Effect Of Mavoko Water Quality On Concrete Compressive Strength, Le Chatelier Expansion And Setting Time

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ABSTRACT

Over time, cases of collapsing buildings have increased. Mavoko water from Ukambani region of Kenya is prone to a combination of several salts attributed to decreasing concrete stability. This study aimed at analyzing the extent by which this water affects concrete compressive strength, soundness and setting time. Ordinary Cement (OPC) and Pozzolanic Portland Cement (PPC) containing 20% filler (PPC-1) and 30% filler (PPC-2) were moulded using different water samples and their setting time, strength and soundness monitored. The results proved Mavoko water retarded concrete compressive strengths, increased soundness and fluctuated setting times. Concrete expansion increased by 2.5mm. This water had large margins of up to 54 ± 2 minutes between early and late setting times recorded. The water gave retarded values for both early (30.51MPa) and late (40.12MPa) compressive strengths. Concrete containing Mavoko water gave outlier late compressive strengths for both cement brands ($p \leq 0.05$, $n= 14$). This study highlighted the need for stricter regulations to be put on this water used in major constructions.

Key words: Concrete, Mavoko water, soundness, setting-time, concrete strength

1. INTRODUCTION

There have been widespread cases of buildings collapsing, mostly in Nairobi County, upper parts of Machakos County and Lower Eastern region as well as The Upper Coastal region of Kenya (Nation news, 2016) These regions are known to have salty water and their local governments and residents are forced to look for alternative means to find drinking water. Concrete is the most widely used building material (Allen and Iano, 2004) in these regions. Apart from the composition of cement used to make concrete, the kind of water used for hydration and curing of concrete is very critical in the quality and durability of the structures made. The principal considerations on the quality of mixing water are related to performance in fresh as well as hardened state (Soo, 2010). Upon mixing with water, cement hydration take place in two key steps that define the chemical and physical output of concrete; the aluminate phase that define its early strength (<7 days) and the silicatious phase that define its late strength (>28 days) (Olugbenga, 2014).

The quality of the water plays an important role in the preparation of concrete. Impurities in water may interfere with the hydration and setting of the cement. These adversely affect the strength and durability of the concrete (Rayaprolu, 2013). The chemical constituents present in water may actively participate in the chemical reactions and thus affect the setting, hardening and strength development of concrete (Iseker and Radlinska, 2010). This eventually affect the compressive strength of the concrete in question. Other factors such as water pH and temperature can as well affect concrete compressive strength though by minute values. Heavy metals such as Cu, Zn, Pb, also cause a retardation of the early hydration and strength development of cement mortar

(Venkatesan and Swaminathan, 2009). Their metals sulphates delay setting and early strength development (Torres-Alvarado and Ian, 2010).

Limits are specified for combining mineral water with their elements such as total alkalis, chloride sulfate etc. Pure mineral water breaks down the set concrete, by dissolving the lime and alumina from cement (Olugbenga, 2014). This activity of draining is continuous and thereafter decelerates until mineral water is able to pass consistently through the mass of the concrete. Water which is acid due to the presences of uncombined CO_2, from organic or inorganic acids, are more competitive in their activity. The degree and rate of attack improves as the acidity improves (Babcock *et al.*, 2008). Water containing sugars is prone to carbonation, which reduces the permeability and porosity of concrete (Castro, 2010). Water containing sugars, sulphates and chlorides is acidic in nature (Venkatesan and Swaminathan, 2009).

In general, acid solutions which strike cement mortars or concrete by dissolving part of the cement do not cause any expansion, but progressively weaken the material by removal of cementing constituents forming soft and mushy mass. Any water with pH value less than 12.5 may be aggressive in their action because of a reduction of the alkalinity of the pore liquid would, eventually lead to removal of the concrete (Torres-Alvarado and Ian, 2010). The pH of the solution directly controls the kinetics of hydration expected. Increased acidity reduces the hydration rate and lead to decreased compressive strength, porosity and fragility (Fereshte *et al.*, 2015).

Mavoko Water and Sewerage Company (MAVWASCO) is the primary source of water for residents around Lower Eastern and Upper Coastal regions of Kenya and derive its water from River Athi. The serenity through which River Athi flows through is densely populated with industries. Effluent wastewater is thus often channeled into the river at various points. With growing unrest over the durability of most buildings in the area, it is evidently justifiable to analyze MAVWASCO water used for concrete making. Parallel analysis using sulphate, chloride and sewer water, all presumed to be in MAVWASCO water were also done using Ordinary Portland Cement (OPC), which has no fillers and Pozzolanic Portland Cement (PPC) brands containing 20% and 30% of fillers (pozzolana).

