Kuwait J. Sci. Eng. **30**(1) 2003

Use of treated wastewater for concrete mixing in Kuwait

IBRAHIM AL-GHUSAIN AND MOHAMMAD J. TERRO

Civil Engineering Department, Kuwait University, P.O.Box 5969 Safat, 13060
Kuwait Corresponding Author, Fax: +965-4841603
E-mail: ghusain@civil.kuniv.edu.kw

ABSTRACT

The suitability of using treated wastewater for mixing concrete was experimentally evaluated. Concrete cube specimens were cast using tap water (TW), preliminary treated wastewater (PTWW), secondary treated wastewater (STWW), and tertiary treated wastewater (TTWW) obtained from the local Reqqa wastewater treatment plant.

The type of water used for mixing did not affect concrete slump and density. However, setting times were found to increase with deteriorating water quality. PTWW and STWW were found to have the most effect on retarding setting time. Concrete made with PTWW and STWW showed lower strengths (i.e., slower strength development) for ages up to 1 yr. At early concrete ages of 3 and 7 days, the strength of concrete made with TTWW was higher than that of concrete made with TW. The possibility of steel corrosion increased with the use of STWW and PTWW, especially when a thinner cover to the reinforcing steel was used. In summary, tertiary treated wastewater, of the type produced from wastewater treatment plants in Kuwait, is found to be suitable for mixing concrete with no adverse effects.

Keywords: Concrete; Kuwait; Wastewater re-use; Wastewater treatment.

INTRODUCTION

In an age of increasing human population and dwindling resources, coupled with the need to curb expenditure in various sectors of the government's budget, attention has been brought to the re-use of resources wherever possible. Perhaps one of the most valuable resources in Kuwait and the Middle East in general, is water. Therefore, efforts towards wastewater re-use have lately gained worldwide consideration and attention in both the agricultural and industrial fields (Metcalf & Eddy 1991).

In arid regions, such as the State of Kuwait, the availability and quality of water poses a challenge to authorities. Despite the available desalination capacity and funds to establish the related infrastructure, the cost of desalination remains high. Certainly, the funds spent by the government on treating the wastewater to tertiary standards produces water of such a decent quality that investigating its use in various agricultural, industrial and other uses becomes essential.

According to the latest figures from the Ministry of Electricity and Water (MEW) in Kuwait, the government spends about KD 200 million annually to produce 240 million imperial gallons per day (1.1 million m^3/d) of subsidized potable water for Kuwait's population. Additionally, about KD 30 million is spent annually to treat the wastewater generated.

In recent years, local attention has been focused on the potential for various aspects of wastewater reuse. Although previous research has been performed on the use of raw or treated wastewater for making concrete (Tay & Yip 1987, Tay 1989, Cebeci & Saatci 1989) no such investigation has been performed in Kuwait.

This paper presents a study of the mechanical properties of concrete mixed using tap water (TW), preliminary treated wastewater (PTWW), secondary treated wastewater (STWW), and tertiary treated wastewater (TTWW). In particular, the effect of water type on the following properties is being studied: setting time; compressive strength at 20, 150, 250, 400, 600, and 700°C; compressive strength at ages up to 18 months; and the potential for corrosion of reinforcing steel bars covered with either 1.0 or 2.5cm of concrete.

Wastewater treatment in Kuwait

The wastewater collection and treatment system in Kuwait has been well established since the Seventies. The wastewater collection system which collects the municipal wastewater from all parts of Kuwait City and its suburbs consists of 4700 km of gravity sewers (hydraulically designed such that the sewage is collected and flows freely under gravity) and 1600 km of pressure mains (Al-Essa 2000). The wastewater is pumped through this intricate network by 17 major pumping stations and 52 secondary pumping stations scattered throughout the city and its suburbs. The collected wastewater is then transferred to three wastewater treatment plants surrounding Kuwait City.

The three plants are:

Ardhiya WWTP: This is the largest of all three plants. It is designed to receive 190,000m^3/d of municipal sewage for treatment, but is nowadays receiving about 200,000 - 220,000 m^3/d.

Jahra WWTP: The Jahra plant has a design capacity of 70,000 m^3/d. It serves the western parts of Kuwait city and the Jahra area.

Reqqa WWTP: The Reqqa plant serves the southern parts of Kuwait and had an original treatment capacity of 85,000 m^3/d. The plant has recently undergone extensive renovation, which increased its capacity to about 180,000 m^3/d.

Additionally, construction of a new 100,000 m^3/d plant in the Um Al-Hayman area is underway to accommodate the projected increase in population in the new suburbs to the south of the city. The future sewage master plan of Kuwait also includes the construction of a large wastewater treatment plant in the Sulaibiya area (Al-Essa 2000). The proposed plant will have a capacity of 350,000 m^3/d. The government of the State of Kuwait has awarded a Build Operate and Transfer (BOT) contract to an international consortium of Kuwaiti and foreign contractors to build the new plant. The plant will combine tertiary treatment, ultrafiltration and reverse osmosis to produce very high quality effluent suitable for domestic re-use.

