

TESTING OF TREATED EFFLUENT FOR USE IN MIXING AND CURING OF CONCRETE

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ABSTRACT

Plain cement and silica fume cement paste and mortar specimens prepared using Type I cement, 8% silica fume, and potable and treated waters were tested for setting time and compressive strength. Pore solutions extracted from the mortar specimens were analyzed for alkalinity and chloride content. The results showed that the treated water tested in this study qualifies to be used in making concrete.

KEYWORDS

Treated effluent; concrete; setting time; compressive strength; pore solution; silica fume

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INTRODUCTION

Normally, desalinated water alone or blended with brackish groundwater is used in concrete making in the Arabian Gulf Countries [1,2]. Due to the high cost of desalinated water, the use of treated effluent has been considered for this purpose. While the treated effluent is widely utilized for irrigation purposes, data are limited for its use in the mixing and curing of concrete. According to El-Nawawy and Ahmad [1], effluent water is being used to prepare cement slurry at a cement factory in Dubai [3]. The results of an investigation regarding the use of reclaimed wastewater for concrete mixing suggested that such water can be used for this purpose without any harmful effects [4]. In view of these encouraging reports, it was decided to investigate the possibility of using the treated effluent in Saudi Arabia from its wastewater plants in Jubail for mixing and curing of concrete.

The objective of this research was to study the feasibility of using treated effluent for mixing and curing of concrete. Paste and mortar specimens prepared and cured using potable and treated water were tested for setting time, compressive strength, and pore solution chemistry.

EXPERIMENTAL PROGRAM

The experimental program consisted of the chemical analysis of potable water and treated effluent, and determination of the setting time, compressive strength, and the pore solution composition of the cement paste and mortar specimens prepared by mixing ASTM (American Society for Testing and Materials) C 150 Type I cement, 8% silica fume (SF), and potable (PW) or treated water (TW). The specimens were cured either in PW or TW until testing. The setting time of the mortar specimens was determined according to ASTM C 191 [5]. The compressive strength was determined after 7, 14, 28, and 90 days of casting in accordance with ASTM C 109 [6].

Materials

Potable and Treated Waters. The potable water and treated effluent were analyzed for anions, cations, dissolved metals, physical and bacteriological content. Total alkalinity was determined by titration; and chloride, nitrate, phosphate, and sulfate were quantified using the ion chromatography method. Total residual chlorine and sulfide were determined using the ion selective electrode method. Cations were determined by Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES). A Dohrmann Xertex DC-80 Analyzer was used for determining the total organic carbon (TOC) in the samples. The samples were acidified with acid and purged with oxygen for at least six minutes prior to the analysis. This procedure was carried out in order to remove the inorganic carbon from the solution. A Dohrmann Xertex DN-100 trace nitrogen analyzer was used for determining the nitrogen in the samples. This technique involves the oxidative pyrolysis of the bound nitrogen and the subsequent measurement of the nitric oxide (NO) produced.

Methods

Setting Time. The setting time of the cement pastes prepared from ASTM Type-1 cement and Type-1 cement blended with 8% SF was determined according to ASTM C 191 [5]. The pastes were prepared using both potable and treated waters for mixing. The tests were conducted by using the Vicat Apparatus [5].

Compressive Strength. Cement mortar specimens, 50 mm cubes, were prepared in accordance with ASTM C 109 [6] using Type-I cement and Type-I cement blended with 8% SF. For mixing, PW or TW was used. Following demolding after 24 hours of casting, the specimens were cured in potable or treated water in the laboratory under immersed conditions. The compressive strength development was measured after 7, 14, 28, and 90 days of casting. The specimens were cast and cured under the following conditions:

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|------|--|---------|
| i. | plain cement specimens cast and cured using PW, | P/PW/PW |
| ii. | SF cement specimens cast and cured using PW, | S/PW/PW |
| iii. | plain cement specimens cast and cured using TW, | P/TW/TW |
| iv. | SF cement specimens cast and cured using TW, | S/TW/TW |
| v. | plain cement specimens cast with PW and cured in TW, and | P/PW/TW |
| vi. | SF cement specimens cast with PW and cured in TW. | S/PW/TW |

The specimens were tested in triplicate at the above intervals using the Instron Mechanical Testing Machine at a loading rate of 2.2 KN/sec.