2. MATERIALS AND METHODS

2.1 EXPERIMENTAL PROGRAM

Concrete moulds were prepared using different water samples for analysis in the variation of compressive strength, soundness and setting time. Both Ordinary Portland Cement (OPC) and Pozzolanic Portland Cement (PPC) samples were used and a sample size of 1kg from the 5 sampling points above were maintained. PPC-1 had 20% pozzolana filler material while PPC-2 had 30% pozzolana filler material. 150ppm solutions of sulphates and chlorides and sewer water, all presumed to be subsets of Mavoko tap water were analyzed against distilled water as a control. The research was done at Mombasa Cement

Limited, Athi River (1.4577^{0}S, 36.9785^{0}E) and a representative cement mixture from 5 sampling points (mill, despatch point, cement silo, rotor packer and from a cement bag) were homogenized for use.

Chemical analysis was done for characterization of the cement using distilled water while physical analysis was conducted using different test water samples.

2.2 MATERIALS

Access to a concrete compressor machine (automatic) (ELE 1881-1-10233), 12 gang moulds, 2 bowels, 2 spreaders, a serving spoon, 2 jolting tables, an automatic programmable concrete mixer (ELE 1676), An analytical balance, 12 18" by 20" clear glasses, fully equipped curing room with humidity cabinet, wet and dry bulb hygrometers, relative thermometers and curing chambers with access to clean water, fully equipped vicat apparatus, Le Chatelier apparatus with pointers, functioning boiler with a thermometer, trowel, and a 1000ml measuring cylinder. The chemical composition of the homogenized cements are as shown in table 1 below.

Table 1: Chemical analysis results for all types of cement using distilled water

TEST/ BRAND	LOI	IR	SO_3	Cl^-	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
OPC (No Filler)	1.11	1.45	2.19	0.011	21.39	5.40	3.79	62.87	1.22
PPC-1 (20% Filler)	2.15	20.86	2.15	0.012	30.20	8.78	4.42	49.70	1.28
PPC-2 (30% Filler)	2.18	21.74	2.10	0.014	31.62	8.67	4.71	47.88	1.24

2.3 DETERMINATION OF CONCRETE PARAMETERS BY STANDARD USP PROCEDURES

2.3.1 SETTING TIME (ASTM, 2012)

Onto a clean steel plate, 400g of cement was evenly spread out. The sample was cooled for 30 minutes at below 20^{0}C. About 130ml distilled water was then added and mixed for 4 minutes by using a trowel to give a paste and was immediately transferred into the mould laying on the steel plate. Using a hand trowel, the excess paste was put into a mould. The top was smoothened then levelled before positioning below the 'Initial set needle' with a 1mm cross sectional area. The needle was gently covered to submerge the paste before releasing into the paste. The procedures were severally repeated in 10 minutes intervals at different mould positions until a stiff mould was obtained. This stiffness was confirmed by not allowing the needle to penetrate for more than 5mm. The difference in time between water addition and initial setting was noted. The needle was then replaced with a square 1mm needle with an annular attachment and the probe allowed to come in contact with the paste surface in 15-minute intervals. An impression made on the paste surface was taken as the final set.

2.3.2 SOUNDNESS TEST (LE CHATELIER EXPANSION) (ASTM, 2012)

An expansion mould was filled with cement paste and the open end closed by tying with a cotton wool. The paste was smoothened and levelled before covering with another piece of glass. It was then immersed in water. A mass of 50g was put on top to compact it. The mould was removed after 24 hours and the distance between

the pointers noted before re-immersing in water again. The water was heated to boil for one and a half hours then cooled. The distance between the pointers was remeasured again and taken to represent cement soundness.

2.3.3 COMPRESSIVE STRENGTH TEST (ASTM, 2012)

Cement, sand and coarse aggregate was mixed in the ratio 1:2:4 in a mixing bowl. Water (10% of the mass) was added before mixing to form a homogenous mortar. A scoop and trowel were used to turn the bowl 3-4 times. 12 pieces of clean 150 x 150 x 150mm cube were moulded and set on the working bench. The bench bolts were tightly closed and the mould bases greased using oil. Very quickly, the concrete mixture was scooped and filled halfway in the moulds early made. The mixture was then stroked 60 times using a tamping bar. More concrete mixture was added to fill the moulds. Stroking was again redone for 60 times.