Use of treated wastewater in concrete mixing

The "conventional wisdom" in the concrete technology literature has been that the water used for mixing and curing concrete would be satisfactory if it is potable and fit for human consumption (Neville 1981, Mindess & Young 1981, Mehta 1986, Raina 1988, Waddell & Dobrowski 1993). The reason for this is that municipal drinking water seldom contains more than 1000 mg/l of dissolved solids. Colored waters containing organic material (tannic and humid acids) may retard the hydration of cement. Many organic compounds that are also available in untreated industrial wastes may affect the hydration of cement or entrain excessive amounts of air (Mindess & Young 1981).

Seawater, which contains about 35,000 mg/l dissolved salts or more, has not been found to be harmful to the strength of plain concrete. However, with reinforced and pre-stressed concrete, the risk of corrosion is increased; therefore, the use of seawater as mixing water should be avoided under these circumstances. Although research performed on the use of raw and treated domestic wastewater in concrete mixing and curing is sparse, some information is available (Tay & Yip 1987, Tay 1989, Cebeci & Saatci 1989) and researchers have concluded some important information on this possibility.

In Kuwait and similar arid regions worldwide, with limited potable water resources and ever increasing demand for water in various industrial and domestic uses, the need to conserve water and develop new water resources becomes more urgent. The use of water considered unfit for human consumption becomes more essential in various industrial and construction uses.

Taking this into consideration, Tay and Yip (1987) investigated the use of various quantities of reclaimed wastewater. The water was reclaimed by coagulation - flocculation, sedimentation, filtration, aeration and chlorination. The reclamation operations followed activated sludge treatment. This polished wastewater was used in various proportions (0%, 25%, 50%, and 100%) to cast 100 mm cubes using a 1:2:4 (cement: sand: course aggregate) mix with a water/cement ratio of 0.6. Both short and long term effects were studied.

Results from Tay and Yip (1987) showed a general increase in early (3-28 day) compressive strength with increasing amounts of reclaimed wastewater used in the concrete mixes. For ages of 3 months and higher, compressive strengths of cubes made with 100% reclaimed wastewater, and those made with potable water, were similar. The use of reclaimed wastewater in concrete mixing did not seem to have an adverse effect on the concrete.

They also studied the effect of curing concrete cubes in reclaimed wastewater. This was performed by casting concrete cubes with potable water, then curing them in 100% reclaimed water. The results were compared to cubes that were both cast and cured in potable water. The results showed that the compressive strength of the cubes cured with reclaimed water was greater than that of those cured using potable water. The 28-day strength of cubes cured in reclaimed wastewater was 1.5% higher than those cured in potable water. The gain of strength for ages three months and beyond was insignificant. In addition to the use of tertiary treated wastewater in concrete, Cebeci and Saatci (1989) reported on the use of both treated and raw wastewater in concrete mixing. Again, treated wastewater was not shown to have an adverse effect on concrete. However, raw sewage reduced the 3- and 28-day compressive strength by 9%. Thus, average raw domestic sewage was shown to increase the initial setting time, entrain air and reduce the strength of mortar and concrete. Cebeci and Saatci (1989) were the only authors to point out the fact that the use of treated sewage in concrete did not pose a health hazard, since the pathogenic activity of the microorganisms was reduced substantially after pH exceeded 12, due to the rapid saturation with the calcium hydroxide formed by cement hydration. Nevertheless, the use of untreated sewage in concrete mixing was not advocated. Additional research on the subject by Tay (1989) also demonstrated that the use of reclaimed wastewater as mixing water for concrete did not affect properties other than strength (i.e., segregation, shrinkage, water absorption, bulk density and setting times).

MATERIALS AND METHODS

Wastewater

The treated water samples used in this investigation were obtained from the Reqqa wastewater treatment plant (WWTP). The plant was constructed in 1982 with an initial design capacity of 85,000 m^3/d. The latest expansion has increased its capacity to 180,000 m^3/d and it currently receives about 120,000 m^3/d. The plant is basically an activated sludge plant with no primary sedimentation and with tertiary (filtration and chlorination) treatment.

The plant was chosen for its operational stability. The relative operational stability of Reqqa over the other two major WWTPs in Kuwait might be attributed to the recent expansion which allows it to operate at about 70% of its design capacity, as compared to Ardhiya, for example, which is currently exceeding its original design capacity. Additionally, to insure consistency, the samples were all collected on the same day and kept refrigerated at 4°C until they were ready to be used. Prior to mixing, all the water samples were tested for the parameters given in Table 1.

Table 1. Water Parameters Analyzed and their Analytical Methods

Parameter	Analytical Method	Part No.	Page No.
T.S.S.	Gravimetric Method	2540	2-56
V.S.S.	Gravimetric Method	2540	2-57
F.S.S.	Gravimetric Method	2540	2-57
T.S.	Gravimetric Method	2540	2-54
T.V.S.	Gravimetric Method	2540	2-57
Sulfate	Turbidimetric Method	4500	4-134
Sulfide	Methyl Blue Method	4500	4-126
Nitrate	Nitrate Electrode Method	4500	4-88
Nitrite	Colorimetric Method	4500	4-85
Chloride	Argentometric Method	4500	4-49
Ammonia-N	Distillation and Titration	4500	4-81
Alkalinity	Titration Method	2320B	2-26
Residual Free Chlorine	Dpd Colorimetric Method	4500	4-45
COD	Closed Reflux Titrimetric Method	5220	5-8
Total Chlorine	DPD Colorimetric Method		

All parameters are analyzed according to the Standard Methods for the Examination of Water and Wastewater (1992).