Pore Solution Composition. Cement mortar specimens, 49 mm in diameter and 75 mm in height, were cast using potable water and treated effluent in plastic vials. The specimens were kept in a sealed condition in the laboratory for 28 days to cure. Then pore solution was extracted from the specimens using a high pressure pore press and analyzed for OH⁻ and chloride concentrations. Hydroxyle (OH⁻) concentration was determined by titrating the pore solution against 0.01 M nitric acid. Chloride ion (Cl⁻) concentration was determined using the spectrophotometric method [13]. A Spectronic Model UV 21 spectrophotometer was used at a wave length of 460 nm against deionized water.

RESULTS AND DISCUSSIONS

Chemical Analysis of the Waters

The results of chemical analyses of the treated effluent and potable water are given in Table 1. The table also provides a list of tolerable limits for various constituents in the water qualified to be used in concrete making.

The physical parameters, and the chemical and bacteriological analyses show that the constituents of both the potable water and treated effluent are within the tolerable limits for use in concrete making.

In general, almost all the parameters tested are lower in the potable water than in the treated effluent. For instance, values of total dissolved solids, total soluble solids, total alkalinity, ammoniacal nitrogen, chemical oxygen demand, chloride, sulfate, nitrate, and phosphate are significantly lower in the potable water than those in the treated effluent. Only the iron content in the potable water is higher than that in the treated effluent. Chloride and sulfate are the two most important anions which affect the durability performance of concrete. The chloride content is about 270 and 151 mg/L in the treated and potable waters, respectively. Likewise, the sulfate content in the treated and potable waters is 106 and 42.2 mg/L, respectively. The treated water contains about 79% more chloride and 151% more sulfate than the potable water. The other significant anions are nitrate and phosphate. According to

the RI analysis results, nitrate is about 57 times more concentrated in the treated water than in the potable water. Whereas, phosphate is about 40 times more concentrated in the treated water than in the potable water. Iron content, on the other hand, is about 3.6 times more concentrated in the potable water than in the treated effluent.

Table 1. Chemical analysis of potable and treated waters.

Parameter *	TW	TW	PW	Tolerable Limits	Reference
	RCJY O&M	RI Results	RI Results		
1. Total dissolved solids	950	580 - 617	3345	2000	CIRIA [2]
2. Total suspended solids	1.6	13.9 - 1.2	0.3	2000	M&Y [10]
3. Turbidity - (NTU)	1.3	1.7 - 3.0	1.7		
4. Conductivity (mMhos)	-	NT	NT		
5. pH	6.3	9.43 - 7.00	8.20	3.0	White [12]
6. Total alkalinity	42.0	11.4 - 20.3	54.6	1000	Neville [7]
7. Ammoniacal Nitrogen	1.4	7.4 - 7.6	0.4		
8. C.O.D.	41.0	26 - 34	<20		
9. B.O.D.	4.2	NT	NT		
10. Total organic carbon	18.0	5.2	1.2		
11. Chloride	295	271 - 269	151	360 - 500	Neville [7]
12. Sulfate	60	106 - 107	42.2	600	
13. Nitrate	10	79.9 - 82.1	1.40 - 0	-	
14. Nitrite	0.06	<0.2	<0.1		
15. Sulfide	0.0	<0.1	<0.1		
16. Phosphate as P	8.5	5.6 - 10.3	<0.2		
17. Silica	-	2.71 - 2.39	2.00		
18. Oil & Grease	<1	NT	NT		
19. Free residual chlorine	0.0				
20. Total residual chlorine	6.5	<0.1	<0.1		
21. Iron	0.5	<0.05	0.180		
22. Manganese	<0.1	<0.05	<0.05	500	M & Y [10]
23. Chromium	ND	<0.05	<0.05		
24. Copper	<0.1	NT	NT	500	M&Y [10]
25. Lead	ND	<0.05	<0.05	500	M&Y [10]
26. Nickel	ND	<0.05	<0.05	-	
27. Cadmium	ND	<0.05	<0.05		
28. Zinc	1.0	<0.05	<0.05	500	M&Y [10]
29. Total Coliforms (MPN/100 ml)	<3	NT	NT		
30. Carbonate	NT	NT	NT	1000	M&Y [10]
31. Bicarbonate	NT	NT	NT	400	M&Y [10]
32. Total Hardness (CaCO ₃)	NT	NT	NT	-	
33. Sodium	NT	NT	NT	Combined Total	BS [11]
34. Potassium	NT	NT	NT		BS [11]
35. Calcium	NT	<0.94	<0.947		BS [11]
36. Magnesium	NT	NT	NT		<2000

