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Statistical Evaluation of Mechanical Strengths of Salt-Water Concrete

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Abstract: *An evaluation of the salt water from River Ovum in Ebony State, Nigeria, was carried to ascertain its suitability as mixing water for concrete production. The chemical analysis showed that the dissolved solids (1300 mg/l), alkalinity (4.1 ppm), and other impurities, are within acceptable limits for mixing water for concrete production. The salt water used as mixing water in cement paste and concrete, showed no adverse effect on the setting times. The cube compressive strength at 7 days (92 %) is above the acceptable limit of 91 %. The compressive strength ratio to flexural strength for both fresh and salt water is approximately 4 and regression models developed for both compressive and flexural strengths are statistically adequate.*
Keyword: *Salt water; Compressive strength; Flexural strength; Regression models*

I. Introduction

Ebonyi State is in the south-east zone of Nigeria and created as a state in 1996. The state has huge salt deposits in Okposi and Uburu lakes. The state is also known for local rice production and many mining activities in and around the state, which are located in the lead-zinc district of Abakaliki, thus, polluting the soil with heavy metals [1]. It is also interesting to note that Ebonyi State is guinea-worm infested due to non availability of safe drinking water [2]. These issues have made it near impossible or impossible to have quality water for drinking purposes and for construction works. These problems have been confirmed by many research works carried out on water quality in Ebonyi State [3, 4, 5, 6, 7].

The principal considerations on quality of mixing water in civil engineering works are those related to their effects on workability, strength and durability, and also health issues which are related to the safe handling of such water. These must be considered. In regard to these, there are conflicting opinions on the effect of salt water that is used as mixing water, on the compressive strengths of concrete.

Ramzi et al [8] using brackish water as mixing water, recorded increase in compressive strengths with no reversal after curing up to ninety months. Jabri et al [9] used 25 – 100 % waste water, to replace tap water used in concrete, and recorded slight decreases in compressive strength for replacement levels of 25 % and 100 % waste water, but slight increase for 50 % replacement. Concrete mixed and cured with seawater showed appreciable increase in compressive strength up to 90 days before the strength started decreasing [10]. Venkateswara and Vangala [11] registered a significant decrease in the compressive strength using strong alkaline substances as mixing water, while, Tiwari et al [12] registered an increase in compressive strength at all ages cured with salt water.

Akinkurolere et al [13] researched on the influence of salt water from Lagos lagoon, on the compressive strength of concrete. They used concrete cubes of 150 mm, a mix ratio of 1:2:4, a water-cement- ratio of 0.6, and cured up to 28 days. They concluded that the salt water used both as mixing and curing water increased the cube compressive strength of concrete.

Islam et al [14] investigated the performance of slag concrete exposed to artificially made sea water, using concrete cube specimens of 100 mm, and cured for 30 days in plain water, before exposing to different seawater environments of salt concentration of 1N, 3N, and 5N, over a period of 12 months. Replacement levels of 15 %, 30 %, and 45 % (by weight) was used and the results showed that slag-concrete of 30 % replacement and cured for 30 days is the most effective in resisting the adverse effect of sea water.

Although, much works have been done on water quality in Ebonyi State, little or no research works have been done on the effects of using the salt water as mixing water for concrete works, and so, there are limited publications in this area. This work evaluates the effects of using the salt water in this state on the mechanical strengths of concrete, and its statistical implications.

II. Materials

The cement used for this work is Dangote ordinary Portland cement and conforms to BS EN 197-1[15]. The physical and chemical properties of the cement are shown in Table 1. The fine aggregate is river sand and free from deleterious substances. It has a specific gravity of 2.62 and a bulk density, 1533 kg/ m^3. The coarse aggregate was obtained from a local supplier with a maximum size of 20 mm. It has a specific gravity of 2.65 and bulk density of 1467 kg/m^3. Both the fine and coarse aggregates conform to ASTM C33/C33 M [16], respectively. The sieve analysis for the fine aggregate is shown in Table 2.The salt water was collected from River Ovum, a tributary of River Ebonyi. The water quality analysis of the salt water is shown in Table 3.

III. Experiments

The setting times of the mixing salt water was evaluated using cement quantity of 200 kg/m^3 and water-cement ratio of 0.47, and tested using the Vicat apparatus. The results are shown in Table 4.

