International Journal of Science, Environment and Technology, Vol. 4, No 3, 2015, 813 – 825

ISSN 2278-3687 (O)
2277-663X (P)

EFFECTS OF SUGAR FACTORY WASTEWATER AS MIXING WATER ON THE PROPERTIES OF NORMAL STRENGTH CONCRETE

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Abstract: Sugar refining plants use a substantial amount of fresh water a scarce resource either in the extraction of sugar products or in cleaning and maintenance of their facilities which either way ends up as a wastewater with no "known" usage afterwards. This research utilized wastewater from Savannah Sugar factory as a total replacement for mixing water in concrete, as well as curing water. Tests carried out include, setting time of cement mixed with wastewater, composition analysis of wastewater as compared with portable water and compressive strength of concrete. Results indicate that the setting time of wastewater increases with an increase with percentage replacement, sugar wastewater from the factory was found to be acidic, and the strength increases with an increase in curing duration. However, there were appearances of hair-like cracks all over the cubes casted with an appreciable volume change in the dimension of the cubes.
Keywords: wastewater; sugar; concrete; setting time; strength.

1.0 INTRODUCTION

Raw sugar refineries generate two types of waste water; namely: spray pond/cooling tower over flows and factory waste. The cooling water is generated by condensing vapour in the barometric condensers and the organic content varies from 0 to 1000mg/L depending on the extent of evaporator entrainment and blow down practice. The factory waste water has many sources; lon exchange effluents, waste from phosphatation and carbonatation, tank overflows, floor washings, heat exchanger and filter chemical cleaning, grease and oil spillage. Modern refineries that have good hygiene and maintenance systems can get away with aerobic systems as the relatively low strength of the waste water is conducive to aerobic system.

The concrete industry alone uses over one trillion gallons of water each year worldwide, not including wash water and curing water (Meyer, 2004) and freshwater accounts for only 2.5% of the Earth's water, and most of it is frozen in glaciers and ice caps.

*Received April 16, 2015 * Published June 2, 2015 * www.ijset.net*

The remaining unfrozen freshwater is mainly found as groundwater, with only a small fraction present above ground or in the air (UNESCO, WMO, and IAEA, 2006). According to Al-Ghusain and Terro (2003), 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. The reason for this is that municipal drinking water seldom contains more than 1000mg/l of dissolved solids. Coloured water containing organic material may retard the hydration of cement.

Comparative tests require that, if the quality of water is not known, the strength of the concrete made with water in question should be compared with the strength of concrete made with water of known suitability. Both concretes should be made with cement proposed to be used in construction works. ASTM C94 requires that the age of 28 days mortar strengths made with test water to be a minimum of 90% of the strength of cubes made with distilled water and the setting time in the test mortar should not be more than 1 hour quicker nor more than 1.5 hours later than the time of setting when distilled water is used (Chini and Mbwambo, 1996).

According to Ashworth (1965) as cited in Neville (1995), it seems that, used in a carefully controlled manner, a small quantity of sugar (about 0.05 per cent of mass of cement) will act as an acceptable retarder: the delay in setting of concrete is about 4 hours. The retardation action of sugar is probably by the prevention of the formation of C-S-H (Birchall and Thomas, 1984). When sugar is used as a controlled set retarder, the early strength of concrete is severely reduced (Bloem, 1959), but beyond about 7 days, there is an increase in strength of several percent compared with non-retarded mix ((Birchall and Thomas, 1984). According to Neville (1995), this is probably due to the fact that delayed setting produces a denser hydrated cement gel.

2.0 LITERATURE REVIEW

According to Chini and Mbwambo (1996), two criteria should be considered in evaluating the suitability of Ready Mixed Concrete (RMC) waste water for producing fresh concrete:

i. Whether the impurities in the waste water will affect the properties and quality of concrete

ii. The degree of impurity which can be tolerated.