* All units are in mg/L unless otherwise stated.

Setting Time

The average results of the setting time tests are given in Table 2.

Table 2. Penetration of Vicat Needle.

Elapsed time (min)	Average penetration (mm)			
	P/PW	P/TW	S/PW	S/TW
30	43	41	42	41
45	41.3	41.5	41.5	41
60	41.5	41.3	41.5	41
75	41.3	41.3	41.3	41
90	41	41.3	40.8	40.8
105	41	41	40.3	40.3
120	40.5	40.8	39.8	39.8
135	39.8	39.0	31.5	32
150	37.9	27.3	1.5	4.8
165	29	9.5	0.8	1
180	7.0	1.5	0	0.5
195	1.0	0.5	-	0
210	0.3	0	-	-
225	0	-	-	-

P/PW Plain cement (Type-I) mixed with potable water (PW).

P/TW Plain cement mixed with treated water (TW).

S/PW Type-I cement containing 8% silica fume (SF) mixed with (PW).

S/TW Type-I cement containing 8% silica fume SF mixed with (TW).

The table shows the average penetration results obtained from two setting time tests simultaneously performed according to ASTM C 191 [5] using the standard Vicat Needle equipment. The average initial and final setting times for plain and SF cement mortars mixed with PW and TW are summarized in Table 3.

Table 3. Initial and final setting times of cement pastes.

	Type I Cement				Type I + 8% SF			
	PW	TW	Difference	Average %	PW	TW	Difference	Average %
Initial Setting Time: (min.)	168	153	-15	-8.9	138	139	1	0.7
Final Setting Time: (min.)	218	203	-15	-6.9	177	195	18	10.2

The results show that treated water reduces the initial and final setting times of plain cement mortar by about 15 minutes (9 %) and 15 minutes (7 %), respectively. Whereas in the case of SF cement mortar, the initial and final setting times are increased by 1 minute (0.7%) and 18 minutes (10.2%), respectively. The results, therefore, are more in favor the using treated water in SF cement concrete.

Earlier researchers [1] reported that the initial setting time varied in the range of 115 to 195 minutes (up to - 41%) when the mix water contained 80% to 0% treated effluent in plain cement mortars. According to the present results (Table 3), the initial and final setting times varied in the range of 168 to 153 minutes (15 min acceleration) and 218 to 203 minutes (15 min acceleration), respectively, in the plain cement with the addition of TW. In the 8 % SF cement, on the other hand, the initial and final setting times varied in the range of 138 to 139 minutes (1.0 min delay) and 177 to 195 minutes (18 min delay), respectively. British Standard (BS) 3148 [11] specifies that the change in setting time should be less than 30 minutes for the water to be suitable for concrete making. According to BS 3148, therefore, the treated effluent used in this study qualifies to be used as mixing water in concrete making from the point of view of the setting time.

The different effects of different waters on the setting time could be due to the rate of hydration reaction of water with cement particles during mixing. This will, in turn, depend, most probably, on the ionic and chemical constitution and physical properties of the waters. Apparently, the TW reacts faster than the potable water with plain cement used in the present study, and the setting of the paste specimens occurs in a shorter time. In the case of SF cement, however, there is not a significant difference in the initial setting time with PW or TW. Final setting time, on the other hand, takes longer with TW than with PW, most probably due to slower progress of the hydration reactions when TW is used in SF containing paste.

