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The Influence of the Physico-Chemical Properties of Water on the Compressive Strength of Concrete

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Abstract:

Objective: To determine the influence of the physico-chemical compositions of the different sources of water on the compressive strength of concrete.

Materials and Methods: Seventy-two 150mm x 150mm concrete specimen were cast using six different sources of water and cured using the same water sources by immersion for 7, 14, 21 and 28 days. Each water sample was used to produce 12 specimen, three each for the four different ages. Concrete cubes were weighed using digital weighing machine before testing. Test for compressive strength was done using digital compressive test machine after which the Average Compressive Strength (ACS) of the three samples was determined.

Results: The silt content of the fine aggregates used was within the recommended percentage specified by the IS part II 1963. The results obtained from the slump test classifies the concrete produced for the study as stiff or extremely dry. Though the Amissano and Aquarium water recorded some amount of slump, their slumps could still be described as no-slump and cannot be classified. The figures for the compacting factor test indicated low workability for the concrete produced for the test. It was only the concrete produced from the Kakum river water that had a medium workability. The sea water recorded the highest pH and was followed by the Kakumdo well water. The least pH was recorded by the Amissano well water. The total dissolved solid (TDS) of the Kakumdo well water and the sea water were far higher than the Ghana standards. On the other hand, the figures recorded by the Kakum water for chloride, total hardness, calcium hardness, magnesium hardness and electric conductivity were below what is prescribed by the Ghana Water Company Limited (GWCL). The calcium hardness of the Kakumdo well water was (160mg/l) more than the standard. The Amissano well water specimen recorded the least ACS both at age 7 and 28. This was the lowest among all the samples produced from the various sources of water used for the experiment. The significant strength increase of the Amissano well water samples was recorded at age 14 and 21. The Kakumdo water specimen recorded the highest earliest strength of 20.339KN/mm^2 and was followed by the Kakum river water. The samples from this source still recorded the highest at age 14 and 21. But at 28, it was overtaken by the Kakum river water samples with the Kakum river samples recording 26.439 KN/mm^2 as against the 25.484 KN/mm^2 registered by the Kakumdo well water samples. The Aquarium well water specimen recorded high strength at both age 7 and 28 than the Amissano well water specimen.

Conclusion:

The Aquarium water and Amissano well water were more acidic, meaning their pHs were lower than 6. This had significant influence on the ACS of the samples produced from them. This was evident in the case of the Amissano well water samples which recorded the lowest earliest strength of (12.173N/mm^2) among the six sources. The ACS difference recorded between the Aquarium and Amissano well water samples which were all acidic was 5.379KN/mm^2. This means that higher the acidity of the water use for the production of concrete, the lower the ACS. The Amissano well water was 10 times more acidic than the Aquarium water and 20 times higher than the Kakum river water, pipe borne water and Kakumdo well water but 40 times higher than the sea water.

Keywords: Physico-Chemical Properties, Water, Compressive Strength, Concrete

Introduction:

Concrete is a very versatile construction material. It is produced using fine and coarse aggregates, cement and water. The cement and water when mixed together form the paste. When a paste is formed, heat is generated and this heat is what is referred to as heat of hydration. From this point the paste enters into another stage called the setting stage where the paste begins to stiffen. These two stages in the life of a concrete member are crucial to the overall achievement of the purpose of the concrete material. But the use of impure water and the presence of certain physical chemical compositions in a water source can interfere with the first important stage of the concrete which is the hydration process and subsequently the setting stage. This interference can greatly influence the strength of the concrete produced which may also affect its purpose.[1] The physico-chemical properties of water can make it more aggressive or otherwise. Water with a reduction in alkalinity is likely to be more aggressive and capable of removing the binder.

pHs of water:

pHs is a determined value based on a defined scale. It is a figure between 0 and 14 which defines how acidic or basic a body of water is along a logarithmic scale. The lower the number on the defined scale, the more acidic the water is. The higher the number of a

body of water defined on a pH scale, the more basic it is. A pH of 7 is considered neutral. The logarithmic scale means that each number below 7 is 10 times more acidic than the previous number when counting down. Likewise, when counting up above 7, each number is 10 times more basic than the previous number. Deleterious substances and dissolved solids in water can cause deterioration in concrete through chemical reactions. It was stated by[1] that, free CO2 and acidic ions such as SO and Cl in soft water and stagnant waters are detrimental to concrete. They are usually responsible for lowering the pH value below 6.