Concrete

Concrete cubes made with the different types of wastewater were prepared and tested for the following parameters:

Compressive Strength

At 3 days, 7 days, 21 days, 28 days, 3 months, 6 months, 12 months and 18 months.

Steel Corrosion

After 12 and 18 months with varying concrete covers of 1.5 and 2.5 cm to investigate the effect of the concrete steel cover on steel corrosion.

Fresh Concrete Properties

Additionally, fresh concrete was tested for slump and setting time.

Concrete mix design

The concrete mix was designed according to Neville (1981) to achieve a compressive strength of 25 MPa. The maximum size was 20 mm, water content = 200 kg/m^3, water/cement ratio of 0.62 and a slump of 75 mm.

ANALYTICAL METHODS

Water

All the water samples used for concrete mixing were analyzed according to the Standard Methods for the Examination of Water and Wastewater (APHA 1992). The standard procedures used for the analysis of each parameter are provided in Table 1.

Concrete

The following is the testing procedure for each of the tested concrete parameters:

Compressive Strength

The compressive strength test was performed according to the British Standard (BS 1881: Part 116). The specimens were molded in 100 mm cubes and tested at the ages of 3 days, 7 days, 21 days, 28 days, 3 months, 6 months and 18 months. An ELE 3000 BS compression machine was used for the compression testing. Curing took place in an environmentally controlled curing chamber at 95% humidity and 25°C for the desired period. A total of 55 cubes were cast using each type of mixing water investigated. Average values for three cubes are used in this investigation. The coefficient of variation (standard deviation relative to the mean) was always within 5%.

Setting Time

The setting time test was made with freshly mixed concrete according to ASTM standard C 484.

Effect of Cover on Reinforcing Steel Corrosion

The steel corrosion test was made according to ASTM C 876-91 by measuring the electrical half-cell potential of the reinforcing steel in order to determine the corrosion activity of the steel. Appendix X1 of the standard states that: if the measured potential is higher than -200 mV, there is a greater than 90% probability that no reinforcement corrosion is occurring. Potentials in the range of -200 to -350 mV indicate that corrosion activity is uncertain at the time of measurement. Potentials lower than -350 mV indicate that there is a greater than 90% probability that reinforcement steel corrosion is in fact occurring.

In order to study the effect of available concrete cover on the corrosion of reinforcing steel, concrete prisms (200 mm × 200 mm × 120 mm) were cast with two different cover thicknesses (1.0 and 2.5). The embedded steel bar had a diameter of 10 mm, had a rectangular shape, and was placed in the molds to provide the two different covers.

RESULTS

Treated wastewater quality

The results for the water analyses (tap water and effluents) are provided in Table 2. An initial inspection of the table shows that there are significant differences in some of the analyzed parameters. Other parameters, such as temperature and pH, remained essentially constant for all types of effluents.

Results of solids analyses, in general, showed a marked difference between the PTWW, on one hand, and the TTWW on another. The level of sulfates showed a decrease from 230 to 180 to 160 mg/l for the preliminary, secondary and tertiary effluents, respectively. Both Nitrates (NO_3^-) and Nitrites (NO_2^-) did not show a significant change, which is expected for this type of plant. The chloride levels also seemed to be stable throughout the treatment process. As expected, an influent COD level of about 407 mg/l was reduced to 61 mg/l in the secondary effluent (85% COD reduction), and to 29 mg/l in the tertiary effluent (93% total COD reduction).

Table 2 also shows that 162 mg/l of the alkalinity present in the preliminary effluent (228 mg/l) was removed in the secondary treatment state (71% consumption). Residual free chlorine and total chlorine were only detectable in the tertiary effluent since the tertiary treatment step includes chlorination both before and after the filtration. Typical analysis of the tap water used in making concrete for this investigation is also given in Table 2.

Table 2. Results of Analysis for the Types of Water Used in Concrete Mixing

		Type of Effluent			
Parameter	**Unit**	**Preliminary**	**Secondary**	**Tertiary**	**Tap Water**
Temperature	°C	26	26	26	25
pH		7.4	7.8	7.3	8.0
T.S.S.	mg/l	221	12	7	0
V.S.S.	mg/l	172	10	5	0
F.S.S.	mg/l	49	2	2	0
T.S.	mg/l	986	876	773	301
T.V.S.	mg/l	716	134	104	116
Sulfate	mg/l	230	180	160	110
Nitrate	mg NO_3^--N/l	0.0	0.4	1.9	0.2
Nitrite	mg NO_2^--N/l	0.0	0.0	0.6	0.0
Chloride	mg/l	287	290	340	133
Ammonia	mg/l	37	44	36	0
COD	mg/l	407	61	29	3
Alkalinity	mg/l as $CaCO_3$	228	66	57	66
Sulfide	mg/l	0.9	0.0	0.2	0.0
Residual Free Chlorine	mg/l	0.00	0.00	0.18	0.02
Total Chlorine	mg/l	0.00	0.00	1.71	0.05

Fresh concrete properties

The type of mixing water did not affect the slump in the testing. This is not unexpected since slump should be affected by water content and not water quality (Neville 1981). Slump values varied between 70 to 80 mm for the four types of concrete tested.