Compressive Strength

Results of the compressive strength (CS) tests at 7, 14, 28, and 90 days of curing age are shown in Fig. 1. Generally, SF increases the CS of concrete due to the pore structure refinement in concrete and pozzolanic activity of SF [14, 15]. The CS of mortar specimens, in this study, increased by SF addition from 8 to 17 MPa to about 23 to 27 MPa in 7-day cured specimens, depending on the mixing and curing water used. The use of TW as mixing and/or curing water in SF containing mortar specimens, on the other hand, did not have additional significant effect on the CS of these specimens.

Effect of TW on the Compressive Strength of Plain Cement Mortar. The effect of TW, whether it is used for mixing or curing, is to increase the compressive strength of the mortar specimens. The effect is most significant when TW is used for both mixing and curing of plain cement mortars. The effect of TW on the compressive strength becomes apparent from 7 days onwards. The 7-day cured mortar specimens had average compressive strengths of 8, 13, and 17 MPa for P/PW/PW, P/PW/TW, and P/TW/TW specimens, respectively. The highest strength was obtained from the specimens which were mixed and cured using treated water. The strength of these specimens (P/TW/TW) was 112% higher than that of the plain cement mortar specimens prepared with potable water (P/PW/PW). The strength of all of the mortar

specimens increased with curing. At the end of 90 days of curing, P/PW/PW specimens had the lowest strength of 32 MPa, whereas the strength of the specimens.