The mould was then vibrated on a jolting machine for 2 minutes. The cubes were then covered with an impervious sheet to prevent evaporation and to cure at ambient room conditions for 1 day. After the first day, they were removed from the curing chamber and marked for 1 day, 2 days, 7 days or 28 days. The weights and Compression strengths of the cubes were taken after their respective curing time. A compressing machine was used to measure compressive strength.

3. RESULTS AND DISCUSSION

3.1 VARIATION OF CONCRETE SOUNDNESS (LE CHATELIER EXPANSION) WITH WATER SAMPLES

Mavoko tap water registered a higher margin of LC-expansion for all types of cement as compared to the rest ($p \leq 0.05$, $n= 14$). Combination of alkalis in pozzolana filler material and the salts in Mavoko water increased concrete soundness values by appreciable margins. This can also be attributed to the amount of free oxides of Calcium and Magnesium (Magnesia and lime) present in tap water (Nawaz *et al.*, 2016). The concrete expansion values in OPC cement were lower than all the others. The Mavoko water sample however still had high LC expansion values of up to 1.5mm using OPC cement. Carboxylic acids present in dirty water affect concrete soundness by up to 15% (Wu *et al.*, 2015). Only sulphate water in the PPC-2 cement had a larger expansion (2.5mm) compared to Mavoko water LC (2.0mm). PPC-2 cement had high levels of filler material containing alkalis and other salts which contribute to the high LC expansion values. The expansion of sewer water in pozzolana cement was suppressed with minimum values of 0.0 and 0.5mm observed. There was no concise trend in increment or decline of concrete expansion for the chloride water samples. The variations of the concrete soundness obtained are summarized in figure 1 below.

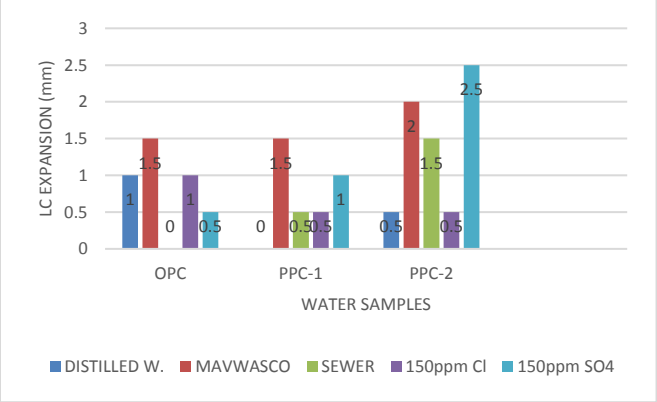
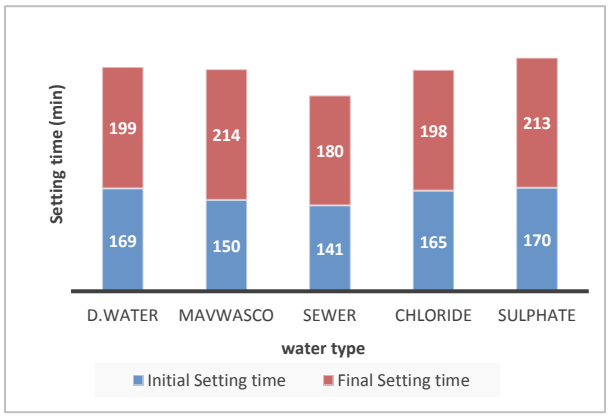


Figure 1; Variation of cement expansion with water analytes

Impure water has more salts which affect the temperature of the water and consequently concrete soundness (Cagnon *et al.*, 2016). PPC and all Mavoko water samples thus registered a higher expansion value for all types of water due to increased levels of this alkalis in pozzolana, which is absent in OPC.

3.2 CONCRETE SETTING TIME VARIATION WITH WATER SAMPLES

Initial setting of cement is the process of setting, after which cracks that appear do not reunite and usually average 150 minutes (Pavementinteractive, 2018). Final setting is that when it has occurred, sufficient strength and hardness is attained and should be less than 240 minutes (Ylmén *et al.*, 2009). Initial set is related to a quick increase in temperature and final set to the highest temperature. Setting time decreases with rise in temperature. While sewer water samples gave retarded setting times (both early and late), Mavoko, chloride and sulphate solutions all gave higher setting times. Sulphate solution gave the highest initial and final setting times (207 and 170 minutes) respectively due to presence of sulphate ions that help decrease hydration temperature. Figures 2 and 3 below illustrate how the setting times of the water samples used varied.