The salt water concrete (SWC) was also tested in the fresh and hardened condition using a mix proportion of 1: 1.5: 4 and with a water cement ratio of 0.47. The mix had a cementitious content of 340 kg/m^3, fine aggregate content of 513 kg/m^3 and coarse aggregate of 1387 kg/m^3 [17]. This mix was used to fabricate specimens that were cured for 7, 28, 60 and 90 days and tested for compressive and flexural strengths, respectively.

For the cube compressive strength test, a cube mould of 150 mm was used. A total number of ninety cubes were cast and cured to the specified number of curing days, and tested to failure. Forty-five each of the cube samples were cast using fresh and salt water respectively. At the end of each curing regime three specimens were tested to failure and the average recorded. The results are shown in Table 5.

The flexural strength test was carried out using beam samples of 150 mm x 150 mm x 500 mm, and testing a total of ninety samples also; forty-five each for the mix with fresh water and salt water, respectively. The loading arrangement was the third-point loading and the modulus of rupture (MR), evaluated using $R = {PL}/{bd^2}$ where, R is the modulus of rupture; P, the maximum applied load; L, the span; and d, the average depth of specimen. The results are shown in Table 6.

IV. Results Analysis And Discussions

Salt Water

The results of the chemical analysis of the salt water in Table 3 shows that the salt water has chemical compositions higher than those of the tap and iodized water. The pH value (7.5) is within the given range of 4.5–8.5, and thus within the acceptable limits for all substances [18]. The standard recommends that water containing less than 2000 ppm of total dissolved solids can generally be used satisfactorily in making concrete.

The maximum total alkalinity of 90 ppm measured is lower than 600 ppm recommended by the standards. Also, the maximum sulphate concentration of 97.7 ppm is less than the threshold limit of 3000 ppm and therefore, the results generally indicate, that the salt water can be used satisfactorily in concrete mixtures.

Setting Times of Salt Water Cement Paste

The results of the setting times of salt water cement paste showed an increase both in the initial and final setting times (Table 4). However, the increase was minimal but exceeded the minimum of forty five minutes stipulated by BS EN 197-1 [15]. The same confirmations were given by Ramzi et al [8] and Lee et al [19] using brackish water and treated effluent water in mixing concrete, respectively, and therefore it will not have any adverse effect on the setting time of the concrete.

Mechanical Strengths of Salt Water Concrete

The cube compressive strengths of the fresh and salt water concretes are shown in Figure 1. The salt water concrete cube strength developments are slightly less than that of fresh water. These strengths ranged from 92 % to 94 % of the fresh water concrete. The 7 day strength of the salt water concrete is approximately 92 % of the strength of the concrete made with fresh water and satisfies the 90 % given by ASTM C 109/C109M-16a [20]. The acceptance criteria for concrete mixing are therefore satisfied.

Figure 2 is the flexural strengths of fresh and salt water concrete. This has similar behavior like the compressive strength. The flexural strength ranged from 87% to 98 %. At 7 days of curing the flexural strength is again above 91 %. The compressive strength to flexural strength ratio (α), for fresh water concrete ranged from 3.8 to 4.2. Averaging, gives approximately, 4, and for salt water the ratio ranged from 3.5 to 4.2. The average is approximately, 4.0.

Statistical Implications of the Mechanical Strengths

The statistical evaluation on the experimental results using the Minitab 16 Software, showed that the cube compressive strength of the salt water concrete can be represented by the regression equation given as:

$f_{c=26.6-2.47\,A+3.71\,B,}$ the standard deviation (s) is 3.703; r^2, the interaction between the mix and age is 70.2 %; A is the mix and B, age of concrete. The ANOVA analysis showed that the chosen model is adequate with $p = 0.000$. This is further confirmed by the normality and residual plots, respectively. These are shown in Figures 3 and 4.

The same behavior is established by the flexural strength of salt water concrete. The regression equation is $f_b = 5.99 - 0.633\,D + 1.22\,F$, with a standard deviation (s) of 0.5190, r^2, 92.7 and $p = 0.000$. The ANOVA analysis showed that the model chosen is adequate and confirmed again by the normality and residual plots (Figures 5 and 6).

