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Effect of sulphate ions in mixing water on cement mortar performance

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Abstract: *The effect of sulphate ions in mixing water on performance of cement mortar was investigated. Mortar prisms were made using selected Portland Pozzolana cement and Ordinary Portland cement with sewage, swampy and bore-hole waters, commonly used as mix waters in most peri-urban set up in Kenya. Potable tap water was used as a control. Compressive strength was determined at 2nd, 7th, 28th, and 90th day of curing. Setting time was also investigated. Results showed that sewage and swampy mix waters had significant sulphate content. The sulphate ions reduced the early compressive strength development of cement mortar in both PPC and OPC. Further, sulphate ions retarded both initial and final setting times in PPC and OPC. The use of sewage and swampy waters as mix water containing high sulphate ions could lead to failure of concrete and/or mortar and hence building and construction.*
Key Words: *Cement Mortar, Mixing water,OPC, PPC, Sulphate ions.*

I. Introduction

Mixing water is very vital for development of concrete and /or mortar. It can also be a source of aggressive ions in the cured concrete/ mortar [1]. In Kenya, there are no legal standards on the quality of mixing water for cement mortar/ concrete. Further, there are no controls on quality of mixing water. Water is majorly scarce in Kenya and therefore, majority of construction workers use any available water for mixing concrete/mortar.

The presence of impurities in mixing water not only affects setting time and strength development of mortar/concrete, but also causes efflorescence, staining, corrosion of reinforcement, volume instability and reduced durability [4]. Presence of sulphate ions in many water masses makes them readily available to cement matrix either during cement paste making or to constructed cement structures [2]. The ingress of these ions into cementitious material exposes building into a durability threat [3]. The principal effect of sulfate attack is to reduce the service life of the mortar and /or concrete structures due to degradation. Sulfate attack results in expansion, cracking, spalling and eventually reduce strength of concrete [5, 6, 7].

Mixing water rich in sulphate ions result into an internal sulphate attack [8, 9]. Sulfates react with the aluminium-containing phases of Portland cement mortar paste causing internal expansion [10, 11, 12]. The expansion is attributed to formation of expansive products such as thaumasite, ettringite and gypsum as shown in equations (1) - (3) respectively.

$$3Ca^{2+} + SiO_3^{2-} + CO_3^{2-} + SO_4^{2-} + 5H_2O \rightarrow 3CaO.SiO_2.CO_2.SO_3.15H_2O \quad \text{..........................} (1)$$

$$3(CaSO_4.2H_2O) + 3CaO.Al_2O_3 + 26H_2O \rightarrow 3CaO.Al_2O_3.3CaSO_4.32H_2O \quad \text{..........................} (2)$$

$$Ca(OH)_2 + Na_2SO4 + 2H_2O \rightarrow 2NaOH + CaSO_4.2H_2O \quad \text{..........................} (3)$$

The study investigated the effect of sulphate ions in mixing water commonly used in peri – urban set up in Kenya. Hence, it is expected that this work would help to establish a clearer guidance on identifying suitable water for mixing concrete/ mortar and also help contractors to safe water sources for their construction works.

II. Experimental Procedure

The test waters were sampled randomly from various construction sites in Nairobi, Kenya. They were kept in a 20 litre plastic containers and well labelled as per the water source. Potable tap water was used as supplied by Nairobi City Water and Sewerage Company. The concentration of sulphate ions was determined in accordance to ASTM D 516 [18].

The test cements were sampled from the Kenyan cement manufacturing plants and labelled as OPC and PPC. Mortar preparation and curing was done in accordance with Kenya Standard KS EAS 148-1 (2000) [19]. Potable tap water was used as a control. Test prisms of 40 mm x 40 mm x 160 mm size were prepared from a batch of a plastic mortar using sample water vis a vis potable tap water. Mortar was mixed mechanically using an automated mixer model JJ- 5. The compressive strength was determined using compressive strength machine model YAW-300 at 2^{nd},7^{th},28^{th} and 90^{th} day of curing. The test results were graphically presented.