The work of Al-Ghusain and Terro (2003) experimented on the use of wastewater for mixing concrete. Concrete cubes were casted using Tap water (TW), Preliminary Treated

Wastewater (PTWW), Secondary Treated Wastewater (STWW) and Tertiary Treated Wastewater (TTWW). They reported that the type of water used 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. And concrete made with them showed lower strength development for up to 1 year. At early ages (3 and 7 days), the strength of concrete made with TTWW was higher than that of concrete made with TW. They also observed that 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 Tay and Yip (1987) investigating 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 100mm cubes using a 1:2:4 mix with a water-cement ratio of 0.6. Both short and long term effect were studied. Impurities in water may interfere with the setting of the cement, adversely affecting the strength of the concrete or cause staining of its surface, and also lead to corrosion of the reinforcement (Steinour, 1960).

The work of Nikhil et al., (2014) studied the effect of chemical impurities in mixing water on different properties of concrete using a mix for Grade M20 using potable, groundwater and sewage water. They reported an increase of 33.34% in compressive strength of potable water concrete when compared with concrete made using sewage water. They also reported a pH value for sewage water of 10.2 compared to 8.2 and 6.6 for portable water and groundwater respectively. A chloride content of 210 mg/l for sewage water compared to 150 mg/l and 175 mg/l for portable water and groundwater. They concluded that, if the pH value of water increases, the strength of concrete reduces substantially. On Comparism with reference specimens at higher concentrations of lead in mixing water, test samples had shown considerable loss of strength, and also their setting times had significantly increased. Al-Ghusain and Terro (2003) reported that early concrete ages of 3 and 7 days strength of concrete made with TTWW (13.6 and 19.0 MPa) was higher than that of concrete made with TW (11.9 and 17.6 MPa respectively). These findings are consistent with those of Tay and Yip (1987) who showed that a general increase in early compressive strength (3 – 28 days) was noticed with increasing amounts of reclaimed wastewater used in concrete mixes. Their result showed (Tay and Yip, 1987) a general increase in early (28 days) 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 with portable water were similar.

Also, Reddy Babu et al., (2007) reported Pb, Zn, Hg, Cu, Ni, Fe and Cr were friendly with cement mortar up to 600mg/L. Mindness and Young (1981) reported a tolerable limit of Cu, Pb, Zn, and Mn as 500mg/L. Also, Reddy Babu et al., (2011), reported that heavy metals such as Cu, Zn, Pb cause a retardation of the early hydration and strength development of cement mortar (Tashiro, 1980). They also delay setting and early strength development (Barth, 1990).The initial and final setting times increased as the concentrations of lead increases from 500mg/L to 5000mg/L. At 500mg/L, the test samples had 67 minutes increase in initial setting time and 74 minutes increase in the final setting, compared to the reference samples at initial and final setting times respectively.

According to Al-Ghusain and Terro (2003), 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 micro-organsms 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.They also reported a minor variation observed between the initial setting times for the different types of concrete made with TW (4.61hrs), PTWW (4.91hrs) and TTWW (4.48hrs). As for the concrete made with STWW, the observed higher value (5.78hrs), they attributed to the larger concentration of ammonia in the secondary effluent. Ammonia salts have been reported to cause bleeding action (Neville, 95). Final setting times seem to be directly related to the quality of the mixing water, TW(7.07hrs), PTWW(8.85hrs) TTWW(7.65hrs). their findings is consistent with what is reported in the literature – that dissolved organic matter in the mixing water (Constituents of COD) retard the final setting time (Neville, 95). Cebeci and Saatci (1989) also reported retardation in the setting time when untreated wastewater was used for mixing the concrete.

Cebeci and Saatci (1989) reported on the use of both treated and raw wastewater in concrete mixing. 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, the average raw domestic sewage was shown to increase the initial setting time, entrain air and reduce the strength of mortar and concrete.