Alkalinity:

According to [2], increasing the alkali content of concrete has harmful effects on mechanical properties such as compressive strength and freeze-thawing strength of concrete made with a water-to cement ratio of 0.41. He argued that a low-alkali concrete shrinks more than the high-alkali concrete. A chemical reaction involving alkali and hydroxyls ions from Portland cement paste and certain sensitive siliceous minerals that are often present in aggregates can result in expansion and cracking of concrete leading to loss of strength and elastic modulus.[1]

Acidity:

Calcium hydroxide is susceptible to hydrolysis.[1] It was stated by [3] that, pure water decomposes set cement compounds, by dissolving the lime and alumina from the cement. This action of leaching is continues and then after slows down till the water is able to pass continuously through the mass of concrete. This exposes the cementitious constituents of the hardened paste to chemical decomposition. The leaching of the concrete leaves behind silica and alumina gels which have little or no strength. Water which are acidic owing to the presence of uncombined carbon dioxide, of organic or inorganic acids, are more aggressive in their action, the degree and rate of attack increases as the acidity increases. In general, acid solutions which attack 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. According to [22], when concrete loses about a fourth of its original lime content, its strength reduced to half of its original strength. He argued that, the leachate of the lime interacts with CO_2 present in the air and forms an off-white crust of calcium carbonate on the surface.

Curing:

All concrete requires curing for development of strength, durability and other mechanical characteristics. To obtain good concrete, the placing of an appropriate mix must be followed by curing in a suitable environment, especially during the early stages of hardening. Curing is the name given to procedures used for promoting hydration of cement.[4,1] It involves a combination of conditions such as time, temperature, and humidity conditions immediately after the placement of a concrete mixture into formwork that promote cement hydration.[1] It is the process of protecting concrete for a specified period of time after placement, to provide moisture for hydration of the cement, to provide proper temperature and to protect the concrete from damage by loading or mechanical disturbance. Curing is designed primarily to keep the concrete moist by preventing loss of moisture from it during the period in which it is gaining strength. According to [1], at a given water-cement ratio, the porosity of a hydrated cement paste is determined by the degree of cement hydration. Some constituent compounds of Portland cement begin to hydrate as soon as water is added, but the hydration reaction slows down considerably when the products of hydration coat the anhydrous cement grains. Other factors affect the development of strength of concrete and consequently its durability other than curing or the curing technique applied. These factors include quality and quantity of cement used in a mix, grading of aggregates, maximum nominal size, shape and surface texture of aggregate.[6] In addition to what was stated above, [1] mentioned time and humidity as important factors which also influence the hydration process controlled by water diffusion. Water/cement ratios, degree of compaction and the presence or otherwise of clayey particles and organic matter in the mix can also affect strength development.[7] It was stated by [8] that the termination of curing goes a long way to affect strength development. They said strength development only continues when a concrete member has enough moisture within it for continues chemical reaction to take place. It was further argued by [9,10], that when concrete is not well cured, especially at the early age, it affects its property requirement.

Compressive Strength:

The response of concrete to applied stress depends not only on the stress type but also on how a combination of various factors affects porosity of the different structural components of the concrete.[1] The factors include properties and proportions of materials that make up the concrete mixture, degree of compaction, and conditions of curing, and water cement ratio, strength of the constituent materials and the control of the production. The lower the water-cement ratio, the higher the compressive strength. A certain minimum amount of water is necessary for the proper chemical action in the hardening of concrete; extra water increases the workability but reduces strength. [11,1,12] Compressive strength test results are used to determine the concrete mixture. According to [1], the relationship between water-cement ratio and porosity are the most critical factors when strength becomes the focus independent of other factors. On the other hand, [13] stated that the strength of concrete has a relationship with its age and the amount of moisture present in the member.

Research Methodology:

Experimental study approach was employed for the study. Prior to the actual experiment in the material laboratory, the six water sources were taken to the Ghana Water Company Limited for physico-chemical analysis. Concrete cubes were produced using fine, coarse aggregates, Portland cement (GHACEM 32.5R) and six different sources of water. Unwanted materials were first removed from aggregates and were thereafter graded for the experiment. River sand and crushed granites were used as both fine and coarse aggregates. Silt test was performed on the sand with the aid of cylindrical glass equipment to establish the percentage of silt present in the sand. The aggregates (coarse) were sieved using shaker vibrator machine to determine the maximum size within the all-in aggregates used in the study. Batching was done by weight using digital weighing scale while thorough mixing of the various constituents of concrete was realized using concrete mixer with designed ratio of 1:2:4.

