Full Paper

EFFECTS OF NON-POTABLE WATER ON THE STRENGTHS OF CONCRETE

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ABSTRACT

Concrete is a composite material made from a mixture of cement, aggregates and water. This study presents the effects of non-potable water on the strengths of concrete. Tap, stream and partially polluted stream water samples were used in moulding the concrete. Optimum water-cement ratios (w/c) were determined for each of the water samples. Concrete specimens were prepared using nominal mix proportion of 1:2:4 and optimum water-cement ratio (w/c) of the known water quality. The concrete specimens were cured by total immersion in water. Compressive and flexural strengths of the concrete were determined using standard methods. The results showed that the optimum w/c were 0.65, 0.55 and 0.65 for concrete made with tap water (A), non-polluted stream water (B) and polluted stream water (C) respectively. At 28-day curing, their compressive strengths were 18.3, 17.13 and 18.00 N/mm^2 while at 56-day curing the compressive strengths were 25.60, 20.87 and 22.56 N/mm^2 respectively. The pHs of the water samples (A, B, C) were 6.7, 9.5 and 6.7 respectively. The concrete made with water (A) gave the highest compressive and flexural strengths while the concrete made with water (B) gave the least strengths. It was concluded that the two stream waters (B and C) are acceptable for concrete production but concrete made with water (C) gave better results. The stream water polluted by partially treated effluent from biological treatment plant does not have serious adverse effect on the strengths of concrete.

Keywords: *Concrete, strength, stream water, suspended solid, treated wastewater.*

1. INTRODUCTION

Concrete is a versatile construction material. It can be easily produced and within short time hardens and develops considerable strength to sustain large loads. Water is an essential ingredient of concrete production as it activates the exothermic chemical reaction with cement. The reaction usually results in the formation of strength giving cement gel in which the quantity and quality of water used are important in this regard. Gross shortage of potable water for domestic use has necessitated the search for alternative sources of water for concreting. This is a common practice almost everywhere, especially in developing countries, like Nigeria, where the cost of water treatment is prohibitive and potable water is almost not available. In addition to the scarcity of potable water for mixing concrete, indiscriminate disposal of domestic and industrial wastes into rivers and streams is making availability of adequate water for concreting more critical. In fact, the substitution of potable water with water from another source for concrete production has many associated problems and risks that must be removed in order to ensure adequate quality and performance of concrete. The study of effects of impurities in water on concrete properties is attracting interest of many researchers because of indispensable nature of concrete to infrastructural development

Impurities (liquid and solid types) can adversely affect performance of concrete. In the work of Oktar *et al.* (1996), impurities in mixing water has been implicated to have been responsible for efflorescence, staining, corrosion of reinforcement, volume instability and reduced durability of concrete. Akinkurolere *et al.* (2007) investigated the effect of salt water on compressive strength of concrete for a constant water-cement ratio (w/c) over different periods of curing with four different possibilities of casting and curing. These are casting and curing with fresh water, casting and curing with salt water, casting with fresh water and curing with salt water and casting with salt water and curing with fresh water. They found that, concrete cast and cured with salt water had drastic increase in 28-day compressive strength. However, use of adequate water-cement ratio (w/c) is important for strength development especially in hot climate, as adequate moisture needed to be available during the first few hours of placing the concrete to aid the hydration process (Ait-Aider *et al.* 2007).

It should be noted that BS EN 1008 (2002) permits the use of natural water and industrial waste water for making concrete but recommends that appropriate tests be carried out to determine their suitability. However, in order not to compromise strengths and durability, limits are usually set for the amount of chloride, sulphate, alkalis and suspended solids in water for concrete production. Also, BS EN 1008 (2002) recommends that the compressive strength of concrete made with water from source other than potable water should not be less than 90% of that made with potable water. Consequently, many authors (Cebeci and Saatci, 1989; Lee et al., 2001; Tahaet al. 2010) have reported on the use of alternative water sources to make concrete. Cebeci and Saatci (1989) reported that untreated domestic sewage is not recommended for mortar and concrete production as it increases the initial setting time and entrained air as well as reduces strength. The effects of all these are detrimental to durability of concrete. The authors added that the characteristics of treated sewage need to be determined for conformity to standards before use for mortar and concrete production. The use of wash water, underground water, ground water and production water for concrete production have been studied by some authors (Su et al. 2007; Al-

