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Evaluation of Water Quality Impact on the Compressive Strength of Concrete

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ABSTRACT

This research presents the influence of mixing-water quality on the compressive strength properties of concrete using secondary and tertiary waste water treatment source, borehole and distilled water sources. Popular criteria for water quality assessment for concrete works involves the impression that once it is fit for consumption or drinking, it is therefore suitable for concrete works while other alternatives are suitability of the water used in terms of being clean and free from deleterious substances. However, these requirements may not provide a water suitability evaluation baseline for concrete works because some water quality which do not meet up with these requirements have been observed to produce satisfactory results in terms of strength and durability property performance of concrete. Statistical comparative-analysis techniques are required to evaluate the effects of water from control or referenced source of absolute quality with those of questionable quality so as to validate its usage for concrete works. The physiochemical characteristics of the water samples were ascertained before they were utilized for the concrete production and the setting time characteristics were derived, showing longer setting time results SWWT and TWWT due to high level of COD compared to DW and BW. The concrete samples produced were cured for varying hydration periods ranging from 7 – 28 days and their respective compressive strength values obtained in the laboratory. From the results, distilled water produced a maximum average compressive strength of 17.96 N/mm2 while secondary wastewater source produced the minimum results of 12.09 N/mm2. Statistical evaluation was carried out on the experimental data using ANOVA and Dunnet post-hoc test to validate the experimental findings and the details derived from the computations explains the importance of ascertaining the quality of water used for concrete production so as to achieve better overall concrete performance in terms of mechanical and durability properties.

Keywords: Concrete compressive strength; cement hydration; water quality; Dunnet test; concrete curing

INTRODUCTION

Water is a very essential concrete ingredient; it reacts chemically with cement in a reaction known as cement-hydration to obtain a required characteristic strength of the concrete produced by formation of cementitious products (Raheem et al. 2013). Water used in the mixing process impacts the workability properties of concrete and determines the required water-cementitious content ratio which affects the durability and strength properties of the concrete mix. Apart from the quantity of water used, its quality in terms of absence of impurities has significant effect on the durability, strength workability, and setting time characteristics of the concrete produced in both fresh and hardened state (Alaneme & Mbadike 2021). After concrete ingredients are mixed thoroughly with water, the concrete mixture starts to solidify due to chemical reaction between hydraulic cement and water known as cement hydration. A node is formed during this reaction which then expands and grows until it links together with the cement particle ingredients or adhere to adjacent aggregates (James et al. 2013; Alaneme & Mbadike 2019).

Potable water is generally accepted for use in mixing and curing concrete. Most concrete production plants possess a municipal water source which supplies water used for concrete production without specified characterization and qualification test. In most rural areas where construction projects are situated, supply of potable water is always limited although use of non-potable water sources for the concrete enhances sustainable concrete infrastructure by potable water resources conservation (Krishna et al. 2010). In order to achieve cost effective concrete production, water management in terms of compliance with environmental regulations becomes very essential and optimization of its consumption can lead to saving cost for the concrete works (Ozyildirim & Carino 2006). After thoroughly mixing the concrete ingredients with water, it is placed in formwork and allowed to stiffen with time. During the concrete placement, the pasty mixture is firmly compacted within the formwork using tamping rod so as to eliminate excess voids, air bubbles and honey combs. Curing starts after the concrete's surface exposed to moisture have hardened to resist marring; it serves as an extension of the cement hydration so that the strength development of the concrete is enhanced. Hydration causes rapid gain in strength from 7 to 28 days but this increment rate becomes slower for longer hydration periods (Zeyad 2017; Alaneme et al. 2021).

When non-potable water is used which possess dissolved salts, grease and oil; it is important to assess the level of impurities to ensure the water do not inhibit concrete performance. Several research studies had been successfully carried out in order to evaluate the effects of water quality and its inherent properties on the mechanical strength characteristics of concrete produced. Terro et al. (2003) in their research work, the concrete mechanical properties whose mixture were produced with treated wastewater at elevated temperature and ambient were investigated. Concrete samples were cast using varying water sources which involves tap water, primary, secondary, tertiary, and local waste water treatment plant; these water were subjected to chemical analysis after collection for characterization. The concrete's setting time, compressive strength at elevated (up to 7000c) and ambient temperature, durability properties in terms of reinforcement resistance to corrosion were ascertained to evaluate the effect of the water quality. The results obtained indicated that concrete made with primary and secondary treated wastewater produced lower strength properties at ambient temperature and longer setting time than concrete samples made with tap water and tertiary treated wastewater. However at elevated temperatures, the strength of concrete produced with treated wastewater exhibited lower strength property values than those of tap water. Also Sandrolini et al. (2001) investigated the re-use of waste wash water from ready-mixed concrete plant for concrete mixing and mortar production with respect to microstructural analysis and physical-mechanical properties to evaluate the effect of the waste water used. The results indicated that the concrete and mortar produced with waste water exhibit 28-day hydration period mechanical strength characteristics in no way lower than 96% of the control materials which is higher than 90% minimum value prescribed by prEN1008. It was observed that the utilization of waste wash water in concrete brings about a reduction of water absorption, concrete capillarity and micro-porosity property of the mortar which enhances the durability of the concrete material. Furthermore, Thandavamoorthy (2015) in his research work on the compressive strength evaluation of in-situ concrete using ANN at six varying locations, the surface of a concrete case is struck with an impactor and induced accelerated reading were recorded and utilized for the concrete strength determination. This accelerated induced readings were fed to the network as the input variables while the concrete strength responses were the target parameter of the network with acceleration values ranging from 0.7 m/s2 to 136.4 m/s2. Compressive strength ranging from 16 MPa to 45.56 MPa were obtained and the generated mould performance were found to be satisfactory from the correlation analysis between measured and predicted results.