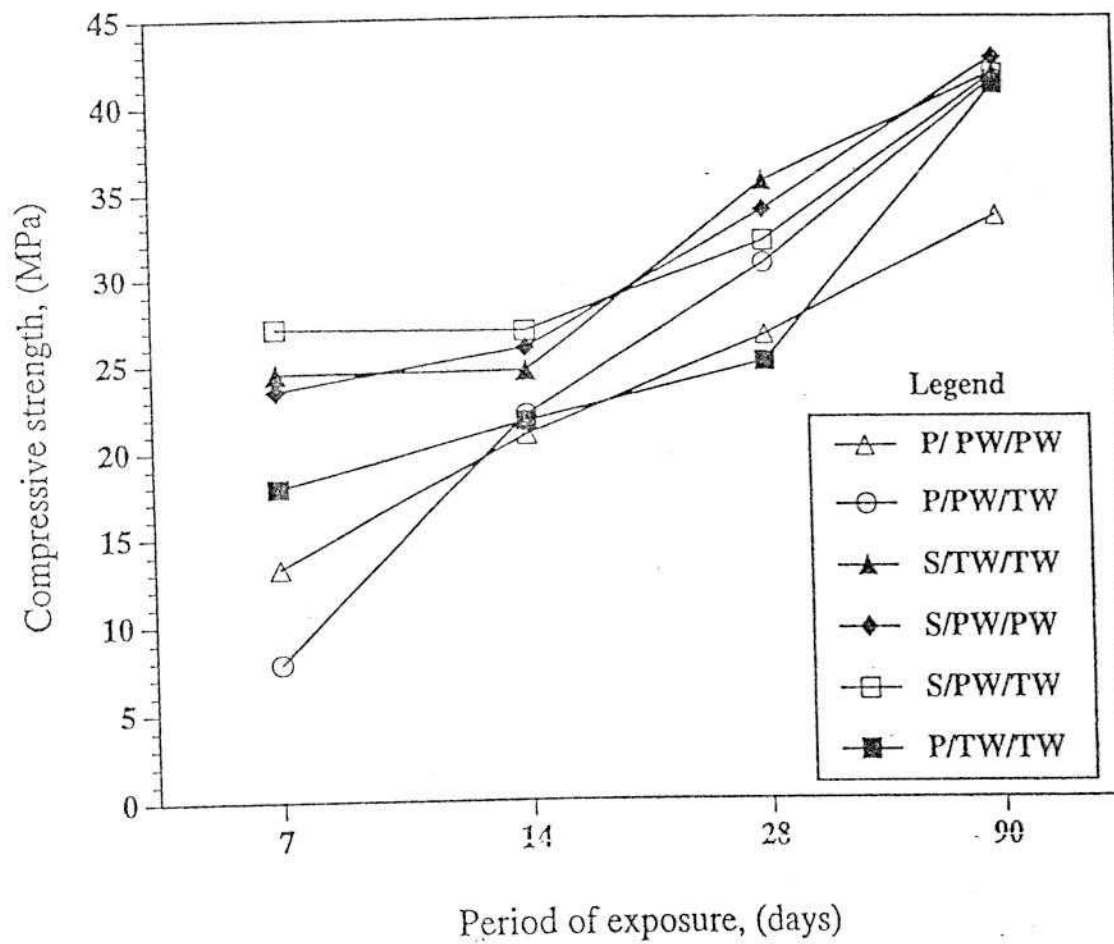


Fig. 1. Variation of compressive strength with curing period in the mortar specimens prepared with potable and treated waters.

prepared and/or cured using TW converged to a higher value of 41 MPa with a 28% increase in the strength.

Effect of TW on the Compressive Strength of SF Cement Mortar. The effect of TW on the strength of SF containing mortars is less significant compared to the effect of TW on the plain cement mortar specimens,. Although the use of TW for mixing and/or curing resulted in slightly higher compressive strength values in the 7-day cured specimens, the compressive strength of all of the mortar specimens became almost similar after 90 days of curing. At seven days of curing, the compressive strength of the specimens was 23 MPa for SF containing mortar specimens mixed and cured with PW (S/PW/PW), 24 MPa for specimens mixed and cured with TW (S/TW/TW), and 27 MPa for specimens mixed with PW and cured in TW (S/PW/TW). Treated water increased the strength by about 17% at maximum. The compressive strength of all the mortar specimens, plain or with SF, which were mixed and/or cured with TW, converged to similar values ranging from 40 to 43 MPa after 90 days of curing. At 90 days, the strength increase in the SF containing specimens was 7.5% compared to the 7-day cured specimens. On the other hand, the compressive strength of P/PW/PW specimens after 90 days of curing was 32 MPa, and that is about 34% less than that of SF containing mortar specimens. Generally speaking, TW increased the compressive strength of plain cement mortar specimens by about 112% and 28% after 7-day and 90-day curing respectively. In the SF containing mortar specimens, however, the compressive strength increased with the use of TW by 17% at the 7-day and 7.5% at the 90-day curing periods. There are, however, controversial reports published about the effect of TW on the compressive strength of mortars and concrete. Tay and Yip [4] reported in 1987 on the favorable effects of TW on the compressive strength of concrete. Whereas, Omar and Ahmad [1] who carried out studies with mortar and concrete specimens, reported that TW reduced the strength when used in mixing the specimens. Starting from the 7-day curing period, the strength of both mortar and concrete specimens was affected detrimentally by the addition of TW in the mixing water. It must be added, however, that the TW used by Omar and Ahmad [1] contained high chloride, sulfate, and TDS beyond the tolerable limits for use in concrete making. On the other hand, Tay and Yip [4] reported that the CS was favorably affected by the use of TW in the concrete specimens. In a 3-year testing program, the constituents of the TW used by the authors [4] were well within the tolerable limits recommended by various standards [1,2,4,7-12]. Thus, it is reasonable to attribute the differences in the test results of the present study and those reported by Omar and Ahmad [1] to differences in the water quality.

The differences in the setting times of mortar specimens with PW and TW are also reflected in the compressive strength results. With plain cement mortar specimens, the strength differential with TW and PW specimens starts right from the 7-day curing and continues throughout the testing, indicating faster hydration reactions with the TW. The increase in the compressive strength of plain cement mortars when TW is used for mixing and/or curing can be attributed to the development of a finer pore structure in these mortars due to a faster rate of hydration reactions during setting and curing of these mortars. In the case of the SF cement mortar, however, the strength differential between the specimens prepared using PW and TW is not large at the 7-day curing, and the difference closes after 90 days of curing.

Pore Solution Composition

The analysis results of pore solution for alkalinity and chloride are given in Table 4. Figs. 2 and 3, show the average values of pH and chloride content in the pore solutions extracted from the mortar specimens prepared and cured with potable and treated waters.

Normally, SF addition reduces pH of concrete pore solution due to reduction in cement quantity, decrease in $\text{Ca}(\text{OH})_2$ caused by pozzolanic action of SF, and reduction of alkali and hydroxide ions in pore solution [16]. The effect of TW on pH of both kinds of the mortars, plain and SF containing, was insignificant as shown by the present results.