Harthyet al., 2005). They found concrete made with wash water or underground water to give compressive strength that was as good as that made with tap water. Al-Harthy et al. (2005) reported that concrete made with groundwater and production water gave lower compressive strength than that made with tap water but the strength was within the acceptable range for flowable fill mixes at 28-day. Flowable fill is a low strength, self-compacting material usually for backfill purposes. Similarly, the use of production and brackish water did not have serious adverse effects on setting time and strength of mortar and concrete (Tahaet al., 2010). On the other hand, Ayininuola (2009) investigated the effects of Ogunpa (Ibadan) stream water on the compressive strength of concrete and found it to be unsuitable for concrete production due to its high level of pollution. Also, El-Nawawy and Ahmad (1991) reported that use of treated effluent alone is unsuitable for concrete production but found the use of up to 20% of treated effluent with potable water gives concrete of acceptable strength.

These show that not all non-potable waters are suitable for concrete production. Therefore, there is need to document results of research on the effects of non-potable water (stream water, partially polluted water or treated sewage effluents) around us on the strengths of concrete before use. By this, correct strength would have been used in the design of concrete structures and this will prevent collapse of such structures that may be due to inadequate strength. Also, this will allow us to identify suitable alternative sources of water for concrete production in order to reduce the need for potable water in sandcrete and concrete production in Nigeria. This is important because currently potable water supply per capita in the country is below the World Health Organisation (WHO) limit of 100 litres per capital per day (lcd) (Oke, 2010).

The focus of this study is to investigate the effects of water from selected sources (of know quality) on the concrete strengths. The study is initiated based on the field observations that many contractors are using these alternative sources of water under study for concrete production without having adequate information on their quality characteristics. It is also noted that treated effluent from biological plant is commonly used for irrigation purposes, but information on its usage for making and curing concrete is limited in Nigeria. Therefore, the results of this study would be a useful guide to potential contractors and house owners in choosing better alternative source(s) of water for mixing concrete. It will also reduce their dependence on the scarce potable water supply for concrete production which has potential for sustainable infrastructural development in concrete structures.

2. MATERIALS AND METHOD

The cement used was Ordinary Portland Cement (OPC) of brand name Elephant and produced by Lafarge/WAPCO Cement Company of Nigeria. It was purchased from a main distributor in Ile-Ife, Osun State. The chemical composition of the cement was determined by X-ray fluorescence (XRF) analysis. The fine aggregate used was obtained from a location beside the new site of the Natural History Museum at Obafemi Awolowo University (OAU), Ile-Ife, Osun State. The particle size distribution curve of the aggregate was determined in accordance with BS 812-103-1 (1985) procedure. Coarse aggregate of maximum size 19 mm was used in this study and was obtained from a construction site at the OAU campus, Ile-Ife. Three sources of water for this study were from Ile-Ife area, Osun State. The tap water, A, as control was obtained from OAU campus; 'unpolluted' stream water, B, was taken under a bridge (at the maintenance junction along Road 1, OAU main gate, Ile-Ife) at one kilometer downstream the dam and stream water, C, was taken under a bridge (one kilometer away from OAU campus main gate along Ife-Ede Road) and at 1.5 km downstream from point of effluent discharge into the stream from an educational institutional oxidation pond. The stream waters were collected during the dry season when pollution and suspended solids of surface water are usually high.

Water samples collected from the three sources were analysed using standard methods (APHA, 1998) to determine the pH value, chloride, sulphate and suspended solids. The concrete cubes were made in accordance with procedure in BS 1881; Part 108 (1983). Batching by weight was used in the concrete production of nominal mix of 1:2:4 at optimum water-cement ratios (w/c) of 0.65, 0.55 and 0.65 for waters (A), (B) and (C) respectively. Optimum w/c for each of the water was used to ensure that the concrete mixes were properly hydrated. The use of adequate w/c is a means of ensuring good curing practice as enough moisture needed to be available during the first few hours of placing the concrete especially in hot climate (Ait-Aidut et al., 2007). Due to small quantity of concrete per batch, manual mixing of the constituents on hard non-absorbent surface was adopted and the concrete cubes produced using steel moulds were of size 150 mm × 150 mm×150 mm. The filling of the mould in each case was in three layers and were manually compacted using 25 mm diameter steel rod at minimum strokes of 35 per layer. The cubes were demoulded after 24 hours and cured in the three water samples (A, B and C) for a period of 3, 7, 14, 21, 28, and 56 days under laboratory conditions. Concrete cube specimens were tested to determine the compressive strength at each curing age. The average crushing loads for three cubes was recorded in each case. Also, concrete beams were cast using steel mould of size 150 mm ×150 mm×500 mm. The mould was removed after 24 hours when the concrete had set. Thereafter, the beams were cured separately in the water samples for 28 and 56 days. The standard test method described by ASTM C 78 was followed using symmetrical two-point loading method. According to Shetty (2007) the two-point loading method gives lower yield value of modulus of rupture (MOR) than the central loading method, this gives conservative but safe design results. The load that caused failure of each beam was recorded. The flexural strength in terms of MOR was determined for the unreinforced beam specimens and the load carrying capacity determined for the reinforced concrete beam specimens. Average of three readings was recorded in each case.