The effect of the type of mixing water on setting times (initial and final) is presented in Fig.1. As shown in the figure, a minor variation is observed between the initial setting times for the different types of concrete made with TW (4.61 hrs.), PTWW (4.91 hrs.) and TTWW (4.48 hrs.). As for the concrete made with STWW, the observed higher value (5.78 hrs.) could be attributed to the larger concentration of ammonia in the secondary effluent. Ammonium salts have been reported to cause bleeding action (flow of water to the top of the concrete due to osmotic pressure) (Neville 1981).

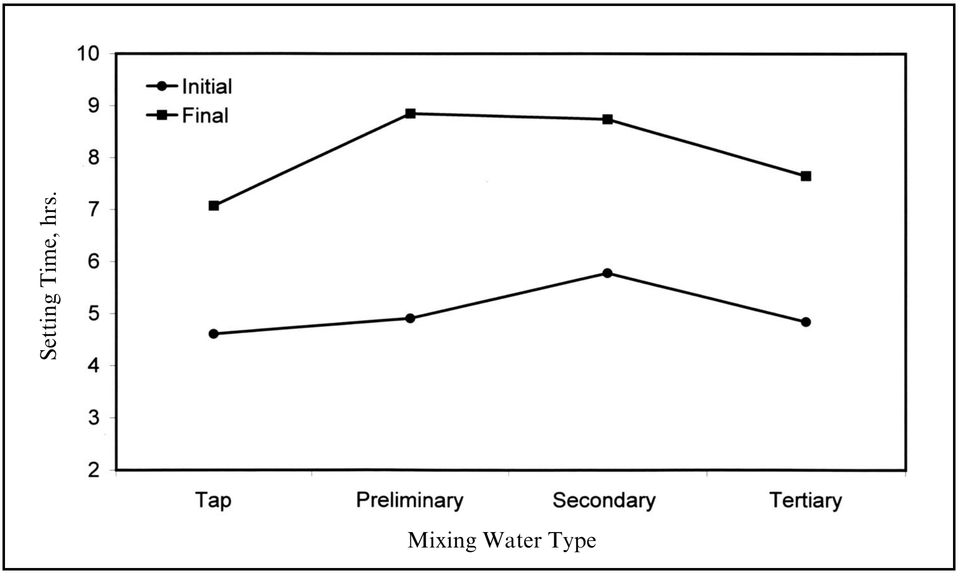

Fig.1. Effect of Mixing Water on Setting Time

Final setting times seem to be directly related to the quality of the mixing water, as indicated by the almost two hour difference in setting time between concrete made with TW (7.07 hrs.) and that made with PTWW (8.85 hrs.). Final setting time is shown to significantly decrease when TTWW is used (7.65 hrs.). This finding is consistent with what is reported in the literature - that dissolved organic matter in the mixing water (constituents of COD, Table 2) retard the final setting time (Neville 1981). Cebeci and Saatci (1989) also reported retardation in the setting time when untreated wastewater was used for mixing the concrete.

Density

The different types of mixing water did not significantly affect the density of the fresh concrete as indicated by the less than 5% variation in density between the concrete made with TW (2320 kg/m^3) and that made with TTWW (2210 kg/m^3) (Figure 2).