V. Conclusions

i. The chemical analysis of the salt water showed that the dissolved solids (1300 mg/l) and alkalinity (4.1 ppm) and other dissolved impurities are within acceptable limits and thus, the water can be used as mixing water for concrete.

ii. The setting times are within acceptable limits and the salt water will have no adverse effects on concrete.

iii. The compressive strength in this work decreases with increase in the mixing water. It ranged from 92 % to 94 % of the fresh water concrete.

iv. The 7 day compressive strength is approximately 92 %. This is greater than the 91% specified by the standard and confirms the water as good for use as mixing water for concrete works

v. The flexural strength development of the SWC ranged from 87 % to 98 % of the fresh water concrete and the 7 day strength is approximately 91 %.

vi. The ratio of the compressive strength to flexural strength (α) is approximately 4, for both the SWC and FWC.

vii. The regression models for the compressive and flexural strengths are represented respectively by: $\boldsymbol{f_c}$ $\boldsymbol{(f_b)}$ = $\boldsymbol{M - kA + Q}$, where for the compressive and flexural strengths, M is 26.6 (5.99), k, 2.47 (0.633), Q, 3.71(1.22), with a standard deviation () of 3.703 (0.5190), an interaction between the mixing water and age () of 70.2 % (92.7 %), and p-values of 0.000 (0.000).

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Table 1: Chemical Properties of Cement

Physical Properties	
Specific gravity	3.15
Bulk density (kg/m3)	1440
LOI (%)	4
Chemical Properties	
	Oxide Composition
MgO	0.09
CaO	11.3
SiO_2	63.0
Fe_2O_3	6.4
Al_2O_3	20.6
TiO_2	0.5
SO_2	2.2
Na_2O	2.1
K_2O	2.6
ZnO	Nil
MnO	Nil
CuO	Nil
CdO	Ni

Table 2: Sieve Analysis of Fine Aggregate

Sieve Size	Percentage Retained (%)	Percentage Passing (%)
8mm	0.00	100.00
5mm	4.64	95.36
2.36 mm	17.68	77.68
1.18 mm	13.16	64’52
600 µm	30.82	33.70
300 µm	22.50	11.20
150 µm	6.36	4.84
Pan	4.84	0.00

Table 3: Water Quality Analysis

	Type of Water		
Parameter	De-ionized	Bore Hole	Salt Water
Colour	0.00	0.002	0.022
Odour	Unobj.	Unobj	Unobj
Taste	Insipid	ND	ND
pH	7.00	6.4	7.5
Temp. (^oC)	28.00	28.00	28.00
Conductivity	0.00	0.24	410.00
Salinity (mg/L)	0.00	0.00	875.00
Total dissolved solid mg/l)	0.00	21	1300
Total suspended solid (mg/l)	0.00	0.04	59.00
Turbidity	0.00	0.08	46.70
DO (mg/l)	0.00	0.06	4.5
Total hardness $CaCO_3$ (mg/l)	0.00	5.20	20.90
Alkalinity (ppm)	0.00	1.04	4.01
COD (mg/l)	0.00	0.03	2.02
Total pet-hydrocarbon (mg/l)	0.00	0.00	1.5
Total hydrocarbon content (mg/l)	0.00	0.00	1.15
BOD (mg/l)	0.00	2.2	14
NO_3^{2-} (mg/l)	0.00	0.002	0.186
Phosphate (mg/l)	0.00	0.08	0.20
Phenols (mg/l)	0.00	0.00	0.51
SO_3 (mg/l)	0.00	6.7	180
Pb (mg/l)	0.00	0.02	0.01
Fe (mg/l)	0.00	0.04	0.42
Cu (mg/l)	0.00	0.34	0.61
Ni (mg/l)	0.00	0.002	0.90
Vanadium (mg/l)	0.00	0.96	0.002
Zn (mg/l)	0.00	0.001	0.03
Cd (mg/l)	0.00	0.00	0.001

Table 4: Setting Times of Mixing Water

Mixing Water	Setting Times (mins)	
Fresh Water	50	587
Salt Water	55	605

Table 5: Cube Compressive Strength Test Results (N/mm^2)