3. RESULTS AND DISCUSSIONS

3.1. Properties of Cement and Fine Aggregate

Table 1 shows the chemical properties of the cement used in this study as determined from the X-ray fluorescence techniques. The chemical composition of the cement is within the acceptable range as specified by BS EN 196-2 (1995). The particle size distribution curve of the sieve analysis carried out on the fine aggregate is shown in Figure 1. The value of the uniformity coefficient (U_c) was 4.73 and that of coefficient of curvature (C_c) was 1.15 (not much different from 1.0). These indicate that the fine aggregate is well graded. Also, as too much fines (silt and clay) content in aggregate has adverse effects on strength of concrete, the percentage of fines was found to be 5.12% and 2.68% for silt and clay respectively. These were less than 10%, which makes the aggregate acceptable for concrete.

Table 1: Chemical composition of the cement

Major oxides	Chemical composition (%)								LOI
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	*Na_2O	K_2O	SO_3	
Cement used	20.8	3.1	2.5	64.5	1.7	0.23	0.85	2.5	3.4
BS EN 196-2 (1995) reference	18-24	2.6-8.0	1.5-7.0	61-69	0.5-4.0	-	0.2-1.0	0.2- 4.0	

*The Code considers the XRF method to determine the Na_2O content as inappropriate because of inadequate precision obtainable at present.

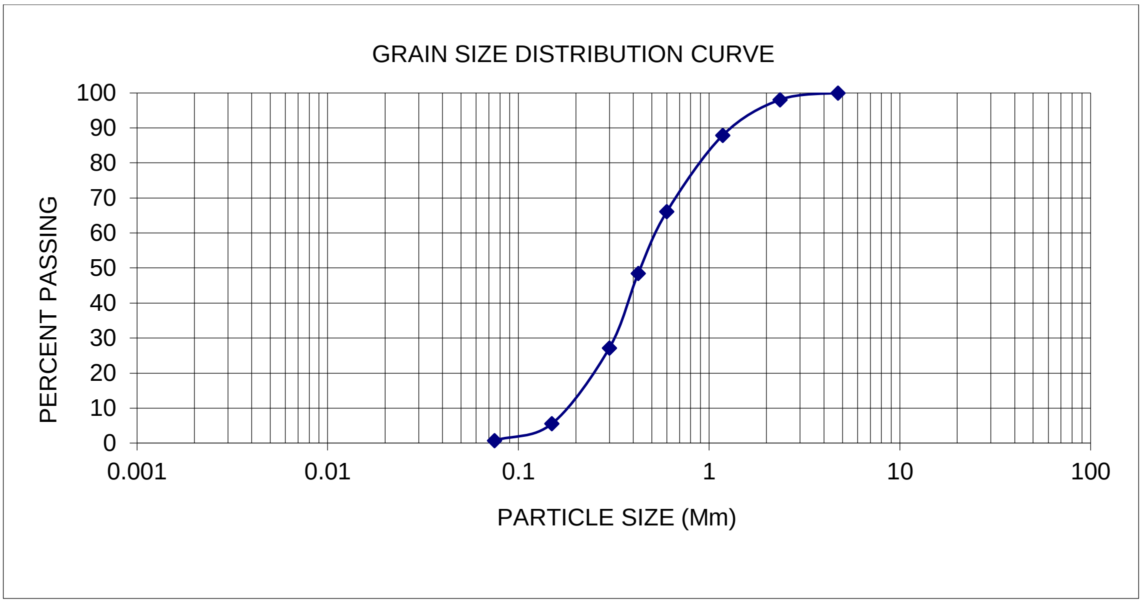

Figure 1: Particle size distribution curve of the fine aggregate.