Compacting factor tests and slump tests were carried out with the help of a compacting factor test equipment and a conical slump test equipment. Each test was performed three times to establish an average test result. Concrete samples were produced using six different sources of water (namely: 3 different well water sources – Aquarium (AQWW), Kakumdo (KWW) and Amissano (AWW), sea water (SW), Kakum river water (KRW) and treated water (pipe borne water) (PBW). Concrete was cast into steel mould boxes of size (150mm x 150mm x 150mm) and compacted using needle poker vibrator. The fresh concrete samples remained in the mould for twenty-four hours to form a cube after which the moulds were removed. The cubes were cured by immersion in the specific water used for mixing for 7days, 14days, 21days, and 28days. The concrete cubes before testing for compressive strengths were weighed using digital weighing machine. Actual testing for compressive strength was done using digital compressive test machine. In all, 72 specimen were produced and tested. Each water source produced 12 samples with 3 going for each curing age.

Material Characteristics:

The mix proportion for the production of the cubes was 1:2:4. The weights of the materials according Table 1 are as follows: coarse aggregates 120kg, fine aggregates 60kg, Ordinary Portland cement 30kg and water 15kg.

Table :. Concrete mix proportions:

Constituent Materials	Proportion by Weight (kg)
Quarry Chippings (coarse aggregates)	120
Sand	60
Ordinary Portland Cement (GHACEM 32.5R)	30
Various water (Kakum river, sea, pipe bond water, Amissano well, Kakumdo well and aquarium well)	15

Silt Test:

Table 2 gives the results of the silt tests that were conducted. Sample test one (T_1) had 5.88% silt whiles (T_2) and (T_3) had 4.41% silt respectively. The average silt percentage for the three tests was 4.90%. This means that the amount of silt that was present in the fine aggregates used was within the range of 6% which is acceptable by IS 2386 part II.[14]

Table 2: Silt test result

Sample Test	Description	Silt Percentage	Average Silt Percentage (%)
T_1	$^4/_{68}\ x\ 100$	5.88	$\frac{5.88 + 4.41}{3}$ = 4.90
T_2	$^3/_{68}\ x\ 100$	4.41	
T_3	$^3/_{68}\ x\ 100$	4.41	

Sieve Analysis for Coarse Aggregates:

All the 10mm - 20mm coarse aggregates measuring 1.500kg that were sieved went through the 37.5 and 28 mm sieves, 1.020kg representing (68%) was retained on the 20mm sieve; (17.33%) that is 0.260kg was retained on the 14mm with 0.220kg representing (14.67%) also retained on the 10mm sieve. The 14mm-5mm sieves recorded a cumulative percentage passage of zero. The aggregates size that was more in this all-in aggregates used for the concrete cubes was 20mm, followed by 14mm and then 10mm.

Table 3: Sieve test of coarse aggregates using shaker machine

Sieve sizes (mm)	Weight of sieve (kg)	Weight of sieve +	Weight retained (Kg)	Percentage retained (%)	Cumulative percentage	Cumulative percentage
37.5	0.639	0.639	0	0	100	0
28	0.675	0.675	0	0	100	0
20	0.601	1.621	1.020	68	32	68
14	0.497	0.757	0.260	17.33	14.67	85
10	0.516	0.548	0.220	14.67	0	100
9.5	0.512	0.512	0	0	0	100
6.3	0.507	0.507	0	0	0	100
5	0.500	0.500	0	0	0	100

Slump Test:

The measure of the workability of the fresh concrete produced with the six different sources of water as depicted in Table 4 revealed no-slump for the Kakum river water, sea water, pipe borne water and Kakumdo well water. According to [15], the concrete produced from these four sources were stiff or extremely dry and that is why they showed no measurable slump after the removal of the cone. The stiffness of the concrete may have resulted from the water/cement ratio used. On the other hand, concretes produced with water from Amissano well water and the Aquarium well water each recorded a true slump of 2mm. The decrease in height of the slumped concrete was measured to the highest point of the cone. Even though, there was a slump of 2mm in the case of both the concrete produced from the Amissano and Aquarium well water, this slump can be described as no-slump according to BS EN 12350-2. Based on the description parameters offered by [16], they cannot be classified even as S1. This is because a slump classification of S1 ranges from 10-40mm.