Mix No	7 d		21 d		28 d		60 d		90 d	
MC-01	31.1 24.4 26.5	27.4	38.0 26.8 28.9	31.3	42.2 33.8 31.1	35.7	39.1 44.9 35.6	39.9	40.4 41.6 45.1	42.3
MC--02	28,4 22.7 24.6	25.2	35.3 26.7 25.3	29.1	36.9 31.3 32.2	33.5	39.0 39.8 34.0	37.6	42.0 39.1 35.1	38.8

Table 6: Flexural Test Results (N/mm^2)

Mix No	7 d		21 d		28 d		60 d		90 d	
MC-01	7.2 6.2 6.4	6.6	7.8 7.1 8.7	7.9	8.9 8.8 9.6	9.1	9.4 10.5 10.8	10.2	10.8 11.9 10.9	11.2
MC--02	5.9 6.0 6.1	6.0	6.9 6.7 7.2	6.9	8.0 8.7 7.6	8.1	9.3 9.0 10.6	9.7	10.7 11.3 11.2	11.0

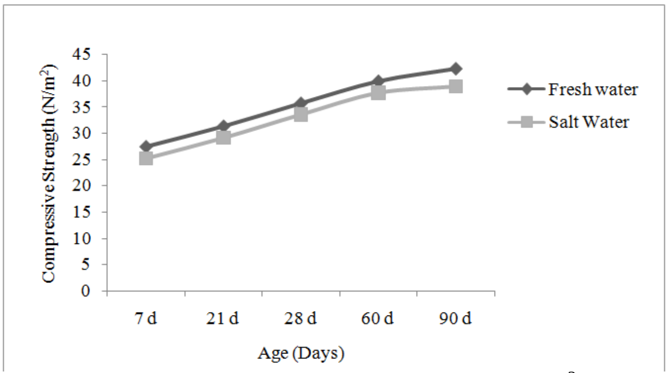


Figure 1: Cube Compressive Strengths (N/m^2)

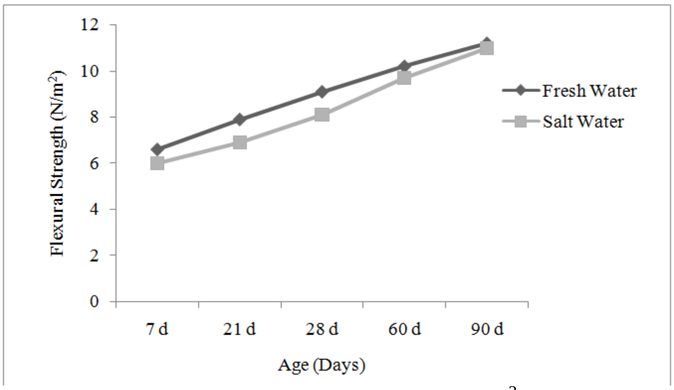


Figure 2: Flexural Strength (N/m^2)

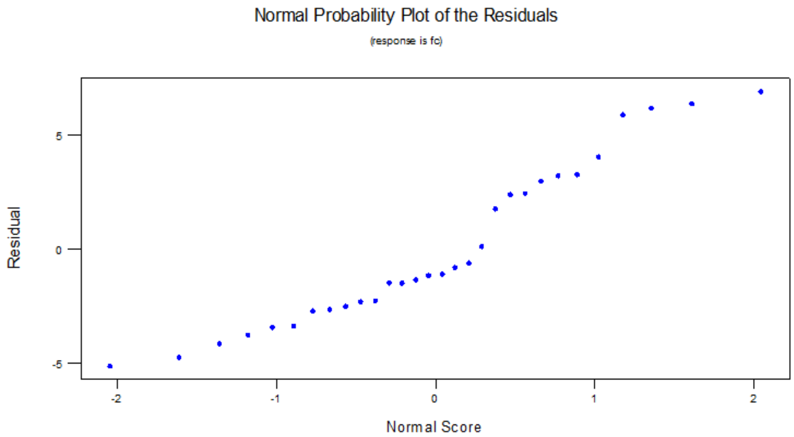


Figure 3: Normality Plot (Compressive Strength)