The cement paste for determining setting time was prepared in accordance with KS EAS 148-3: (2000) [20] using cement paste mixer model NJ- 160. 125 g of each test water was weighed and poured in the mixer bowl to which 500 g of test cement was carefully added in about 5 to 10 seconds and the paste mixer switched on. The cement paste was mixed vigorously in a paste mixer and transferred immediately in a mould placed on a lightly greased plane base plate. The mortar paste was filled into the mould and the excess was removed by a gently sawing motion with a straight-edged steel ruler in such a way as to leave the paste filling the mould and having a smooth upper surface. The mould was placed in a humidity cabinet set at a temperature of 25 ± 1 °C. Vicat apparatus was used to determine initial and final setting times. The same was repeated using potable tap water and the setting time results compared graphically.

III. Results and Discussions

3.1 Analysis Results for SO_4^{2-} ions in Test Water Samples

The results for test water samples are presented in table 1

Table 1: Test Results for Water Samples

Mix water Source	SO_4^{2-} (ppm) Mean ± SE
Sewage Water	955.52 ± 2.32
Swampy Water	788.83 ± 0.53
Runoff Water	233.55 ± 0.04
Bore hole Water	74.66 ± 0.02
Potable tap Water	7.28 ± 0.02

Sulphate ion content in test waters varied significantly from different water sources .Sewage and swampy water had the highest sulphate concentrations in comparison to other test waters. ASTM C 1602/ C 1602M-12 requires that a suitable mixing water for concrete should have sulphate ion concentration of ≤ 250 ppm [13]. From the test results, sewage water and swampy water indicated high sulphate levels as compared to the ASTM standard requirements. The sulphates could be a source of internal sulphate attack to mortar or concrete. Internal sulphate attack leads to an overall loss of concrete strength[9].

The products of sulphate attack (gypsum, ettringite and thaumasite) are dependent on conditions favourable for one product or the other to be formed. Thaumasite sulphate attack for example, is much favoured by the presence of $CaCO_3$, mixing or contact water with $SO4^{2-}$ and low temperatures. Mingyu *et al.* (2006) while studying on the thaumasite form of sulphate attack in concrete of Yongan Dam observed that $Ca(OH)_2$ reacted with SO_4^{2-} to form gypsum ($CaSO_4.2H_2O$). The formed gypsum further reacted with CSH and $CaCO_3$ to form thaumasite.

3.2 Compressive Strength Test Results

Fig. 1 shows the compressive strength performance of PPC and OPC whereas figure 2 shows the percentage change in compressive strength of PPC and OPC in different mix waters.