3.0 METHODOLOGY

3.1 Materials

The cement used in this research was a brand of Portland cement with a specific gravity of 3.14 which satisfied BS 12: 1996 specification for ordinary Portland cement. Graded river sand passing the gradation size 4.75mm with a specific gravity of 2.75 was used. Coarse aggregate from crushed stone with a maximum nominal aggregate size of 19mm and specific gravity of 2.65 was used, both the fine and coarse aggregate conform to BS 812: Part 103-1990: Testing Aggregate specification. Portable water from Modibbo Adama University of Technology, Yola borehole was used. And, waste water from Savanna Sugar Company, Nigeria Limited, Numan, Adamawa State. The samples of water were analyzed at Adamawa State Water Board treatment plant.

3.2Mix Proportion

A control mix with a mix ratio of 1: 2: 4: 0.56 containing OPC, natural sand and crushed rock aggregate was designed for a compressive strength of 25 MPa at 28 days with a slump range of 25-75mm non-air entrained concrete using ACI Method of mix design. Portable water was replaced with waste water from Savannah Sugar Factory in the following percentages 0%, 75%, and 100%.

3.3 Detail of Tests

Grain size analysis conducted was in accordance to BS 410:2000 test sieves. Specific gravity was tested based on pycnometer procedure using ASTM D 854-00. Chemical analysis was conducted on the wastewater samples, the results compared with that of portable water according to WHO standard. Hardened concrete properties were determined for the sample prepared; compressive strength test was carried out in accordance to BS 1881: Part 116: 1983.

The volume change for concrete cubes was measured with a digital meter, and subsequent calculations done using the formulation below;

$$\frac{V_1 - V_0}{V_1} \times 100\%$$

Where;

V_o = Volume of cube at cast

V_1 = Volume of cube at moment prior to crushing.

4.0 RESULTS AND DISCUSSION

4.1Grain size analysis

Grain size analysis for both fine and coarse aggregates is as presented.

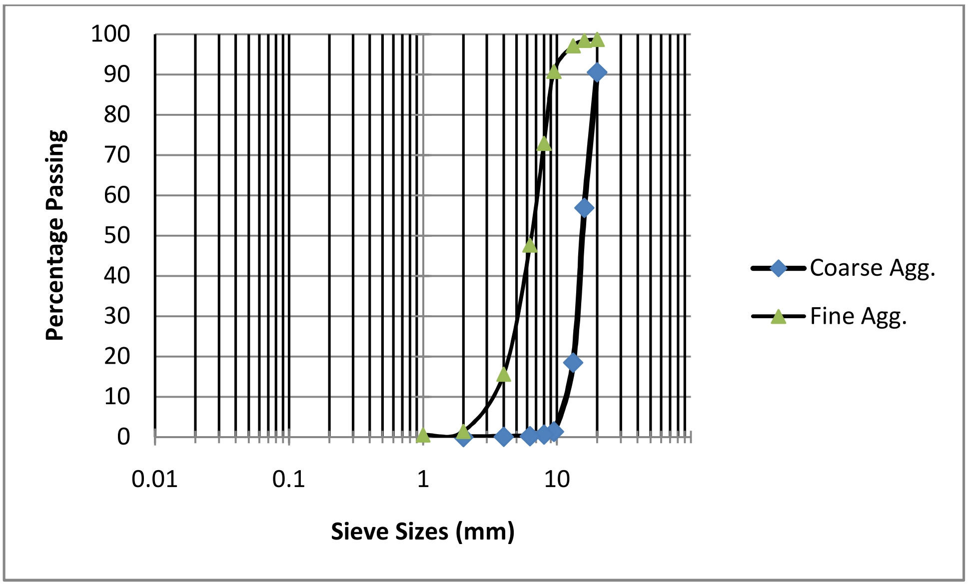

Figure 1: Grain size analysis for both fine and coarse aggregates used

4.2 Setting times

The result of the setting time of cement mixed with wastewater is presented in table 1 below, and it shows an increase in the initial and final setting time with an increase in the quantity of wastewater percentage. Setting which refers to the stiffening of the cement paste, a change from liquid to a rigid stage.ASTM C 150-94 prescribes a minimum time for the initial set of 45 minutes using Vicat apparatus. The European Standards (EN 450-1, 2005) require the initial setting time of fly ash paste should be at most 120 minutes longer than that of the reference without ash.