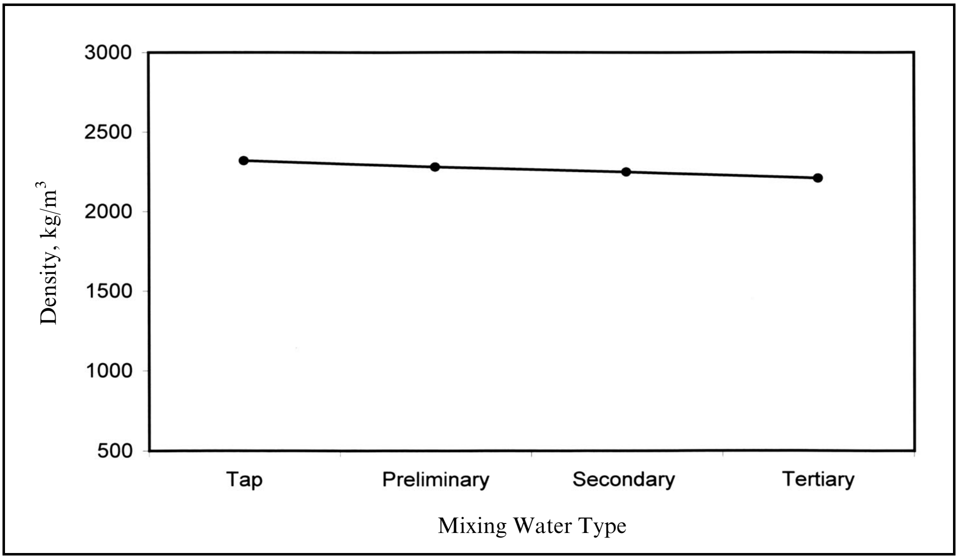

Fig.2. Effect of Mixing Water on Concrete Density

Concrete strength

The effect of the type of mixing water on the development of strength is shown in Fig.3. Fig.4. however, shows the effect of age (21 d, 180 d, 1 yr, and 1.5 yrs.) on the strength of the four different types of concrete. In general, concrete made with PTWW and STWW showed lower strengths (i.e. slower strength development) for ages up to 1 year. ANOVA statistical analysis showed, with

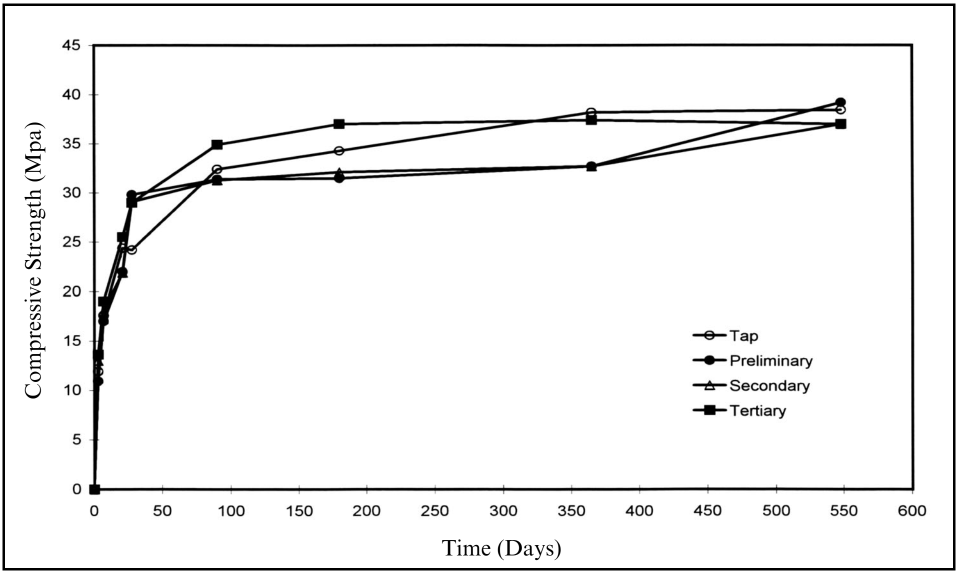

Fig.3. Compressive Strength Development for Different Types of Concrete

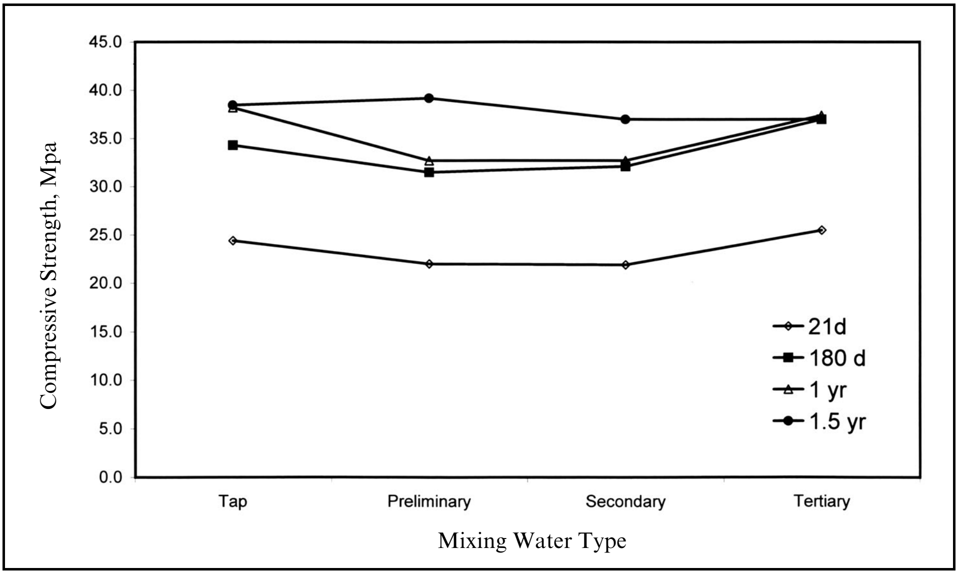

Fig.4. Effect of Water Type on Concrete Strength

95% confidence, that the average values presented in Figs.3 and 4 were indeed statistically different and that strength values for concretes made with PTWW and STWW were actually lower than those values for concretes made with TTWW or TW. The previous observation is also valid for the stress-strain relationships at 28 days for concrete made with the three types of treated wastewater (shown in Fig.5).