Table 4: Slump Test

Water sources	Description of workability	Classification of workability	Height of slump
Kakum river water	No-slump	-	0
Sea water	No-slump	-	0
Pipe borne Water	No-slump	-	0
Amissano Well Water	No-slump	-	2
Kakumdo Well water	No-slump	-	0
Aquarium Well Water	No-slump	-	2

Compacting Factor Test:

According to Table 5, the water source which recorded the highest compacting factor was Kakum river water with a compacting factor (CF) of 0.87, followed by the pipe borne water and Aquarium well water with a CF of 0.85. The Amissano well water recorded 0.84 and came fourth. The sea water and the Kakumdo well water came fifth and sixth with compacting factors of 0.83 and 0.81 respectively. The average compacting factor for all six different samples produced from the six sources of water was 0.84. The average compacting factor calculated describes the concrete produced for the study as one with low workability. The only water source whose workability description was medium was the Kakum river water, the rest were all low.

Table 4: Compacting factor test

Water sources	Compacting factor	Description of workability
Sea water	0.83	Low
Pipe borne water	0.85	Low
Kakum river water	0.87	Medium
Kakumdo well water	0.81	Low
Aquarium well water	0.85	Low
Amissano well water	0.84	Low
Average compacting factor for all sources	***0.84***	***Low***

pHs of Water Sources:

Out of the six water sources used for the study, four of them namely; the Kakum river water, pipe borne water, sea water, and Kakumdo well water all had their pHs within the acceptable range of 6.5 - 8.5 pH units recommended by the World Health Organisation.[18] However, the Amissano and Aquarium well water had their pH units falling outside this range. The sea water recorded the highest pH with the Amissano well water recording the least. The Amissano and Aquarium well water were found to be more acidic but the acidity of the Amissano water was higher than that of Aquarium. The Kakum River water, the pipe borne water and the Kakumdo well water were also considered acidic based on the classification given by logarithmic scale but their acidity was less than the two mentioned earlier because their readings were near neutral. The sea water on the other hand was alkaline.

Table 5: Physico-chemical properties:

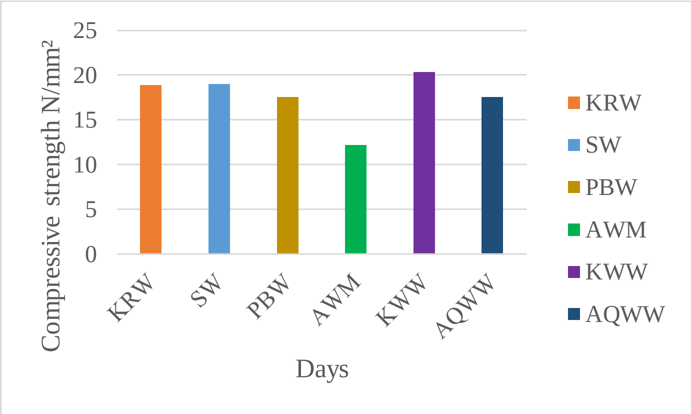
Physico-chemical Analysis of Different Water Sources									
Parameter	**Test method**	**Unit**	**Ghana standards**	**Results**					
				KRW	**PBW**	**SW**	**AQWW**	**AWW**	**KWW**
pH	Electrometric	pH Unit	6.5 – 8.5	6.76	6.76	8.12	5.71	4.96	6.89
Colour	Spectrophotometric	Pt. Co	Acceptable	5	5	18	8	7	5
Turbidity	Photometric	NTU	2000	0.55	0.55	1.70	0.25	0.60	0.40
TDS	Electrometric	mg/l	600	127.58	127.58	37192.5	388.13	332.1	1829.25
Elect. conductivity	Electrometric	µS/cm	1000	189.0	189.0	55100	575	492	2710
TSS	Spectrophotometric	mg/l	10	0	0	8	0	0	2
Salinity	Electrometric	mg/l	-	99	99	28100	270	237	1400
Zinc	Spectrophotometric	mg/l	5	0.15	0.15	0.23	0.41	0.09	0.18
Chloride	Titrimetric	mg/l	500	45	45	18900	205	112.5	490
Phosphate	Spectrophotometric	mg/l	-	0.09	0.09	0.14	0.22	0.34	0.35
Sulphate	Spectrophotometric	mg/l	1000	23	23	435	41	1	107
Total hardness	Titrimetric	mg/l	500	90	90	19200	155	120	475
Calcium hardness	Titrimetric	mg/l	200	55	55	15100	105	85	360
Magnesium hardness	Calculation	mg/l	150	35	35	4100	50	35	115
Alkalinity	Titrimetric	mg/l	1000	35	35	95	125	10	230
KRW - Kakum River PBW - Pipe Borne water SW - Sea Water AQWW - Aquarium Well Water AWW - Amissano Well Water KWW - Kakumdo Well Water									

