARS-CoV-2 in sewerage and their removal: step by step in wastewater treatment plants. Environ Res. 2022;207:112204.
27. Schmitz BW, Innes GK, Prasek SM, Betancourt WQ, Stark ER, Foster AR, et al. Enumerating asymptomatic COVID-19 cases and estimating SARS-CoV-2 fecal shedding rates via wastewater-based epidemiology. Sci Total Environ. 2021;801:149794.
28. Wang X. Life cycle inventory analysis of typical wastewater treatment chains. Energy consumption, chemical use and carbon footprints of wastewater treatment alternatives. Singapore: Springer; 2020. p. 29–55.
29. Sabeen AH, Noor ZZ, Ngadi N, Almuraisy S, Raheem AB. Quantification of environmental impacts of domestic wastewater treatment using life cycle assessment: a review. J Clean Prod. 2018;190:221–33.
30. Xia B, Ding T, Xiao J. Life cycle assessment of concrete structures with reuse and recycling strategies: a novel framework and case study. Waste Manag. 2020;105:268–78.
31. Jeong K, Ji C, Kim H, Hong T, Cho K, Lee J. An integrated assessment of the environmental, human health, and economic impacts based on life cycle assessment: a case study of the concrete and steel sumps. J Clean Prod. 2019;239:118032.
32. BS EN 1008-02, (2002), Mixing water for concrete. Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete.
33. ASTM C94/C94M-22a. Standard specification for ready-mixed concrete. Philadelphia, PA: American society for testing and materials; 2022.
34. ASTM C1602/C1602M-18. Standard specification for mixing water used in the production of hydraulic cement concrete. West Conshohocken, PA: ASTM International; 2018.
35. AS 1379. Specification and supply of concrete standards. Homebush, NSW: Australian Standards; 2007.
36. NZS 3121. Specification for water and aggregate for concrete. Wellington: New Zealand Standards; 2002.
37. SANS 51008. Mixing water for concrete. Groenkloof, Pretoria: South African National Standards; 2006.
38. U.S. Environmental Protection Agency. Federal Register, 40 CFR Parts 122, 123, and 124, Vol. 55(222), pp. 47990–48074. Cincinnati, Ohio: EPA; 1990.
39. Reddy Babu G, Madhusudana Reddy B, Venkata Ramana N. Quality of mixing water in cement concrete—a review. Mater Today Proc. 2018;5:1313–20.
40. Hamdan M, Aldossary A, Ahmad S, Bahraq AA. Effect of total dissolved solids-contaminated water on the properties of concrete. J Build Eng. 2020;32:101496.
41. ACI 211.1-91, (2002), Standard practice for selecting proportions for normal, heavyweight, and mass concrete.
42. ASTM C191-19. Standard test methods for time of setting of hydraulic cement by Vicat needle. West Conshohocken, PA: ASTM International; 2019.
43. IS 456-00. Plain and reinforced concrete-code of practice. New Delhi: Bureau of Indian Standards; 2000.
44. BS 3148-80. Method for test for water for making concrete. London: British Standard Institute; 1980.
45. ASTM C1202-19. Standard test method for electrical indication of concrete's ability to resist chloride ion penetration. West Conshohocken, PA: ASTM International; 2019.
46. AASHTO TP 95. Standard test method for surface resistivity of concrete's ability to resist chloride ion penetration. Washington, DC: American Association of State Highway and Transportation Officials; 2014. p. 10.
47. Designation: FM 5-578. Method of test for concrete resistivity as an electrical indicator of its permeability. Tallahassee, FL: Florida Department of Transportation Florida; 2004.
48. Polder RB. Test methods for onsite measurement of resistivity of concrete—a RILEM TC-154 technical recommendation. Construct Build Mater. 2001;15(2–3):125–31.
49. Elkey W, Sellevold EJ. "Electrical resistivity of concrete", supplement 80. Oslo, Norway: Norwegian Road Research Laboratory; 1995.
50. Song HW, Saraswathy V. Corrosion monitoring of reinforced concrete structures-a review. Int J Electrochem Sci. 2007;2:1–28.
51. ACI 222R-01. Protection of metals in concrete against corrosion. Farmington Hills, MI: ACI World Headquarters; 2010.
52. Operating Instructions Concrete Durability Testing. Operating instructions Resipod family manual. Schwerzenbach: Proceq SA; 2017.
53. BHRC NO. S-428, (2005), National code of practice for concrete durability in the Persian Gulf and Oman Sea, "In Farsi".
54. BHRC NO. R-434, (2006), Assessing concrete durability with different cements and Pozzolans in the Persian Gulf and Environment, "In Farsi".
55. BS 1881-122:2011+A1, (2020), Testing concrete method for determination of water absorption.
56. BS EN 12390-8, (2019), Testing hardened concrete depth of penetration of water under pressure.
57. Sheikh Hassani M, Asadollahfardi G, Saghravani SF, Jafari S, Peighambarzadeh FS. The difference in chloride ion diffusion coefficient made with fresh water and wastewater. Construct Build Mater. 2020;321:117182.
58. Sheikh Hassani M, Asadollahfardi G, Saghravani SF. Durability and morphological assessment of concrete manufactured with sewage. Construct Build Mater. 2020;264:120202.
59. Asadollahfardi G, Delnavaz M, Rashnoiee V, Ghonabadi N. Use of treated domestic sewage before chlorination to produce and cure concrete. Construct Build Mater. 2016;105:253–61.
60. Asadollahfardi G, Mahdavi AR. The feasibility of using treated industrial sewage to produce concrete. Struct Concr. 2018; 20(1):123–32.
61. Babu GR, Reddy BM, Ramana NV. Feasibility of sewage as mixing water in cement. Mater Today Proc. 2018;5(1):1607–14.
62. Khushboo M, Salmabanu L. Effect of wastewater on properties of concrete. J Build Eng. 2019;21:106–12.
63. Raza A, Rafique U, Haq FU. Mechanical and durability behavior of recycled aggregate concrete made with different kinds of wastewater. J Build Eng. 2021;34:101950.
64. Kaboosi K, Emami K. Interaction of treated industrial wastewater and zeolite on compressive strength of plain concrete in different cement contents and curing ages. Case Stud Construct Mater. 2019;11:e00308.
65. Taherlou A, Asadollahfardi G, Salehi AM, Katebi A. Sustainable use of municipal solid waste incinerator bottom ash and