Table 4. Average values of alkalinity and chloride concentration of pore solutions.

Specimen	OH mM/L	pH	Chloride concentration	
			mM/L	ppm
P/PW	342.8	13.53	0.434	15.50
S/PW	45.97	12.66	0.278	9.84
P/TW	376.15	13.57	1.119	39.71
S/TW	42.76	12.63	0.458	16.25

Alkalinity of Pore Solution. The pH of the pore solutions extracted from plain mortar specimens prepared with PW ranged between 13.48 and 13.56, with an average value of 13.53, whereas the pH values for plain mortars prepared with TW were 13.57 and 13.58 with an average value of 13.57. The results (Fig. 2) show that there is no significant effect of TW on the alkalinity of plain cement mortars. Similar results were obtained for the SF containing mortar specimens. The average pH of pore solutions extracted from the SF containing mortars prepared with PW was 12.66, whereas the pH for SF containing mortars prepared with TW was 12.62. The effect of TW on the pH of the pore solution of the SF cement mortars was also insignificant.

Chloride Content of Pore Solution. As shown in Fig. 3, the use of treated water had a significant effect on the chloride content in the pore solutions of the mortar specimens. However, the effect is more pronounced in the plain cement mortar specimens than in the SF containing mortars.

The chloride content was 15.41 and 39.71 ppm in the plain cement mortar specimens prepared with PW and TW, respectively. The chloride content in the plain cement mortars prepared with TW was 158% high compared to those prepared with PW. The chloride content in the SF containing mortars was 9.84 and 16.25 ppm in the specimens prepared with the PW and TW, respectively. The increase in chloride content due to the use of TW in the SF mortars was 65%. The results showed that although the effect of TW on the pH of both plain and SF cement mortars was negligible, the effect on the chloride content of both kinds of mortars was significant.