The colour of all the water sources were acceptable. The turbidities were within the acceptable standard recommended by the Ghana standards (GS). The total dissolved solids of Kakum river water, pipe borne water, Aquarium well water, and the Amissano well water were acceptable. The sea water and the Kakumdo well water fell outside the GWCL range. Their electric conductivity were far in excess of the standard. The total suspended solid parameters were acceptable. The chloride, total hardness, calcium hardness and magnesium contents of the sea water were all outside the range of the acceptable. The calcium hardness of the Kakumdo well water was 160 mg/l more than what is recommended by the GS.

Compressive Strength Analysis for Concrete Samples Produced and Cured for 7 Days:

The average compressive strength (ACS) of the three samples for each source of water is recorded as presented in Figure 1. The Kakumdo well water specimen recorded the highest ACS of 20.339N/mm^2. This was followed by the sea water 18.970 N/mm^2, Kakum river water 18.846N/mm^2, pipe borne water 17.575 N/mm^2 and the Aquarium well water 17.552 N/mm^2. The least recording was registered by the Amissano well water 12.173 N/mm^2.

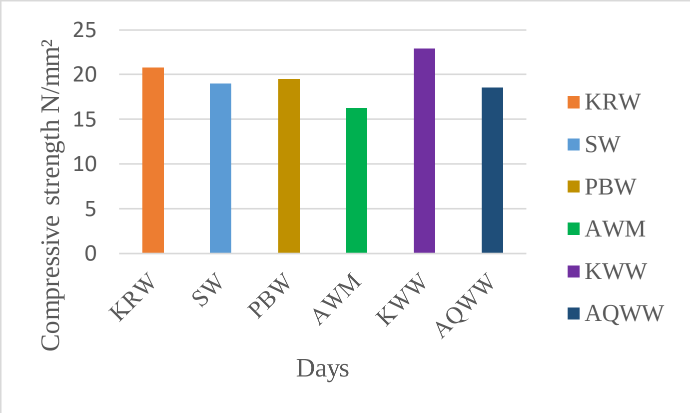
Figure 1: 7 Days compressive strength of the various sources of water:



Compressive Strength Analysis for Concrete Samples Produced and Cured for 14 Days:

The second test was carried out at the end of 14 days and the following figures were recorded as indicated in Figure 2. The Kakumdo well water samples still recorded the highest ACS of 22.909N/mm^2 and was followed by the Kakum river water 20.797 N/mm^2 and then the pipe borne water. The sea water came fourth with all other sources maintaining their positions after 14 days. All the samples from the various sources of water saw significant increase in their ACS. But again, the Amissano well water sample is still placed at the bottom with an ACS of 16.212 N/mm^2.

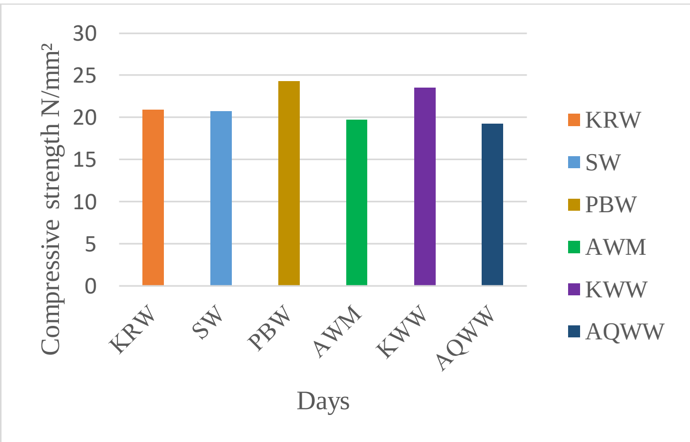
Figure 2: 14 Days compressive strength of the various sources of water