Table 1: Setting times of cement paste with wastewater.

Per cent Wastewater (%)	Initial Setting Time	Final Setting Time
0	00:52	03:30
25	02:19	05:45
50	03:10	06:32
75	04:20	07:05
100	04:48	08:56

Mechanism of setting using retarders works on the principle that sugar molecules combine with metals to form insoluble chemical complexes that coat the cement grains delaying the process of hydration. As it has been reported, quality of the mixing water influences the setting time than the workability. The work of Al-Ghusain and Terro (2003), showed that the type of mixing water did not affect the slump, as expected because slump is affected by water content not water quality.This also corresponds with the work of Cebeci and Saatci (1989), that wastewater retards the setting time.

4.3 Chemical Composition of the Wastewater

Table 2: Chemical constituents of the wastewater compared to WHO drinking H_2O quality standard

Parameter	**Waste Water (mg/L)**	**WHO Standard 2004 (mg/L)**	**Conformity**
PH	3.14	6.8 – 8.5	No
Chloride (Cl)	287.85	0 – 250	No
Carbonate (CO_3^2)	9.6	-	No
Bicarbonate (HCO_3^2)	400	0 – 1000	Yes
Phosphate (PO_4)	12.01	0 – 10	No
Iron (Fe)	4.96	0.04 – 0.13	No
Manganese (Mn)	1.073	0 – 0.2	No
Calcium (Ca)	29.37	0 – 200	Yes
Magnesium (Mg)	27.82	0.1 – 0.5	No
Sodium (Na)	43.62	0 – 200	Yes
Sulphate(SO_4)	84.36	0 – 250	No
Zinc (Zn)	1.109	0 – 31	Yes
Lead (Pb)	0.183	0 – 0.01	Yes
Turbidity (NTU)	56.21	0 – 5	Yes
Colour (TCU)	43.27	0 – 15	No
Test (TCU)	Objectionable	Unobjectionable	No
Odour (TCU)	Objectionable	Unobjectionable	No
Temperature (^{O}C)	33.01	Ambient	No
Hydrogen	9.62	-	No
sulphide(H_2S)	19.71	-	Yes
Potassium (K)	0.217	-	No

Cyanide (CN)	0.052	-	No
Nickel (Ni)	0.43	-	No
Nitrite (NO_2)	96.88	-	No
Nitrate (NO_3)	2.87	-	No
Flouride (F)	1.14	-	No
Copper (Cu)	4.2	-	No
Salinity (NaCl)	54.21	-	No
Total Hardness (CaCO_3)	227	-	No
Conductivity			

The result of the waste water analysis shows that most of the parameters tested or presence in the waste water were outside approved values of WHO standard for drinking water, these parameter includes, Cl^- , CO_3^-, PO_4^{2-}, Fe, Mg, Mn, NaCl, Cu^{2+} , $CaCO_3$, F, NO_2 , NO_3^{2+}, CN, Ni, H_2S , K^+, Na^{2+}. The pH of the wastewater was more acidic and outside the range of 6.8 – 8.5 WHO standard.

4.4 Volume change of concrete cubes

Concrete cubes casted and cured in both portable and wastewater were measured for volume change based on the formula presented in section 3.3, the result is as presented below.

Table 3: Seven (7) days volume change of concrete cured in portable H_2O

Portable/Waste H_2O mix ration (%)	**Cube weight (g)**	**Dimensions at cast (mm)**			**Dimension at crushing day (mm)**			**Volume change (%) $\frac{V_1 - V_0}{V_1} \times 100$**
		L	B	T	L	B	T	
25 : 75	8614	150	150	150	150	150	150.5	1.00
	8973	150	150	150	150	150	151.5	3.03
	9005	150	150	150	150.5	152	150	1.67
Average	8864	150	150	150	151.2	151	150.7	1.90
00 : 100	8828	150	150	150	152	151	152	3.37
	8892	150	150	150	151	151	152	2.69
	8835	150	150	150	151.5	153	150	3.02
Average	8851	150	150	150	151.5	151.7	151.3	3.03