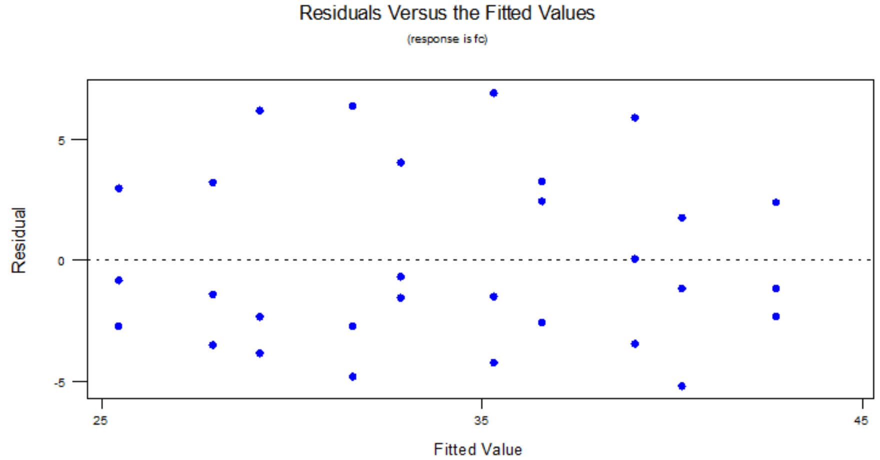


Figure 4: Residual Plot (Compressive Strength)

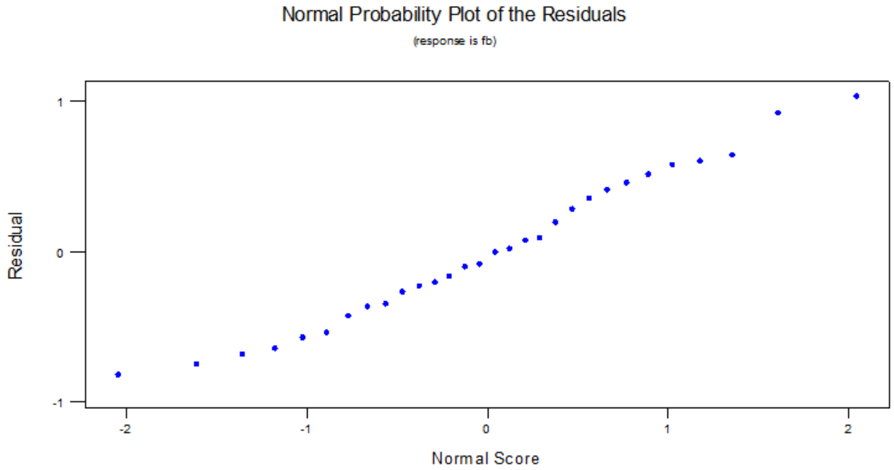
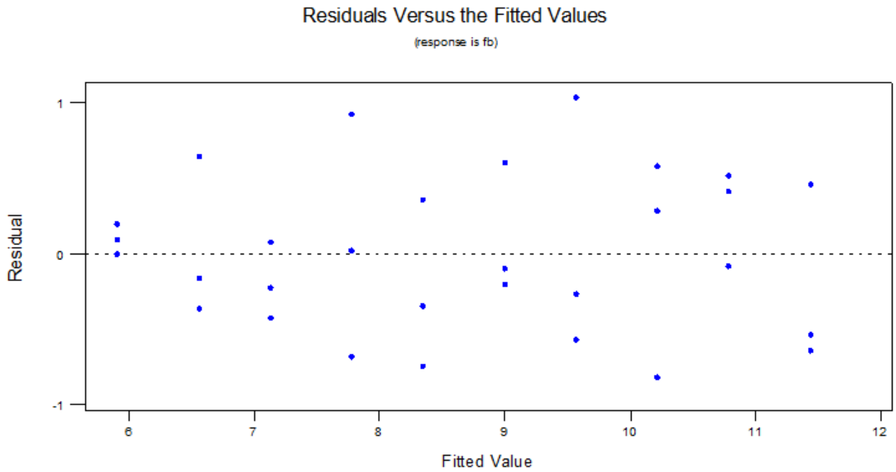


Figure 5: Normality Plot (Flexural Strength)



Figur 6: Residual Plot (Flexural Strength)