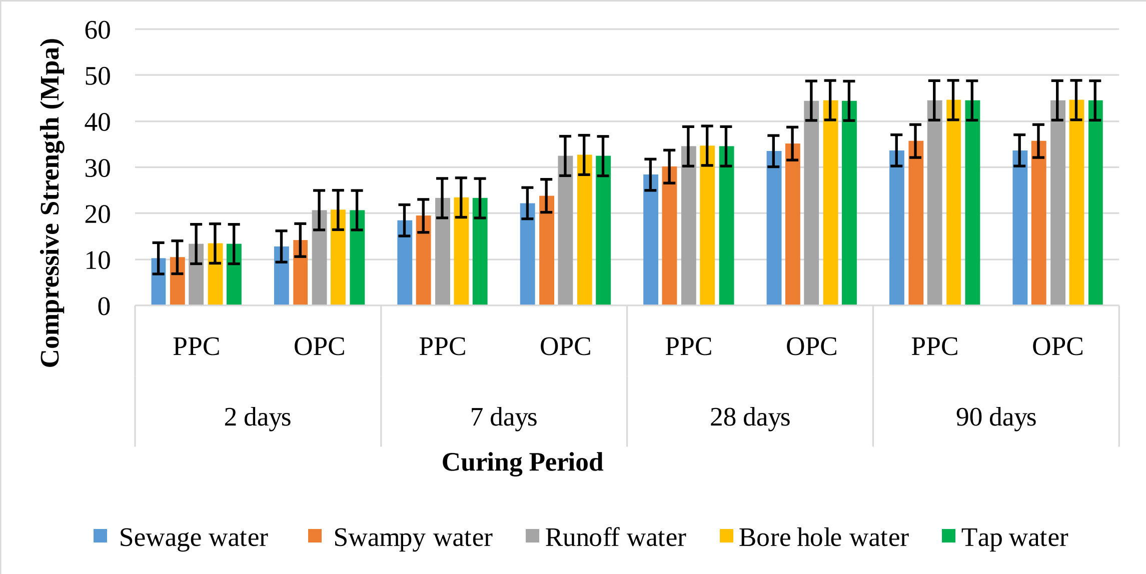

Fig.1: Compressive Strength Performance for PPC and OPC in Different Mix Waters

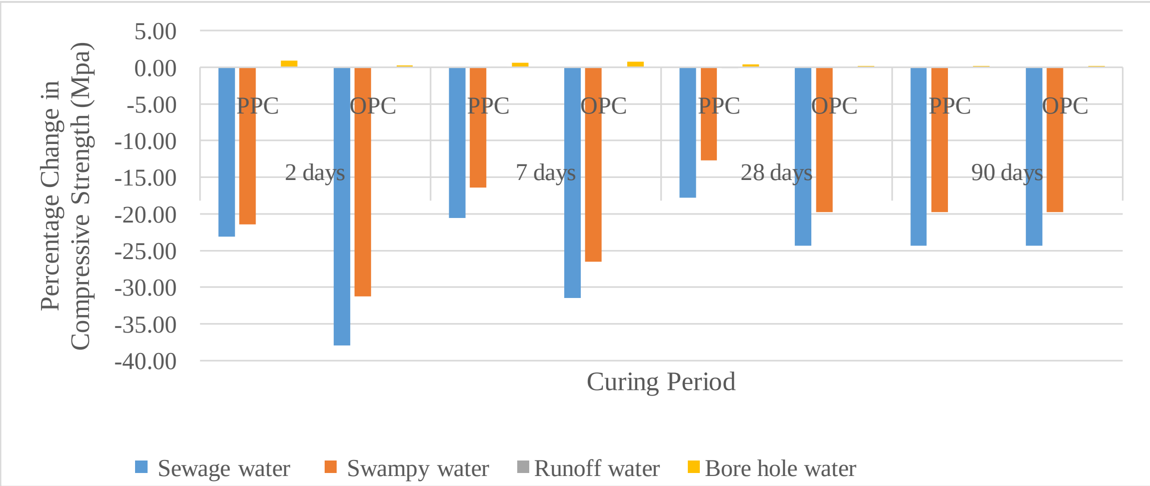

Fig.2: Percentage change in Compressive Strength Performance for PPC and OPC in Different Mix Waters

The test results showed that the compressive strength increased with increase in curing period for both test when mixed with all test waters. The degree of hydration increases with curing period and thus increasing the gel/ space ratio. This leads to increase in compressive strength. The test results showed that cement mortar made with tap, runoff and bore-hole mix waters met the compressive strength requirements at all curing ages as described in KS EAS 18-1: 2001[14].

It was however observed that the cement mortar made with sewage and swampy mix waters did not meet the standard requirement. The compressive strength was lower as compared to tap, borehole and runoff water in both test cements. This could be attributed to higher sulphate ion concentration in the mix waters as shown in table 1. Sulphate ions forms deleterious expansive products such as thaumasite, ettringite and gypsum in cement. The effect of these ions lead to decline in physical properties of cement mortar and /or concrete such as compressive strength. Similar observations were made Sunil Kumar in 1994 [15].

OPC exhibited more decreased compressive strength than PPC. This could be attributed to high C_3A phase in OPC than PPC. The presence of a higher proportion of aluminate phase increases the uptake of the SO_4^{2-} in OPC hence making it more prone to sulphate attack. This is as shown in figure 2. The less decreased compressive strength in PPC as compared to OPC could be attributed to low permeability from the resultant secondary CSH from pozzolanic reaction. Pozzolana grains arrangement between the cement grains and the aggregates also contributes to reduction of sulphates permeability.