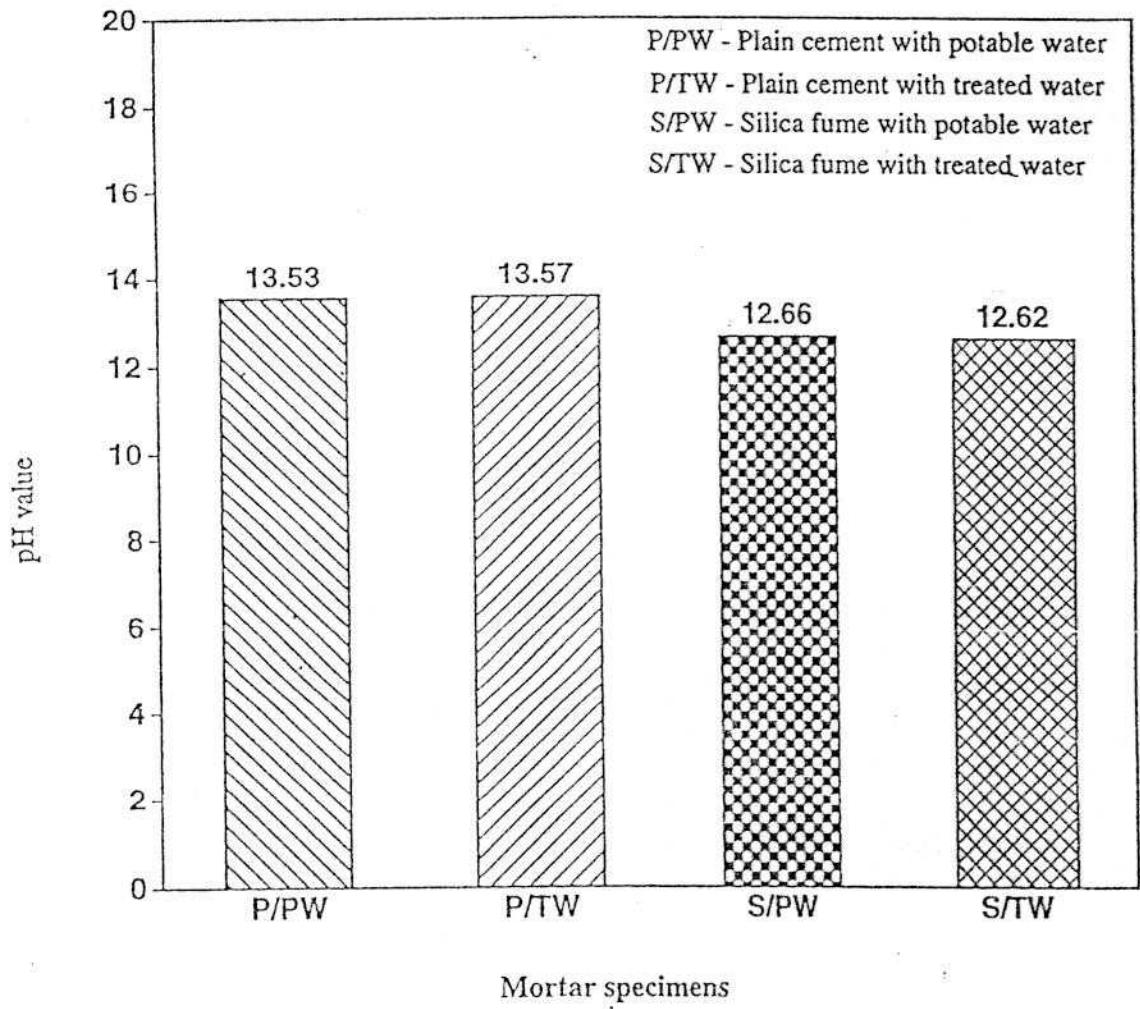


Fig. 2. pH of pore solution of mortar specimens.