Table 4: Seven (7) days volume change of concrete cured in waste H_2O

Portable/Waste H_2O mix ration (%)	**Cube weight(g) (g)**	**Dimensions at cast (mm)**			**Dimension at crushing day (mm)**			**Volume change (%) $\frac{V_1 - V_0}{V_1} \times 100$**
		L	B	T	L	B	T	
25 : 75	8828	150	150	150	150	152	151	2.69
	8835	150	150	150	150.5	150	152	1.67
	8892	150	150	150	150	150.5	151	1.00
Average	8851	150	150	150	150.5	150.8	151.3	1.79
00:100	8765	150	150	150	152	151	151.5	3.03
	8940	150	150	150	151	152	151	2.69
	8835	150	150	150	150	151	150.5	1.00
Average	8846	150	150	150	151	151.3	151	2.24

It was observed that there was an appreciable increase in volume for concrete cubes cured in portable water by 1.90% for 75% replacement of mixing water with wastewater and 3.03% for 100% replacement. Similarly, a percentage increase of 1.79% for 75% wastewater cured in wastewater and 2.24% for 100% wastewater with sugar wastewater as curing medium. An important observation made was the appearance of a substantial number of hair-like cracks all over the concrete cubes cured in both portable and wastewater and the phenomenon was not completely understood. However, if we may speculate, we can attribute that to the used of sugar wastewater. Further study especially at the micro-level is needed to fully understand the cause.

4.4 Compressive strength test

Compressive strength test of the concrete was determined by crushing the cubes at 7, 21, 28 and 90 days. The result of compressive strength is presented below for both curing in portable and waste water.

Table 5: Compressive strength of wastewater and portable water at percentage replacements

Age (Days)	**Compressive Strength (MPa)**			
	Portable Water Curing Medium		Wastewater Curing Medium	
	100% Mixing Water	75% Mixing Water	100% Mixing Water	75% Mixing Water

7	15.41	15.85	15.23	15.62
21	16.58	17.77	16.87	17.63
28	20.73	22.44	20.80	22.81
90	31.17	32.45	31.26	32.29

