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Effect of using Wastewater on the Properties of High Strength Concrete

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Abstract

This paper investigates the effect of using wastewater on the properties of high strength concrete. Wastewater samples were collected from three car washing station in Muscat area. The collected wastewater samples were mixed together and chemical analysis was carried out. Four water samples, including a controlled potable (tap) water were analysed for pH, total dissolved solids (TDS), chloride, hardness, alkalinity, and sulfates. Chemical analysis results showed that although the chemical compositions of wastewater were much higher than those parameters found in tap water, the water composition was within the ASTM standard limits for all substance indicating that the wastewater produced can be used satisfactorily in concrete mixtures.
High strength concrete mixtures were prepared using different proportions of wastewater and water-to-cement ratio of 0.35. The percentage of wastewater replaced ranged between 25-100% of tap water used in concrete. For each concrete mixture, Six 150mmx150mmx150mm cubes, three 300mmx150mm dia. cylinders and three 100mmx100mmx500mm prisms were cast. Slump, compressive, tensile and flexural strengths were determined at 28-day of curing. Cube compressive strength was also determined at 7-day of curing. Also, initial surface absorption test was conducted at 28-day of curing in order to assess the durability of concrete.
Results indicated that the strength of concrete of the mixtures prepared using wastewater was comparable with the strength of the control mixture. Also, the water absorption of concrete is not affected when wastewater was used.

Keywords: Wastewater, High strength concrete, Strength, Absorption, Durability.

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1. INTRODUCTION

Oman is located in an arid region where freshwater is considered as a precious and scarce commodity. Due to erratic and irregular rainfall, extremely hot weather during summer months, and the over exploitation of groundwater in the coastal regions causing water salinity, Oman faces serious deficit in freshwater. The increase in the economic activities as well as the population growth caused a substantial increase in the water demand As water is becoming scarce, it is important to reduce freshwater consumption in all sectors including the construction industry. Finding viable alternatives to reuse non-fresh water diminishes the pressure on potable water resources and hence creates a balance between the resources and the demands.

In the construction industry, potable water is usually used since it is recommended by most specifications and its chemical composition is known and well regulated. In the design codes, it is recommended that the compressive strength of concrete cubes made of untried water not to be less than 90% of cubes made with tap water (Taha et al. 2010). There are various sources of non-fresh water that were previously tested for use in concrete mixtures. These include sea and al-kali waters, mine and mineral waters, waters containing sewage and industrial wastes, and oily and brackish waters from oil wells (Cebeci and Saatci 1989, Mujahed 1989, El-Nawawy and Ahmad 1991, Chini et al. 1999, Taha et al. 2005, Taha et al. 2010, Al-Jabri et al. 2010). Due to the different types of impurities that exist in each water types, it is difficult to draw a sound conclusion concerning the use of non-fresh water in concrete mixtures. Neville (2000) reviewed extensively the research literature on the use of wastewater in concrete, and concluded that much work needs to be done on water use in concrete and that there is a need to review the existing standards on water quality in light of the various types of cementitious materials and water-reducing admixtures in use today.

The main objective of this study was to investigate the potential use of wastewater obtained from car washing stations on the properties of high strength concrete. The following were specific tasks:

1. Perform chemical characterization of the wastewater.
2. Determine compressive, tensile and flexural strengths of high strength concrete mixtures
3. Assess the durability of concrete made with non-fresh water by conducting initial surface absorption and total absorption tests.

2. MATERIALS

2.1. Cement

The cement used in this study was ordinary portland cement (OPC) purchased from Oman Cement Company. This cement is the most widely used one in the construction industry in Oman.

2.2. Coarse and Fine Aggregates

Coarse aggregates (i.e. 10 mm) and fine sand were purchased from a nearby crusher in Al-Khoudh area, which are typically the same materials used in normal concrete mixtures. The gradation test conducted on aggregates showed that they met specifications requirements.

2.3. Silica Fume

The silica fume used in the production of high strength concrete was supplied and added to the mix in a powder form (Elkem Emsac 500s).

2.4. Superplasticizer

In order to improve the workability of high strength concrete, superplasticizer in the form of a polynaphthalene sulphonate-based admixture (conplast SP430) was used. This had 40% active solids in solution.