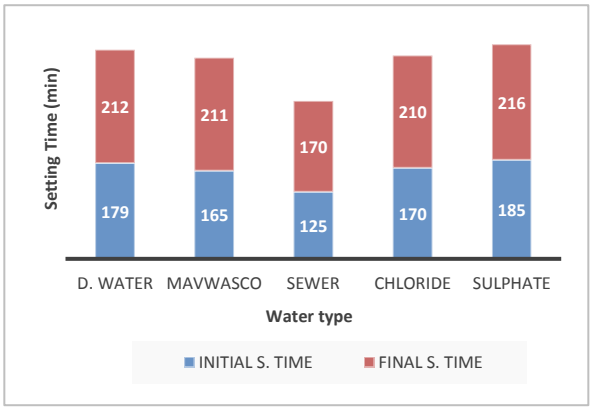


Figure 2 &3; Variation of cement setting time with water analytes for PPC-1 (right) and PPC-2 (left)

All samples with sewer water had retarded initial and final setting times i.e 132±9 and 173±7 respectively. It is worth noting that Mavoko water sample had the second lowest initial setting times (after sewer water) and the highest average final setting time 207±9 minutes. Variations in the initial and final setting times were in

the order of Mavoko water (54 ± 2 *minutes*), sewer water (41 ± 1 *minutes*), sulfate water (37 ± 3 *minutes*), chloride water (32 ± 1 *minutes*) and distilled water (30 ± 0 *minutes*). This implies that using Mavoko water for curing affected the duration between initial and final setting of concrete. This phenomenon can potentially affect the workability of concrete resulting to poor architecture of buildings and weak structures (Guo *et al.*, 2014). More gypsum is thus required for cement whose concrete is to be cured using Mavoko water, increasing cement cost of production. Figure 4 below illustrates the variations in setting time with different types of water used for curing.

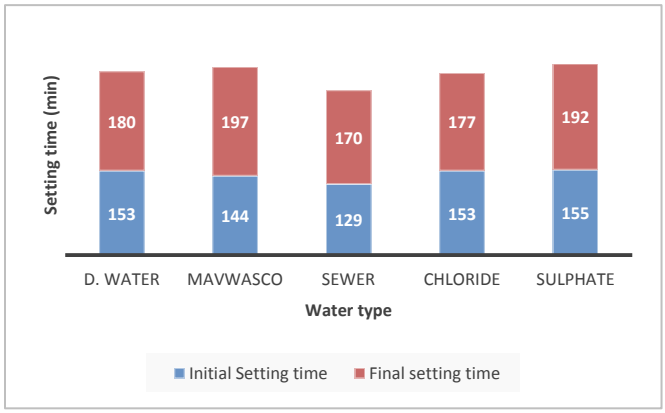


Figure 4; Variation of cement setting time with water analytes for OPC cement

The setting time of the 3 brands increase with increasing pozzolana level, both for Initial and Final setting times. OPC cement has a larger setting time as compared to PPC cement. This is because increasing CaO lower the rate of concrete hydration for both aluminate and silicate phases (Suryakanta, 2016). Thus, PPC-2 registered the largest setting time while OPC registered the least, for all samples except sewer water sample for equal amounts of gypsum used (4%). The effective composition of gypsum in OPC is higher because in OPC, only two compounds are involved in concrete formation ie clinker and gypsum. The effect of gypsum is therefore reduced in PPC where an additional compound (pozzolana) is involved even when both OPC and PPC use the same percentage of gypsum. Gypsum is known to retard setting time by hindering hydration of the silica in water to form C-S-H (Arun, 2019). Sulphate water registered higher setting time values due to increase in sulphates which hinder hydration of concrete.

3.3 COMPRESSIVE STRENGTH VARIATION WITH WATER SAMPLES

Generally, concrete compressive strength increases with curing of the concrete. The strength registered between the 2nd day of concrete beam casting and the 7th day indicates the early strength of the concrete. OPC and PPC cement have different concrete strengths as a result of varying effective CaO present. It is thus only feasible to discuss the effects of different water on their strengths separately. Figures 5 and 6 below illustrate the effects of varying water samples on PPC concrete strength.