Compressive Strength Analysis for Concrete Samples Produced and Cured for 21 Days:

After 21 days of curing as depicted in Figure 3, the strength of the pipe borne water sample overtook that of Kakumdo well water. It recorded an ACS of 24.304 N/mm^2 as compared to the 23.567 registered by the Kakumdo well water. The Kakum river water and the sea water were placed third and fourth respectively. The Amissano well water samples after 21 days registered ACS which was higher than the Aquarium water.

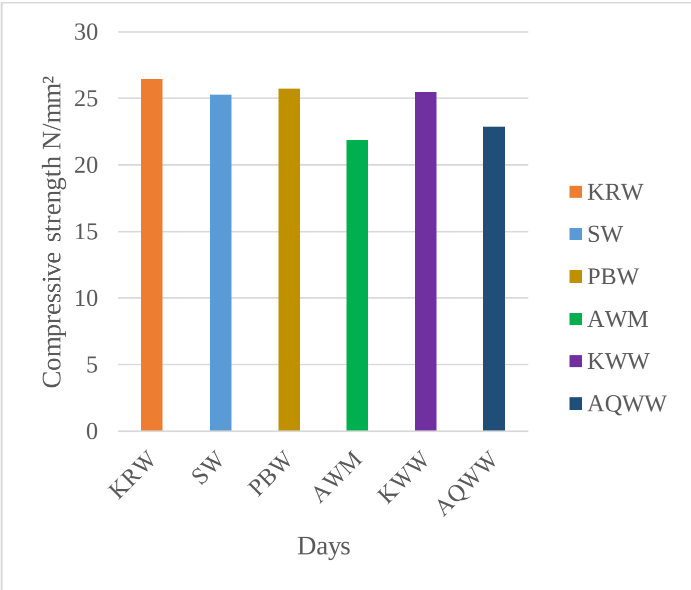
Figure 3: 21 Days compressive strength of the various sources of water



Compressive Strength Analysis for Concrete Samples Produced and Cured for 28 Days:

The last test was undertaken after 28 days with test results displayed in Figure 4. The Kakum river water samples after 28 days recorded the highest ACS of 26.439 N/mm^2. It was followed by the pipe borne water samples 25.702 N/mm^2, Kakumdo well water 25.484 N/mm^2, and the sea water sample 25,261 N/mm^2. The Aquarium well water after 28 days recorded ACS of 22.861N/mm^2 which was higher than the Amissano well water.

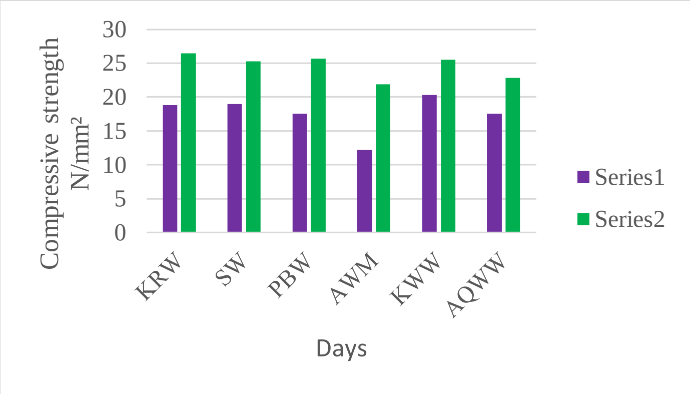
Figure 4: 28 Days compressive strength of the various sources of water



Overview of Earliest Strength against Latest Strength Development:

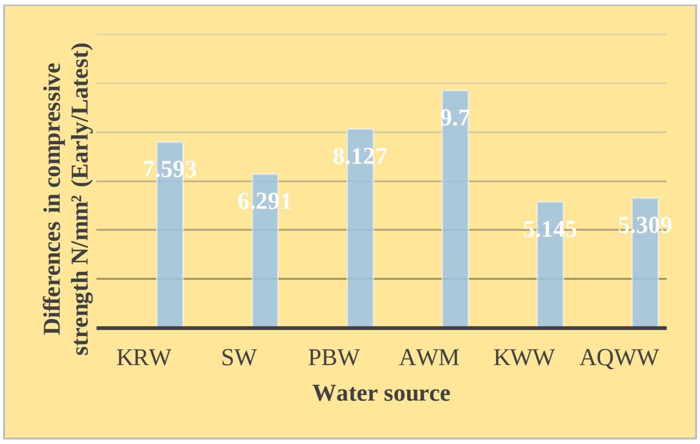
The Figure 5 depicts the earliest average compressive strength development of the samples of the different sources of water against the latest. The highest earliest ACS was recorded by the Kakumdo well water. The least recording came from samples produced from the Amissano well water. At age 28 days, the highest latest reading was registered by the Kakum river water. The Amissano well water samples still produced the smallest latest ACS.

Figure 5: Compressive strength: Earliest and Latest



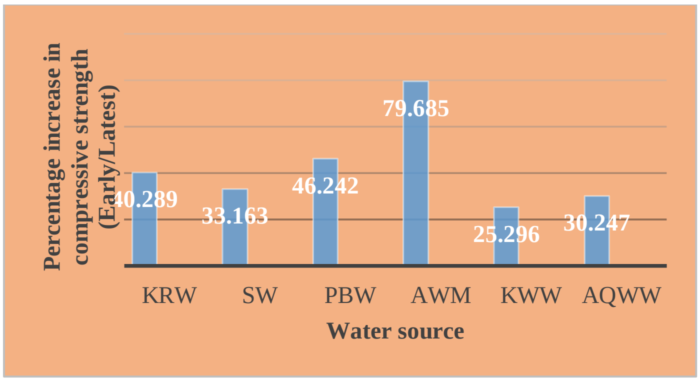
The difference in ACS between the earliest strength and the latest strength development is presented in Figure 6. The Amissano well water recorded the highest strength difference (9.700N/mm^2) and was followed by the pipe borne water (8.127N/mm^2) and the Kakum river water (7.593N/mm^2). The least was recorded by the Kakumdo well water.

Figure 6: Differences in compressive strength between Earliest and Latest



The highest percentage increase was registered by the Amissano well water (79.685%) as shown in Figure 7.

Figure 7: Percentage increase in strength



Discussion of Results:

The experiment made use of six different sources of water, namely; the Kakum river water, pipe borne water, sea water, Aquarium well water, Amissano well water and the Kakumdo well water. The pHs of the water sources outlined above were: 6.73, 6.76, 8.12, 5.71, 4.96 and 6.89 respectively. The physico-chemical analysis revealed that only four sources of the water used for the experiment had their pHs within the recommended Ghana standard as depicted by the various physico-chemical analysis. According to [19], any water which has a pH degree of acidity of 6.0 to 8.0 and does not taste saline or blackish is satisfactory for concrete. By making this inference from Neville, it can be concluded that the Aquarium well water and the Amissano well water are not satisfactory for concrete production since their pHs fall outside the range of 6 to 8 or possibly 9.[20] The claim by Neville was buttressed by[1] that, water whose pH is below 6 would be detrimental to concrete. The study revealed that five out of the six sources used were all acidic. The sea water was classified as a base because its pH was above 7.[17] The Amissano water source was found to be more acidic than all the other sources.

The earliest average compressive strength of the Kakumdo well water was higher than all the other sources. It had an earliest ACS of 20.339N/mm^2. The earliest ACS of the Kakum river water and sea water; and the pipe borne water and the Aquarium well water were close with strength differences of (0.124N/mm^2) and (0.023N/mm^2) respectively. The percentage early strength between the least and the highest was 68%. The Kakum river water recorded the highest latest strength of 26.439N/mm^2. The least 28 days strength recorded was 21.873N/mm^2 and this still came from the Amissano well water.

Conclusions:

The paper concludes based on the findings that:
The silt content of the fine aggregates used was within the acceptable range of 6%. The maximum coarse aggregates size was 20mm occupying 68% of the total coarse aggregates used for the study.
The concrete used for the study was harsh. Though some concrete produced from some water sources recorded 2mm slump, by their description they are classified as no-slump. This means the workability of the concrete material in its fresh state was low.

The condition of no-slump was as a result of the water/cement ratio used.