2.5. Mixing Water

Waster samples were obtained from three car washing stations in Muscat region. These samples were mixed together and analyzed for certain impurities that could affect concrete mixes. Measurements included: total alkalinity, sulfate content (as SO_4), chloride content (as NaCl), total dissolved solids (TDS), and water hardness. Other parameters such as pH and conductivity were also measured.

3. LABORATORY TESTING PROGRAM

3.1. Mix Design and Sample Preparation

The mix proportions chosen for this study are given in Table 1 for high strength concrete. The constituents were weighed in separate buckets. The materials were mixed in a rotating pan in accordance with ASTM C192-98. The overall mixing time was about 4 minutes. The mixtures were compacted using vibrating table. The slump of the fresh concrete was determined to ensure that it would be within the design value and to study the effect of wastewater replacement on the workability of concrete. The specimens were demoulded after 24 hours, cured in water and then tested at room temperature at the required age.

Table 1: Mix proportions and water-to-cement (w/c) ratios for concrete mixtures

Mix proportions (kg/m^3)					w/c ratio	Superplasticizer (l/m^3)
Cement	Silica fume	Sand	10mm Aggregate	Water		
400	44	710	1190	140	0.35	7.9

To determine the unconfined compressive strength, six cubes (150mm x 150mm x 150mm) were cast for each mix and water-to-binder ratio, and three samples were tested after 7 and 28 days of curing. Three 150 mm diameter x 300 mm long cylinders were prepared for each mix in order to determine the 28-day tensile strength of concrete. Also, to determine the flexural strength (modulus of rupture) for each mix, three 100mm x 100mm x 500mm prisms were cast and tested after 28 days of curing.

3.2. Testing Procedure

After curing, the following tests were carried out on the concrete specimens:

- 7- and 28-day cube compressive strength test was conducted in accordance with BS 1881: Part 116 using a loading rate of 2.5 kN/s;

- 28-day cylinder tensile (splitting) strength test was done in accordance with ASTM C496-96 using a loading rate of 2 kN/s; and
- 28-day flexural strength test was conducted in accordance with ASTM C78-94 using a simple beam with third point loading at a loading rate of 0.2 kN/s, and
- the initial surface absorption test was conducted on concrete cubes after 28 days of curing in accordance with BS 1881: Part 208

All strengths tests were conducted using a DARTEC compression machine.

4. TEST RESULTS AND DISCUSSION

4.1. Water Quality Analysis

Table 2 presents the chemical analysis results which were performed on the wastewater and the tap water. The data indicate that all the chemical compositions of the wastewater were much higher than those parameters found in tap water. The pH values were more on the acidic side. However, the chemical analysis of the wastewater shows that the water composition was within the ASTM standard limits for all substances (ASTM T26-79 1996). Results show that pH values were within the permissible range (4.5-8.5). The maximum total dissolved solids were 254 ppm, which is acceptable since it is below the standard requirement of 50,000 ppm. The standard recommends that water containing less than 2,000 ppm of total dissolved solids can generally be used satisfactorily in making concrete. The maximum total alkalinity of 90 ppm was measured, which is lower that the value specified in the specifications (600 ppm). Also, the maximum sulfate concentration of 97.7 ppm was less than the threshold limit of 3,000 ppm.

The results generally indicate that the wastewater produced can be used satisfactorily in concrete mixtures. However, the high chloride contents could raise concerns with the potential for corrosion in reinforced concrete. Also, the high sulfate content could lead to sulfate attack and cracking in concrete. Thus, it becomes imperative that durability-based tests are conducted to investigate potential corrosion and sulfate attack that could result from the use of wastewater from car washing stations in concrete.

4.2. Effect of Wastewater Replacement on the Strength of Concrete

Results of strength tests for all of the concrete mixtures are presented in Table 3. The 7- and 28-days average cube compressive strengths of concrete specimens are presented in Fig. 1. The results presented in Fig. 1 indicate that the cube compressive strength values for mixtures with 25% and 100% wastewater substitution are slightly lower than the strength of the control mixture (100% tap water) at 7 and 28 days of curing. However, the mixture with 50% wastewater substitution yielded strength value that is comparable to the control mixture.