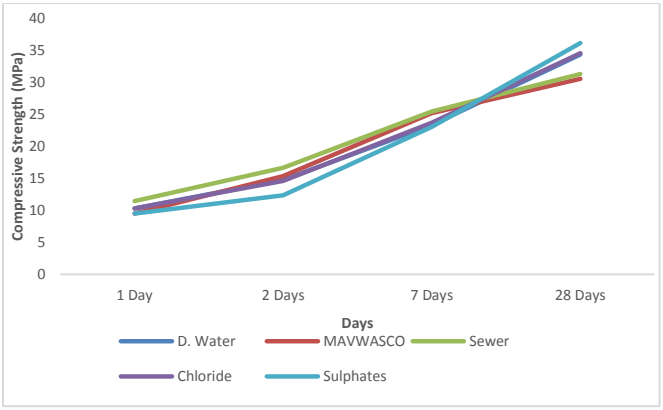


Figure 5; Variation of PPC-2 concrete strength with water samples used for curing

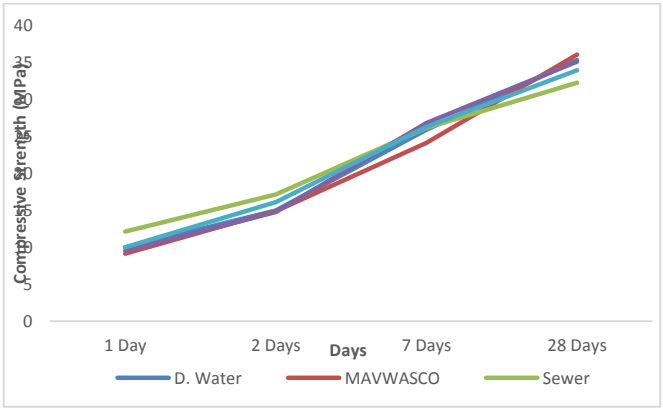


Figure 6; Variation of concrete strength with different water samples using PPC-1 cement

Early strength of concrete is as a result of high silica content (Kim *et al.*, 2019). This explains why Pozzolanic cement always has a higher value of early strength than Ordinary cement.

The order of late concrete strengths for PPC-2 containing 30% pozzolana filler was distilled water (35.38MPa), chloride water (35.17MPa), sulphate water (33.99MPa), Mavoko water (33.10MPa) and sewer water (32.29MPa). That for PPC-1 containing 20% pozzolana filler was distilled water (36.29MPa), sulfate water (36.10MPa), chloride water (34.51MPa), sewer water (31.29MPa) and Mavoko water (30.51MPa). The ultimate compressive strength of sulphate water was closer to the control one, partly attributable to formation of ettringe and mono-sulfates that contribute to concrete strength (Chithambaram *et al.*, 2018). The chloride water did not have a significant strength disparity from the control sample at this concentration.

Mavoko water and sewer water samples had retarded late concrete compressive strengths for both types of pozzolanic cements. This can be attributed to its salty nature implying that it had compounds that hindered reactions of both aluminates, ferrates and silicates in the solution during hydration (Sağlam and Akcay, 2016). These compounds mask the ettringe forming silicates and instead form other by-products (Sağlam and Akcay, 2016). Sewer water which is highly infested with organic and organometallic compounds alongside other carbonates and hydro-carbonates. Concrete made with this water gave exemptionary high early strengths, for

1-day strengths of PPC. The late strength however decreases over time due to carbonation of concrete that form $CaCO_3$ instead of the C-S-H complex of concrete (Zhang *et al.*, 2015).

OPC Cement usually gives higher compressive strengths especially after 28 days. Due to lack of alkalis as a result of fillers, it has more effective CaO and a higher Silica net effect resulting to formation of the stable compact product of Calcium-Silica-Hydrate (C-S-H) (Chithambaram *et al.*, 2018). The overall market strength of OPC is thus usually higher (min. 42.5 MPa) than that of OPC (min 32.5 MPa). Figure 7 below indicates the variation in concrete strength with types of water used for curing.