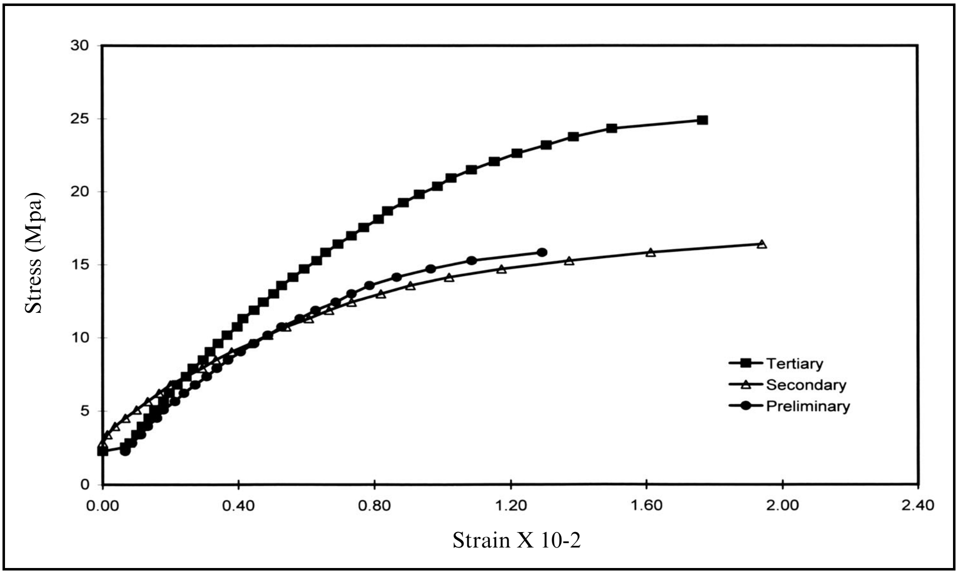

Fig.5. Stress Strain Curves for Different Water Types Used

It should also be noted that at the early concrete ages of 3 and 7 days, the strength of concrete made with TTWW (13.6 and 19.0 MPa at 3 and 7 days, respectively) was higher that that of concrete made with TW (11.9 and 17.6 MPa at 3 and 7 days, respectively). These findings are consistent with those of Tay and Yip (1987) who showed that a general increase in early compressive strength (3-28 day) was noticed with increasing amounts of reclaimed wastewater used in the concrete mixes. For ages of 3 months and higher, compressive strengths of cubes made with 100% reclaimed wastewater, and those made with potable water, were similar. The 28-day strength of cubes cured in reclaimed wastewater was also reported to be 1.5% higher than those cured in tap water. Cebeci and Saatci (1989) also reported that treated wastewater was not shown to have an adverse effect on concrete. However, raw sewage reduced the 3- and 28-day compressive strength by 9%.

Corrosion Potential

Figures 6 and 7 show the effect of the type of mixing water on the corrosion of reinforcing steel with concrete covers of 1 cm and 2.5 cm, respectively. The effect of the quality of mixing water and age on the potential of corrosion is shown in Figs.6 and 7 for covers to reinforcing steel of 1.0 cm and 2.5 cm, respectively. Both figures indicate the increase in the possibility for corrosion with the decrease in the quality of mixing water. This is clearly indicated by the values of the half cell potential which are lowest (maximum in absolute value) for concrete made with PTWW and highest for concrete made with TW.

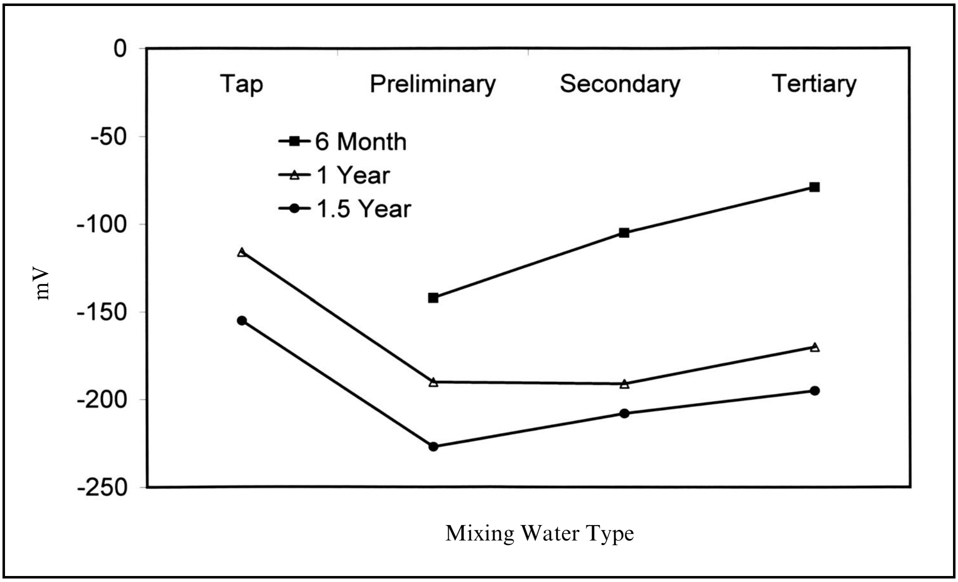

Fig.6. Effect of Mixing Water on Corrosion (1.0 cm Cover)