the treated industrial wastewater in self-compacting concrete. Construct Build Mater. 2021;297:123814.
66. Arooj MF, Haseeb F, Butt AI, Irfan-Ul-Hassan M, Batool H, Kibria S, et al. A sustainable approach to reuse of treated domestic wastewater in construction incorporating admixtures. J Build Eng. 2021;33:101616.
67. Ahmed S, Alhoubi Y, Elmesalami N, Yehia S, Abed F. Effect of recycled aggregates and treated wastewater on concrete subjected to different exposure conditions. Am Univ Construct Build Mater. 2021;266:120930.
68. Abushanab A, Alnahhal W. Combined effects of treated domestic wastewater, fly ash, and calcium nitrite toward concrete sustainability. J Build Eng. 2021;44:103240.
69. Bouaich FZ, Maherzi W, El-hajjaji F, Abriak N, Benzerzour M, Taleb M, et al. Reuse of treated wastewater and non-potable groundwater in the manufacture of concrete: major challenge of environmental preservation. Environ Sci Pollut Res. 2022;29:146–57.
70. Vanitha S, Rajan NK. Influence of pre-treated wastewater and encapsulated nanoparticles on properties of green concrete. Appl Nanosci. 2022;1232:13003.
71. Tanlı T, Damdelen O, Pehlivan S. Influences of recycled plastic and treated wastewater containing with 50% GGBS content in sustainable concrete mixes. J Mater Res Technol. 2022;16:110–28.
72. U. S. Environmental Protection Agency Science and Ecosystem Support Division. Procedures for collecting wastewater samples. Athens, GA: U. S. Environmental Protection Agency Science and Ecosystem Support Division; 2017.
73. AASHTO T 26-79. Standard method of test for quality of water to be used in concrete. Detriot: American Association of State and Highway Transportation Officials; 2008.
74. American Concrete Institute. Use of concrete in buildings: design, specifications and related topics. Detriot: American Concrete Institute; 1998.

AUTHOR BIOGRAPHIES

Mohammad Sheikh Hassani, Department of Civil Engineering, University of Minho, ISISE, Guimarães, Portugal. Email: id10079@alunos.uminho.pt.

Jose C. Matos, Department of Civil Engineering, University of Minho, ISISE, Guimarães, Portugal. Email: jmatos@civil.uminho.pt.

Y.X. Zhang, School of Engineering, Design and Built Environment, Western Sydney University, Kingswood, New South Wales 2751, Australia. Email: sarah.zhang@westernsydney.edu.au.

Elisabete Teixeira, Department of Civil Engineering, University of Minho, ISISE, Guimarães, Portugal. Email: elisabeterodriguest@gmail.com.

How to cite this article: Sheikh Hassani M, Matos JC, Zhang YX, Teixeira E. Concrete production with domestic and industrial wastewaters—A literature review. Structural Concrete. 2023. https://doi.org/10.1002/suco.202200637