The highest pH was recorded by the sea water (8.12 pH units) while the Amissano well water recorded the least pH of (4.96 pH units). The Kakum river water recorded the highest total suspended solid (TSS). The TSS was higher than the recommended. The sea water parameters for total dissolved solids, electric conductivity, salinity, chloride, total hardness calcium hardness, and magnesium hardness were far higher than the limits prescribed by the Ghana standard.

The acidity of the Aquarium water and Amissano well water affected the compressive strengths of their concrete samples. This was evident in the case of the Amissano well water sample, recording the lowest earliest ACS of (12.173N/mm^2) among the six sources. In all, concrete produced from the Kakum river water performed better than all the other sources. The high parameters for certain chemical compositions in the sea water did not impair the strength development of its samples. The Amissano and Aquarium well water had their pHs falling outside the standard given by the GWCL and could be classified as being more acidic when the figure is read from the pH scale. Even though the Amissano well water and the Aquarium well water had their chemical composition parameters falling within the standards, they did not actually influence the power of the pH on the concrete.

Recommendation:

The study recommends based on the outcome of the study that, water sources should be tested to ascertain their pHs and other chemical parameters before they are used for concrete production. This is because the chemical compositions and pH of water can have detrimental effect on the strength properties of concrete and also lead to strength decline.

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References:

1. Monteiro PJM, Mehta PK. Concrete microstructure, properties and materials (3rd.). United States: McGraw-Hill publication, 1999.
2. Smaoui N, Berube MA, Fournier B, Bissonnette B. Effect of alkali addition on the mechanical properties and durability of concrete. C and Conc Res 2005;35:203-212.
3. Lea FM. The chemistry of cement and concrete (3rd ed.). London, Longman scientific & Technical publication, 1970.
4. Neville AM. Properties of Concrete (4th ed.). New York, John Wiley and Sons, 1996.
5. Price WH. Factors influencing Concrete Strength. Detroit: America Concrete Institute, 1991.
6. Arum C, Alhassan YA. Combined Effect of Aggregate Shape, Texture and Size on Concrete Strength. J of Sci, Eng and Tech 2005;13(2):6876-6887.
7. Arum C, Udoh I. Effect of dust inclusion in aggregate on the compressive strength of concrete. J of Sci, Eng and Tech 2005;12(2):6170-6184.
8. Mamlouk MS, Zaniewski JP. Materials for Civil and Construction Engineers (2nd ed.). New Jersey: Pearson Prentice Hall, 2006.
9. Ramezianpour AA, Malhotra VM. Effect of curing on the compressive strength, resistance to chloride-ion penetration and porosity of concrete incorporation slag, fly ash or silica fume. C and Conc Comp 1995;17(2):125-133.
10. Zain MF, Safiuddin M, Yusof KM. Influence of different curing conditions on the strength and durability of high performance concrete, 2010.
11. Alilou K. Teshnehlab M. Prediction of 28-day compressive strength of concrete on the third day using artificial neural networks, Int J of Eng 2010:3.
12. American society for testing and materials. West Conshohocken, PA ASTM C39, 4. 2, 2009.
13. El-Reedy MA. Steel-reinforced concrete structure. Cairo: Gulf of Suez Petroleum Company, 2009.
14. Standards Indian. Indian Standards IS 2386 Part II: Methods of Test for Aggregates for Concrete, Estimation of Deleterious Materials and Organic Impurities. India: Bureau of Indian Standards, 1997.
15. ACI Manual of Concrete Practice. Part 1: ACI 116R-90, Cement and concrete terminology, Materials and General

Properties of Concrete. Michigan: Detroit, 1994:68.
16. Standards British. British Standards BS EN 12350-2: Testing fresh concrete. London: British Standard Institution, 2009.
17. Fondriest Environmental Incorporate. Fundamentals of Environmental Measurements, 2013. Retrieved from http://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/
18. World Health Organization. Guidelines for Drinking-Water Quality (4th ed.). Geneva: Switzerland, WHO Press, 2011.
19. Neville AM, Brooks JJ. Concrete Technology (2nd ed.). Edinburgh Gate: Pearson Education Limited, 2010.
20. Neville, A. M. (2011). Properties of concrete (5th ed.). Edinburgh Gate: Pearson Education Limited, 2011.
21. Terzaghi RD. J. ACI, Proc 1948 44:977.