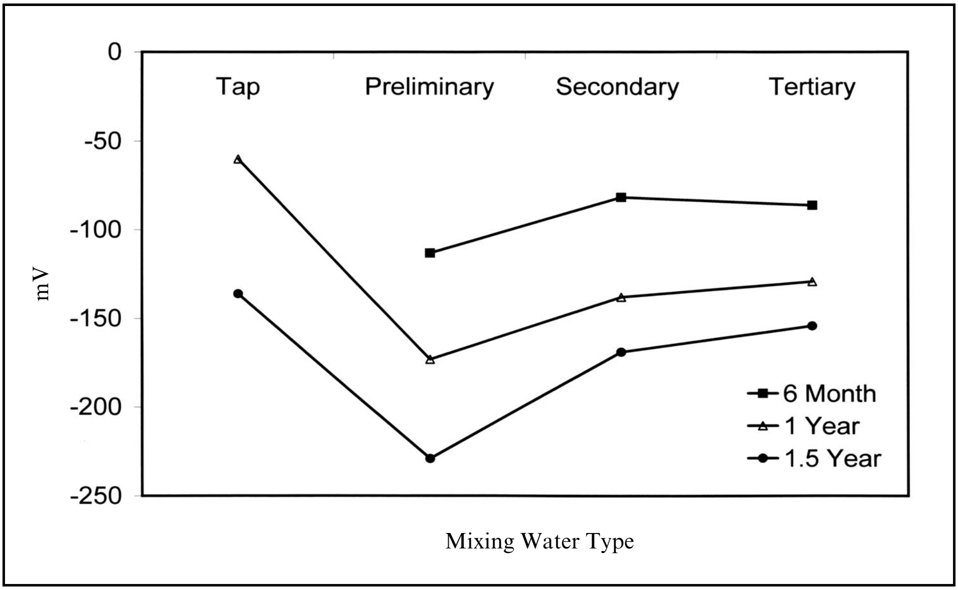

Fig.7. Effect of Mixing Water on Corrosion (2.5 cm Cover)

Also, the possibility of corrosion was higher for samples with 1 cm cover than those for 2.5 cm cover (as indicated by the lower values of the half cell potential). After 1.5 years, however, even in the critical case of 1.0 cm concrete cover, the recorded half cell potential values were higher than -200 mV

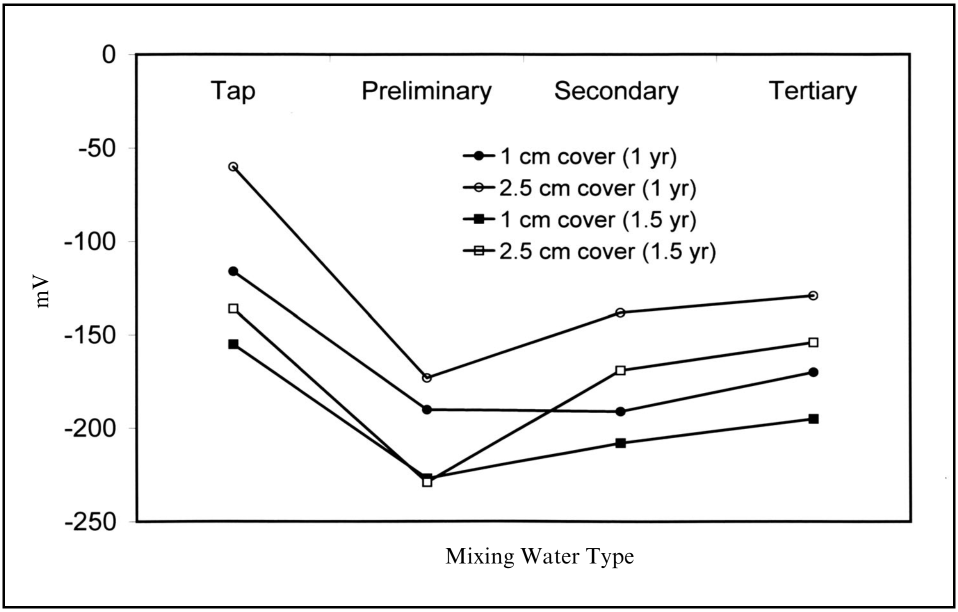

Fig.8. Effect of Mixing Water on Corrosion

(indicating a greater than 90% probability that no reinforcing steel corrosion is occuring). The recorded half cell potentials for concrete made with PTWW were -227 mV and -229 mV for reinforcement steel covers of 1.0 cm and 2.5 cm, respectively, indicating that corrosion of the reinforcing steel in that case is uncertain. A graphical comparison between the effects of concrete cover and age of concrete on corrosion potential is presented in Fig.8.

CONCLUSIONS

The following conclusions on the effect of mixing water on the properties of concrete are drawn from the experimental study presented in this paper.