Table 2: Comparison between qualities of water samples with the standard

Sample	Alkalinity (mg/L)	Chloride (mg/L)	Sulphate (mg/L)	Total solids (mg/L)	Total suspended solid (mg/L)	pH
A	63	16	82.50	300	60	6.7
B	12	17	111.15	760	170	9.5
C	48	18	40.65	240	160	6.7
SON	150	250	100	500	-	6.5 - 8.5

3.2. Water Quality Analysis

Physical observation of the two stream waters (B) and (C) showed that they had no offensive odour, no floating organic matter; but stream water (B) was a little bit turbid while stream water (C) was brackish in colour. The results of the analysis of water samples (A, B and C) which were compared with the standards specified by Standard Organization of Nigeria (SON, 2007) for drinking water in Nigeria are shown in Table 2. It is seen that the alkalinity and chloride contents of all the three water samples were below the maximum specified by the Standards (150 mg/L and 250 mg/L respectively). Similar trend is observed in sulphate content except that water (B) contained sulphate which is about 12% higher than specified (100 mg/L). It is suspected that the high content of sulphate in water (B) may be due to the discharge of the alum residues into the downstream of Opa River from which the water was taken. The pH value of stream waters (A and C) was 6.7 each which is in the range of 6.5 – 8.5 specified by SON whereas the pH value of stream water (B) was highest with a value of 9.5.

It is equally observed that stream water (B) had the highest total solids (760 mg/L) which is higher than the acceptable standard as well as total suspended solids (170 mg/L). This could also be due to the sludge from the waterworks being disposed into the river.

3.3. Effects of the Non-Potable Waters on Workability, Compressive and Flexural Strengths of Concrete

The slump values of the fresh concrete made with waters (A, B and C) at optimum water-cement ratio (w/c) were 50, 40 and 55 mm respectively. These show that concrete made with water (C) has the highest slump and was the most workable at optimum w/c. The slump value of the concrete made with stream water (B) was lower than that of stream water (C); this might be due to the quantity of total solids as shown in Table 2. Also, the effect of the three water samples on the compressive strength of the concrete made from and cured in them for 3, 7, 14, 21, 28 and 56 days was studied. The relationship between the curing ages and compressive strength for each water source is shown in Figure 2. The different effect of the waters on the compressive strength can be observed when they were used to mix and cure concrete. Compressive strength of concrete made with each of the water samples had positive logarithmic correlation (R^2 = 0.970, R^2 = 0.997 and R^2 = 0.989 for waters A, B and C respectively) with the increase in age.

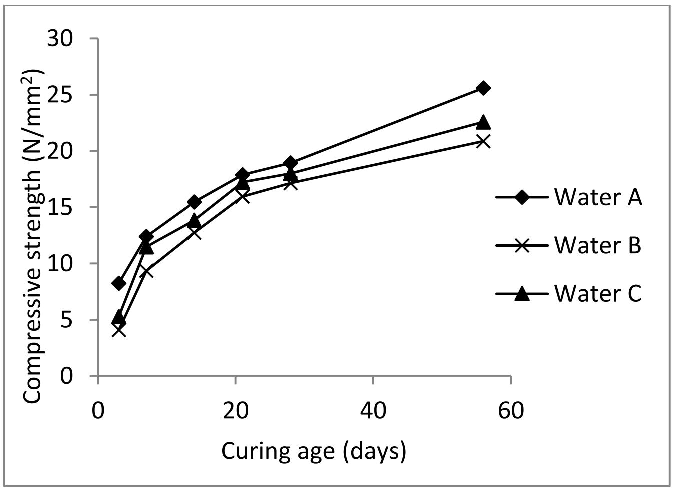

Figure 2: Compressive strength of concrete at different ages

It can also be observed from Table 3 that at 28-day curing, the highest compressive strength (18.93 N/mm^2) was obtained when tap water (A) was used while the concrete made with water (B) had the least compressive strength (17.13 N/mm^2). At 56-day curing the compressive strength was 25.60, 20.87 and 22.56 N/mm^{2}for waters A, B and C respectively. Also, at 28-day the compressive strength of concrete made with water (B) was 90% of that made with water (A) while that of water (C) was 95% of that of water (A). However, at 56-day these were 81% and 88% respectively. These show that the concrete made with tap water (A) developed strength at higher rate than that made with waters B and C respectively.