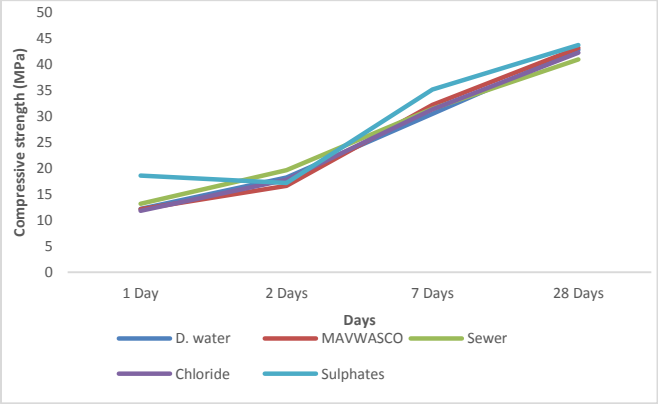


Figure 7; Variation of compressive strength with water samples for OPC cement

The late concrete strengths were in the order of distilled water (44.73N), sulfate water (43.67N), chloride water (42.17N), sewer water (40.89N) and Mavoko water (40.12N). As seen with PPC cement above, Mavoko water sample used for curing had a combination of several salts leading to formation of by-products that mask the ettringe forming silicates (Chithambaram *et al.*, 2018). Some heavy metals in the water also react with oxides and sulphates in cement, preventing C_3A and C_4AF from fully reacting.

Sewer water had an accelerated early strength. This accelerated early strengths can be attributed to the formation of an enol-aluminate complex. On exposure to Calcium aluminates (e.g.C_3A), sugars undergo an enol-keto isomerization process yielding keto isomers and the intermediate compound is the above enol-aluminate complex. This is a compact complex which together with other ettringe formed parallel with this organic reaction, combine to give accelerated early strengths. The complex plays the role of a catalyst and is gradually regenerated back to C_3A to proceed with the aluminate phase (Earthwise, 2017). By now not all the initial precursor Calcium will be available to take part in the Silicate phase as some are still slowly dissociating from the organic complex formed above. Less C-S-H is attained. Therefore, a remarkably low late strength of 40.89MPa was achieved. With increased carbonates in solution, (e.g. for sewer water), CO_2 react with $Ca(OH)_2$ to give $CaCO_3$ which is harder than the lime water thus a stronger concrete is formed for early strength (Jooste *et al.*, 2018). However, with time the carbonate is reconverted back to CH as the amount of CO_2 circulating slowly diminishes. This reduce its strength, and since some Calcium ions are depleted in the exchange process,

less C-S-H than norm is formed. This cause the unusual retarded late strengths of concrete made with sewer water.

Concrete compressive strength using sulphate water is normally depressed for the early stages, primarily because of the formation of the intermediate C-A-S-H above which result to lower ettringe and monosulphates in the process inhibiting C-S-H formation. Therefore the 1-day strengths of both OPC and PPC are lower than the standard. With time, sulphate ions accumulate in solution to make it acidic. This acidity reduce the $Ca(OH)_2$ or (C-H) formed by neutralizing it. This has a desired effect of increasing the presence of its co-product, C-S-H which in turn yields higher late strengths as observed for the 28-day strength values of and OPC.

Chloride solution at this concentration did not directly affect concrete compressive strength. This is because chloride ions are not involved in formation of strength yielding intermediates and products such as ettringe, monosulfate, CH and the C-S-H complex (Neville and Brooks, 2016).

4. CONCLUSION

Mavoko water samples used for concrete hydration and curing were found to have adverse effects on all the three physical parameters of concrete analyzed. This water accelerated the expansion of concrete to up to 1.5mm in both PPC cement brands and 2.5mm in OPC cement. These values were significantly different from those obtained by other water samples ($p \leq 0.05$, $n= 14$). While sewer water samples had very low initial setting times, Mavoko water had low early setting times with prolonged late setting times. The average deviation in the two setting times was highest in Mavoko water (54 ± 2 minutes) and significantly different from the other water samples ($p \leq 0.05$, $n= 14$). Thus, using this kind of water necessitates for more gypsum in the cement to be used increasing production costs.

Both sewer water and Mavoko water had the least concrete compressive strengths. Sewer water however had more early compressive strengths but lower late compressive strengths of 31.29, 32.29 and 40.89MPa for PPC-1, PPC-2 and OPC cement brands respectively. Mavoko water samples had retarded concrete compressive strengths for both early and late strengths. Very low compressive strengths of 30.51 and 40.12MPa were recorded for PPC-1 and OPC cement using Mavoko water samples. Sulfate water retarded the early concrete strengths while increasing its late strength whereas chloride water samples did not have any effect on concrete compressive strength.

The research proved that use of Mavoko water for concrete hydration and curing had negative implications on the quality and durability of concrete made.

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CONFLICTS OF INTEREST

The authors declare to have no conflict of interest whatsoever.

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