The effect of sulphate ions on cement mortar / concrete has been investigated by many authors. Ranjani *et al, 2012* for example while studying on the behaviour of foam concrete under sulphate environments observed that sulphate ions resulted to expansion of concrete. The authors attributed this to formation of expansive products such as ettringite, thaumasite and gypsum. These expansive products results to reduced concrete durability. Mingyu *et al*,2006 made similar observations [16, 17].

3.3 Setting Time Test Results

Figure 3 shows the test results for initial and final setting times for PPC and OPC when mixed with different test mix waters.

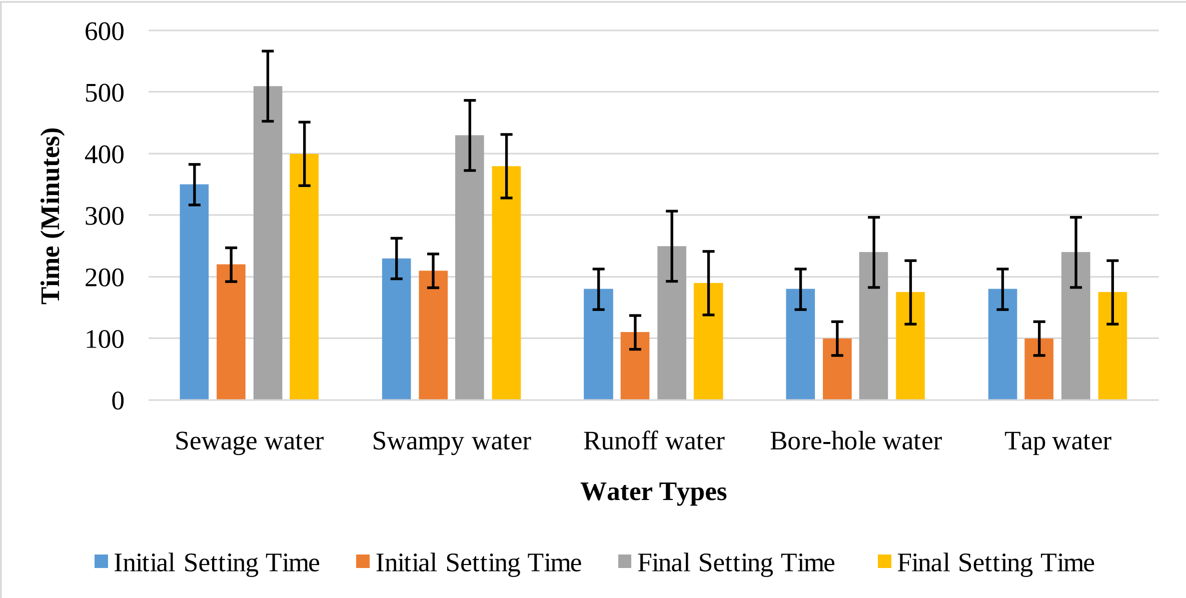

Fig. 3: Initial and Final Setting Times for PPC and OPC in Different Mix Waters

The initial and final setting times for PPC and OPC met the KS EAS 18-1:2001 requirements when mixed with runoff, bore-hole and tap water. Sewage and swampy mix waters exhibited prolonged setting times in both OPC and PPC. This could be attributed to high sulphate ion concentration as shown in table 1. Sulphates are known to retard the setting time of cement mortar and/ or concrete. Sulphates reacts with C_3A phase in cement in presence of water to form ettringite. Ettringite slows down the hydration process by forming a diffusion barrier on the surface of C_3A.

Presence of sulphate ions also contributes to formation of excess gypsum in the concrete which slows down the hydration process and thereby retarding the setting of the cement mortar and/or concrete.The effect of sulphate ions on the setting behaviour of cement has been investigated by many authors. Kumar *et al*, in 1994 while studying the effect of sulfates on the setting time of cement and strength of concrete observed that the type of sulphate ion and the concentration affects the setting time significantly.

IV. Conclusion

The results of this work showed that mixing water with high sulphate ions reduces the compressive strength development of cement mortar. This may lead to failure of concrete works. It was further observed that sulphate ions retards setting times both in PPC and OPC. This may affect workability of cement paste and hence its placement period. It is therefore necessary for prior analysis to be carried out before sewage and swampy waters are used as mix waters for cement mortar and/or concrete.

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