Table 3: Compressive and flexural strengths of the concrete at 28-day and 56-day curing

Water sample	Water-cement ratio (w/c)	Compressive strength (N/mm^2)		Flexural strength (N/mm^2)	
		28-day	56-day	28-day	56-day
A	0.65	18.93	25.60	2.14	2.89
B	0.55	17.13	20.87	1.40	1.70
C	0.65	18.00	22.56	1.70	2.14

Noting from Table 3 that the compressive strength of concrete made with waters (B and C) at 28-day curing were 90 and 95% respectively of that made with potable water, the BS EN 1008 (2002) recommendations of 90% minimum for the acceptance of such water in concrete production was satisfied. However, the same mix proportion was used in this study; the strength results in Table 3 for concrete made with stream waters (B and C) could be improved if richer concrete mix was used. Therefore, it is recommended that the non-potable waters (B and C) considered in this study can be used for concrete making provided that they do not pose threat to the health of the handler(s).The advantage of the results of this study is that the need for potable water for concrete will be reduced and potable water would be available for domestic uses thereby reducing the prevalence of communicable diseases in our society.

Furthermore, from Table 3 the flexural strength as percentage of the compressive strength of concrete made with waters (A, B and C) at 28-day curing were 11.30, 8.17 and 9.44%, while at 56-day curing it is 11.29, 8.15 and 9.49% respectively. It had been established (Ghosh et al., 1972) that subject to maximum aggregate size, the flexural strength of concrete is about 10% of its compressive strength. In this case only the concrete made with potable water (A) met this criterion and marginally that of stream water C. However, in reinforced concrete structures design, the flexural (tensile) strength of concrete is not usually considered as the steel is assumed to be carrying all the tensile stress, but it is useful in the design of rigid pavement.

3.4. Effect of Non-potable Water on the Load Capacity of Reinforced Concrete Beams

The load carrying capacity at different steel ratio of the cured concrete beams made from the water samples was presented in Table 4. It was observed that for all the mixes, the failure load increased as the percentage of reinforcement increases. Also, similar trend in the compressive strength is observed here in which concrete made with water A gave best result and that made with water C had better result than that made with water B. For instance at 28-day, the percentage increase in the failure load of concrete made with water (C) over that made with water B at steel ratios 1.0, 1.5, 2.0, 2.5% and 3.0 were 18.7, 9.3, 5.2, 12.5 and 23.3% respectively, while at 56-day they were 21.6, 11.9, 8.6, 16.0 and 26.4%, respectively.

Table 4: Load carrying capacity of the beams at different steel ratios

Steel reinforcement percentage (%)		1.0	1.5	2.0	2.5	3.0
Water sample	Curing age (day)	Maximum failure load (kN)				
A	28	22.00	27.20	34.20	43.60	52.50
	56	29.70	36.72	46.18	58.86	70.88
B	28	15.00	20.50	26.80	30.40	35.20
	56	18.30	25.02	32.70	37.08	42.94
C	28	17.80	22.40	28.20	34.20	43.40
	56	22.26	28.00	35.50	43.00	54.26

4. CONCLUSION

This study examined the suitability of non-potable water for making concrete and concludes that:

Concrete made with the two stream waters (B and C) had lower strengths (compressive and flexural) and lower load carrying capacity when reinforced, compared to that made with tap water (A). However, based on the strength criterion, they were found suitable for use to make concrete as their compressive strength was within the permissible 90% of that made with potable water (A); but concrete made with water (C) performed better.

All the waters contained varied quantities of dissolved chemicals and suspended solids. However, water (C) polluted by the partially treated effluent from a biological treatment plant had all quality parameters considered to be within specified standards and did not have serious adverse effect on the strengths of concrete. This showed that water for concrete production does not necessarily have to be safe for drinking; a way of reducing the need for scarce potable water for concrete production.

There is need to determine necessary quality characteristics of alternative source of water other than potable water before use for concrete production in order not to compromise strengths and durability. Also, further studies are needed to ascertain the long term effects of these stream waters (B and C) on the deterioration of concrete due to carbonation and corrosion respectively.

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