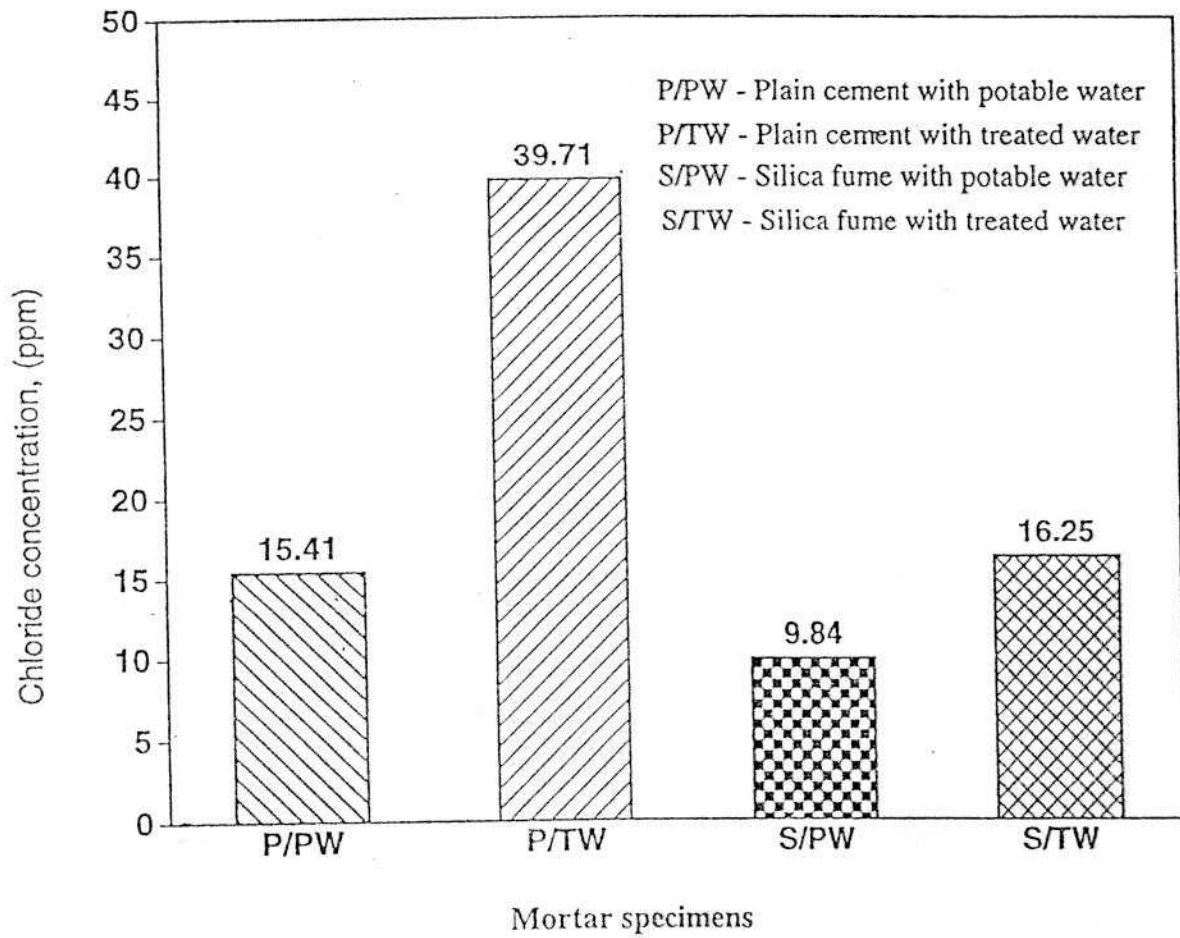


Fig. 3. Chloride concentration in pore solution of mortar specimens.

CONCLUSIONS

The following conclusions are drawn from results of this study:

1. The main difference between the potable and treated waters used in the study is in the chloride, sulfate, nitrate, phosphate, and iron concentrations, though they are all within the tolerable limits given in the standards. The treated water contained about 79% more chloride and 151% more sulfate than the potable water. Nitrate and phosphate ions were about 57 and 40 times more concentrated, respectively, in the treated water than in the potable water. The iron content, on the other hand, was about 3.6 times more concentrated in the potable water than in the treated effluent.
2. Setting time decreased slightly (9 and 8% in the initial and final setting times respectively) in the plain cement pastes prepared with TW. Whereas, in the SF containing pastes prepared with TW, the setting time increased slightly (0.7 and 10% in the initial and final setting times, respectively) compared to the control specimens.
3. The compressive strength of plain mortar specimens incorporating TW attained a higher value (41 MPa) than the control specimens (32 MPa) after 90 days of curing. The strength increase after 90 days was about 28%. The specimens prepared with TW as mixing and curing water demonstrated a higher strength (18 MPa) compared to the control (13 MPa) and the specimens which used TW for curing only (8 MPa) right from the 7 days of curing.
4. The compressive strength of SF containing mortars incorporating TW were slightly higher, at 7 days of curing, than the SF containing mortars prepared with PW. They demonstrated a similar strength trend throughout the curing period, and had almost the same strength (41 to 43 MPa) after 90 days of curing. However, all SF containing mortar specimens had higher strength than the plain control mortars right from the 7-day curing period. The SF incorporating mortars had about 76 to 115% higher strength than the plain control mortars at the 7-day curing. However, the differences became less with curing. After 90 days of curing, the SF mortar specimens had 28 to 34% higher compressive strength than the plain cement control mortars.
5. The pH of the pore solution, however, was not affected by the use of TW in preparing the mortar specimens. In the case of plain cement mortars, the average pH values were 13.2 and 13.57, respectively, in the control specimen and in the specimen prepared with TW. In the SF cement mortars, on the other hand, the pH was 12.66 in the SF control specimen and 12.62 in the SF specimen prepared with TW.
6. The use of TW increased the chloride concentration in the pore solution in both plain and SF cement mortars. The chloride concentration in the plain mortars increased by 15% due to TW compared to the plain mortars prepared with PW. Whereas in the SF cement mortars, the increase in chloride concentration in the pore solution due to TW was 65%. The actual chloride concentration in the pore solutions, however, was very low after 90 days of curing. It varied from 16 to 40 ppm in the plain cement mortars and from 10 to 17 ppm in the SF cement mortars depending on the use of PW and TW respectively.

results indicated that the SF containing cement combined with more chloride than plain cement in both of the cases utilizing PW as well as TW.

7. The results showed that the TW tested in this study qualifies to be used in concrete making according to BS 3148.

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