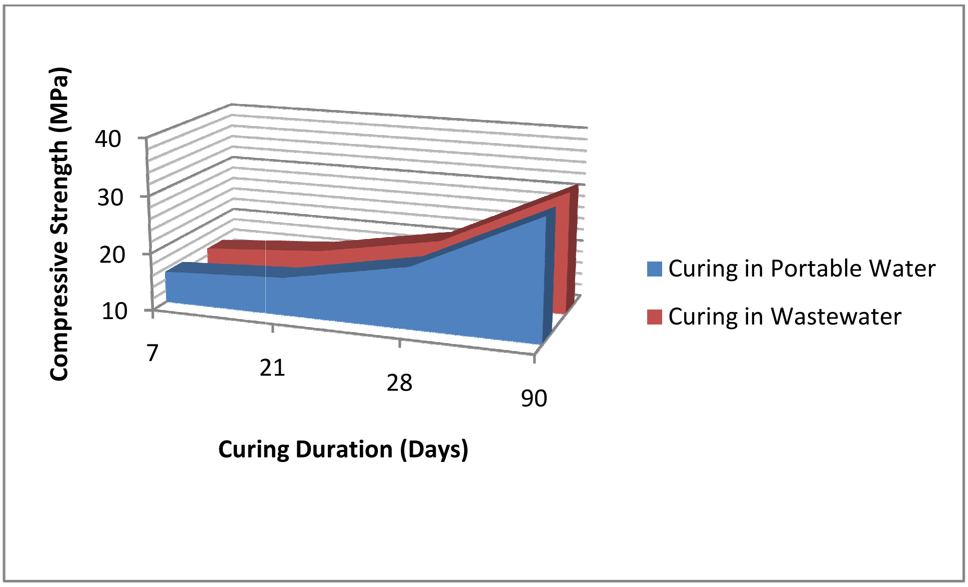

Fig. 1: One hundred (100) per cent mixing with wastewater

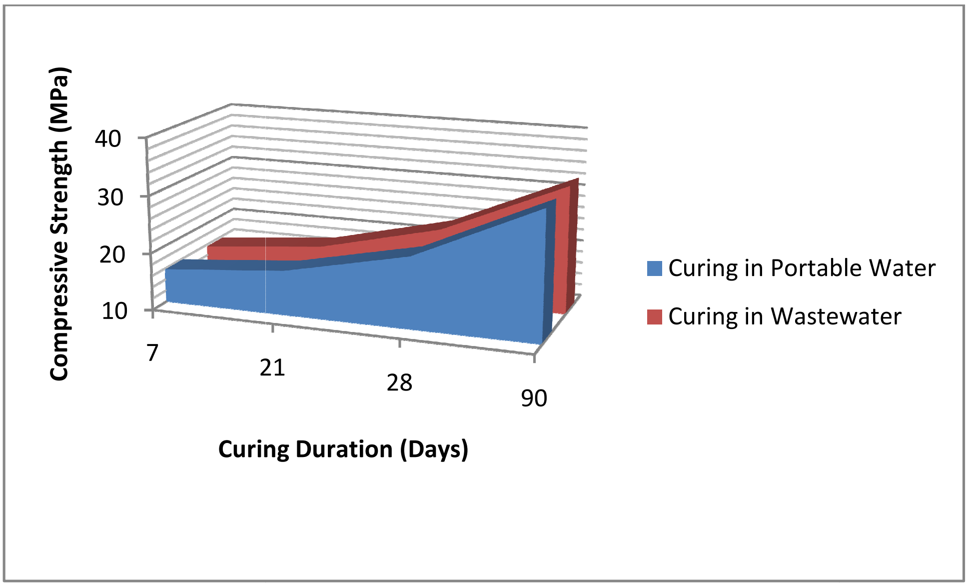

Fig. 2: Seventy five (75) per cent mixing with wastewater

The result of the compressive strength of wastewater as mixing water at 100% equaled that of the control sample from 21- 90 days. Both percentages of wastewater as mixing water started steadily up to 28 days, however, when the curing duration was extended to 90 days the strength of both cubes cured in different media reached between 31.17 – 32.45MPa. The lowest value for the 7 days strength was at least 73% of the 28 days strength cubes, while the highest value for the 7 days strength was 69% of the 28 days strength cubes. Increase in strength at prolong curing duration is in agreement with the work of Tay and Yip (1987) that for ages of 3 months and higher, compressive strengths of cubes made with 100% reclaimed wastewater and those with portable water were similar. Even though the concrete did not achieved the targeted strength of 25MPa at 28 days, but when the curing was extended it did achieve the strength. The delay in the early age strength could be attributed to the use of a sugar by-product, which according to Bloem (1959) when sugar is used as a controlled set retarder, the early strength of concrete is severely reduced. In this particular case, it was not intended as a retarder; rather the wastewater was used as a mixing water and curing medium.

CONCLUSION

The following conclusions can be drawn from an analysis of the use of wastewater from sugar factor as mixing water in concrete:

1. There is a substantial delay in the setting time of the cement mix using wastewater, the delay increase with an increase in the percentage of mixing wastewater.
2. Concentrations of metallic elements as measured from the wastewater and compared with that of portable water revealed that Zinc, Lead and Sodium were within the range of WHO standard and the wastewater had a pH that is acidic, outside the quoted standard.
3. Positive volume change as much as 3.03% was observed and measured using a digital meter.
4. Target strength at 28 days was not met, but it ranged from 83% - 91%, however, when the curing duration was extended to 90 days, the concrete cubes produced strength that surpassed the target strength.

ACKNOWLEDGEMENT

The authors would like to acknowledge the assistance rendered by Savannah Sugar Company Numan, Adamawa State a subsidiary of Dangote Group for facilitating the use of their plant wastewater for mixing.

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