1 - Concrete slump and density were not affected by the type of mixing water.

2 - Both initial and final setting times were affected by the type of mixing water. Setting times were found to increase with deteriorating water quality. PTWW and STWW were found to have the most effect on retarding setting time.

3 - In general, concrete made with PTWW and STWW showed lower strength (i.e., slower strength development) for ages up to 1 year. At early concrete ages of 3 and 7 days, the strength of concrete made with TTWW was higher than that of concrete made with TW.

4 - The possibility for steel corrosion also increased with the use of treated wastewater. The highest corrosion possibility occurred when PTWW was used, and the lowest was for TTWW and TW. The need for using an adequate concrete cover to the reinforcing steel is also emphasized, especially when PTWW is used. Reducing the concrete cover increased the possibility of corrosion in all cases.

5 - Tertiary treated wastewater, of the type produced from wastewater treatment plants in Kuwait, is suitable for mixing concrete. The fresh concrete properties, strength characteristics and steel reinforcement corrosion potential for concrete made with TTWW, were all similar to those produced using tap water. Moreover, from a health perspective, TTWW is the most suitable type of treated wastewater for use on-site and for handling by the construction workers.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the Kuwait University Research Administration for supporting this research under project number (EV-086). The efforts of both Eng. Baheeja Amin and Eng. Mohammad Abdelghany from the Civil Engineering Department are also appreciated.

REFERENCES

Al-Essa, W. 2000. Wastewater management in Kuwait. Procedings of the Workshop on Wastewater Reclamation and Reuse. Arab School for Science and Technology, Kuwait Foundation for the Advancement of Science. Al-Sulaimi, J. and Asano, T. (Eds.), Kuwait.

APHA 1992. Standard Methods for the Examination of Water and Wastewater. American Public Health Assoc. (APHA), American Water Works Assoc. (AWWA), Water Environment Federatoin (WEF). APHA, Washington, DC, USA.

Cebeci, O. Z. & Saatci, A. M. 1989. Domestic sewage as mixing water in concrete. ACI Materials Journal **86**(5): 503-506.

Metcalf and Eddy, Inc. 1991. Wastewater Engineering: Treatment, Disposal and Reuse. Third Edition, McGraw-Hill.

Neville, A. M. 1981. Properties of Concrete. Third Edition. Longman Scientific.

Mehta, P. K. 1986. Concrete: Structure, Properties and Materials. Prentice-Hall, Inc. Englewood Cliffs, NJ, USA.

Mindess, S. & Young, J. F. 1981. Concrete. Prentice-Hall, Inc. Englewood Cliffs, NJ, USA.

Raina, V. K. 1988. Concrete for Construction: Facts and Practice. Tata McGraw-Hill, New Delhi, India.

Tay, J. H. 1989. Reclamation of wastewater and sludge for concrete making. Resources, Conservation and Recycling **2**(3): 211-227.

Tay, J. H. & Yip, W. K. 1987. Use of reclaimed wastewater for concrete mixing. Journal of Environmental Engineering, American Society of Civil Engineers **113**(5): 1156-1161.

Waddell, J. J. & Dobrowski, J. A. 1993. Concrete Construction Handbook. McGraw-Hill Inc.

Submitted : *11/9/2001*
Revised : *25/6/2002*
Accepted : *8/7/2002*

استخدام المياه المعالجة لخلط الخرسانة في الكويت

إبراهيم الغصين و محمد ترو
كلية الهندسة والبترول – جامعة الكويت
ص.ب. 5969 الصفاة 13060 الكويت

خلاصة

تمت الاختبارات على صلاحية استخدام مياه الصرف المعالجة لخلط الخرسانة وذلك باستخدام عينات من كل من المياه المعالجة أولياً وثانوياً وثلاثياً في محطة الرقة لمعالجة مياه الصرف في دولة الكويت ومقارنتها باستخدام مياه الصنبور لهذا الغرض.

دلت النتائج على عدم تأثير نوعية المياه المستخدمة على كثافة واختبار الكزازة (الهبوط) (Slump) للخرسانة اللينة بينما كانت هناك علاقة عكسية بين نوعية المياه وإطالة زمن التصلب (setting time) للخرسانة.

وقد أدى استخدام كل من المياه المعالجة ثنائياً وثلاثياً إلى انخفاض قوة تحمل الخرسانة (وكذلك تطور قوة التحمل) وذلك لغاية سنة من بدء التجارب. أما في المراحل الأولى من عمر الخرسانة (3–7) أيام فقد لوحظ بأن الخرسانة التي خلطت باستخدام المياه المعالجة ثلاثياً كانت أقوى من تلك المعدة باستخدام مياه الصنبور. وقد أدى استخدام كل من المياه المعالجة أولياً وثانوياً إلى زيادة قابلية التآكل في حديد التسليح وخصوصاً عند استخدام غطاء خرساني أرق. وأخيراً، فإن المياه المعالجة ثلاثياً كالتي تنتجها محطات معالجة مياه الصرف في دولة الكويت صالحة للاستخدام في صناعة الخرسانة.