The flexural and splitting strength results were determined by testing prisms and cylinders as shown in Table 3. The tensile strength of concrete was similar in most mixture, except for the control mixture, where it yielded the lowest tensile strength of 4.39 MPa among all the mixtures. However, the highest tensile strength of 5.32 MPa was achieved for the concrete with 25% wastewater substitution. Table 3 also indicate that the flexural strengths of control mixtures and mixtures with 50% and 100% wastewater substitution were similar, whereas it was higher (6.29 MPa) for mixture with 25% wastewater replacement.

Table 2: Chemical analysis of water samples

Parameters	Tap Water	Wastewater
pH	7.41	6.94
Electrical Conductivity	480	498
Total Dissolved Solids	240	254
Total Alkalinity	82	90
Bicarbonate Alkalinity	82	90
Carbonate Alkalinity	0	0
Hydroxide Alkalinity	0	0
Total Hardness	152	152
Calcium Hardness	96	100
Magnesium Hardness	56	52
CATIONS		
Sodium	35.6	45.1
Potassium	2.7	4
Calcium	38.4	40
Magnesium	13.59	12.6
Iron (Fe)	0.09	0.1
ANIONS		
Fluoride	0.43	0.97
Chloride	45.77	74.2
Bromide	0.23	0.22
Nitrate	9.96	0.07
Phosphate	2.15	8.14
Sulphate	54.32	97.7
Silicates as SiO_2	3.90	9.56

Units

Electrical Conductivity as microSiemens per centimeter (µS/cm) @ 25 °C

Alkalinity, Hardness as milligrams Calcium carbonate per Litre (mg/L)

Total Dissolved Solids as milligrams per Litre (mg/L)

Cations & Anions as parts per million (ppm)

Table 3: Average strength of concrete at 7 and 28 days of curing with various wastewater replacement

Mix	Slump (mm)	Strength (MPa)			
		$(F_{cu})^*$	$(F_{cu})^+$	$(F_t)^+$	$(F_{cr})^+$
Tap Water (100%)	0	66.0	77	4.39	5.17
Wastewater (25%)	20	64.3	70	5.32	6.29
Wastewater (50%)	10	66.8	75	4.95	5.76
Wastewater (100%)	10	63.8	72	5.21	5.26

F_{cu}= cube compressive strength, F_t= tensile strength, F_{cr}= flexural strength
*= cured at 7-days, += cured at 28-day

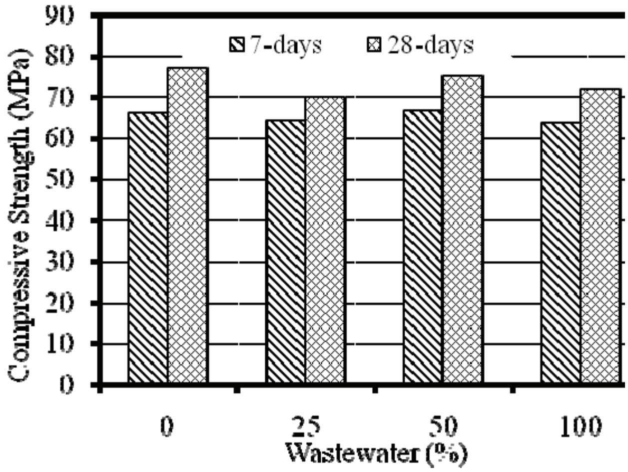

Figure 1: Cube compressive strength for high strength concrete at 7- and 28-days of curing

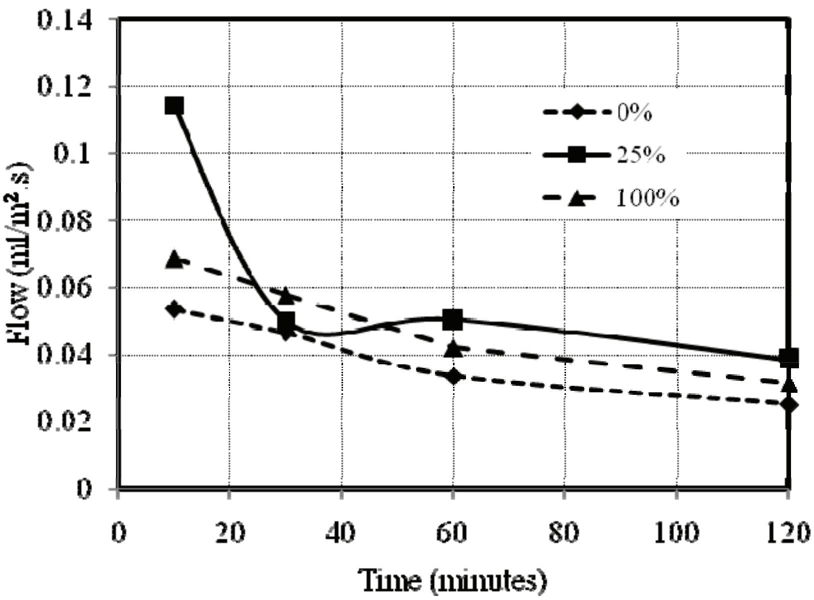

Figure 2: Surface water absorption of concrete with time for different concrete mixtures

4.3. Effect of Wastewater on the Durability of High Strength Concrete

The initial surface absorption test was used to assess the durability of high strength concrete. The results from the initial surface absorption test are shown in Fig. 2. Fig. 2 indicates that all mixtures showed a similar trend of decreasing surface water absorption with time. The decrease was generally rapid during the first 30 minutes, which later decreased afterwards up to 120 minutes. All mixtures yielded flow rate values within the specified limits, which were between 0.05 ml/(m^2.s) and 3.6 ml/(m^2.s) in the first 10 minutes. Also, Fig. 2 shows that all concrete mixtures with wastewater replacement showed similar water absorption rates to the control mixture.

5. CONCLUSION

The following conclusions are warranted regarding the effect of wastewater usage on the strength of cement mortars and concrete:

- The chemical composition of the wastewater is generally higher than tap water, but within the standard limits specified in ASTM. The high concentrations of some substances could raise concerns about the potential for corrosion and sulfate attack in reinforced concrete structures.
- As the curing period increases the compressive strength of the concrete is also increased irrespective of the wastewater percentage used.
- There was no significant difference in the cube compressive strength of concrete among different mixes after 28 days of curing.
- All concrete mixtures with wastewater replacement showed similar water absorption rates to the control mixture.
- It may be concluded from this study that the use of wastewater produced from car washing stations has negligible effect on the strength of concrete. However, the study should be extended to investigate the effect of wastewater on the durability of concrete, since it may contain harmful substances that may affect adversely the concrete after prolonged exposure times.

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REFERENCES

[1] Al-Jabri KS, Taha R and Al-Saidy AH (2010). Effect of using non-fresh water on the mechanical properties of cement mortars and concrete. Proceedings The Third International fib Congress and PCI Annual Convention & Exhibition, May 29 – June 2, Washington D. C., USA.

[2] ASTM T26-79 (1996). Standard test method for quality of water to be used in Concrete", ASTM International, West Conshohocken, PA.

[3] Cebeci OZ, and Saatci AM (1989). Domestic sewage as mixing water in concrete, ACI Materials Journal. 86(5), pp. 503-506.

[4] Chini AR, Muszyasti LC, and Ellis PS (1999). Recycling process water in ready-mixed concrete operations. Final Report Submitted to the Florida Department of Transportation, University of Florida, Gainesville, FL.

[5] El-Nawawy OA, and Ahmad S (1991). Use of treated effluent in concrete mixing in an arid climate. Cement and Concrete Composites. 13(2), pp. 137-141.

[6] Mujahed FS (1989). Properties of concrete mixed with red sea water and its effects on steel corrosion. Unpublished M.S. Thesis, Jordan University of Science and Technology, Jordan.

[7] Neville A (2000). Water-Cinderella ingredient of concrete. Concrete International. 22(9), pp. 66-71.

[8] Taha R, Al-Rawas A, Al-Oraimi ., Hassan H, and Al-Aghbari M (2005). The use of brackish and oil-contaminated water in road construction, Environmental and Engineering Geoscience. XI(2), pp. 74-150.

[9] Taha R, Al-Harthy AS, and Al-Jabri KS (2010). Use of production and brackish water in concrete. Proceedings International Engineering Conference on Hot Arid Regions (IECHAR 2010. March 1-2, Al-Ahsa, Kingdom of Saudi Arabia, pp. 127-132.