This research study aims to investigate the effects of varying water quality to the compressive strength of concrete cured for hydration period of 28 days; the concrete prepared and mixed with distilled water is used as control. This research study will add to existing knowledge in concrete material development and also the importance of water quality assessment in concrete production. The research gains expected will encourage better decision-making in terms of batching and grade of concrete with special care on the water quality. Careful mixing and proportioning of concrete mixture ingredients help to achieve durable and strong concrete because proportioning of the mixture constituents influences the availability of cementing paste and voids in the concrete aggregates to ensure improved strength characteristics of the concrete. The proportioning is expected to ensure that the material consumption is optimized i.e., the right quality and quantity of the mixture ingredients to obtain desired concrete strength and durability property is utilized (Al-Gahtani et al. 1998; Alaneme et al. 2021a).

MATERIALS AND METHODS

TEST MATERIALS

The test materials investigated in this research study constitute the concrete mixture ingredients which includes; cement, fine and coarse aggregates, and water. The cement used is Dangote limestone Portland cement. The fine aggregate was obtained from the sand beach at Ofrekpe, Ikwo LGA of Ebonyi state while the coarse aggregates was sourced from Umuoghara Quarry site in Ezza North, Ebonyi state.

WATER USED

The water samples used for the analysis were ordinary borehole water from Alex Ekwueme Federal University Ndufu-Alike, Ebonyi State. The distilled water were obtained from the pipe of an LG dual inverter electronic air-conditioning unit while the wastewater were sourced from the Lagos waste treatment plant, Parliament road, Amuwo Odofin Estate, Lagos State. It satisfies ASTM C1602-12 requirement of water for use in concrete mixture.

AGGREGATES USED

Coarse aggregates used were in the form of graded crushed granite ranging from size 20 mm to 1.18 mm which was sourced from the local stone market at the area of study while the fine aggregate, whose size ranges from 0.05 to 4.5 mm was procured from the local river was used in the experimental investigation and conforming to ASTM C125-16 (2016).

EXPERIMENTAL METHOD

This research investigated the effect of different sources of water on the compressive strength of concrete. The water samples used for the analysis were distilled water obtained from the pipe of an LG dual inverter electronic air-conditioning unit and ordinary borehole water from Alex Ekwueme Federal University Ndufu-Alike, Ebonyi State. The chemical compositions of these water qualities were determined by carrying out a physiochemical analysis. Three replicated concrete cubes were produced for each of the curing ages according to BS 5328 in the ratio of 1:1.80:3.32 using each water quality type. The cubes were cured and crushed at 7, 14 and 28 days respectively using the Stewarts Elle universal testing machine to calculate the concrete's compressive strength response with respect to the varying days of hydration and the findings were statistically processed to observe the performance of concrete mixed and cured with the two different water qualities evaluated in this study (Ikpa et al. 2019; Aghamelu et al. 2011; Attah et al. 2020; Safiuddin et al. 2007).

CONCRETE INGREDIENTS MIX DESIGN

Design of concrete mix M20. Quality control (Institution, I.S. 2000).

Concrete characteristic compressive strength at 28 hydration period =20N/mm2;

Nominal mix size of aggregate = 20mm;

Concrete aggregate shape = Angular;

Require slump = 50 -75mm;

Concrete exposure condition = severe condition of exposure;

Type of cement used = Portland Limestone cement (Dangote).

DESIGN OF CONCRETE MIX PROCEDURE

Particle size distribution for Fine aggregates and coarse aggregates.

Specific gravity of FA and C.A. 2.64 & 2.84 respectively: cement = 3.15

Fine aggregate is in zone II (Institution, I.S. 1970).

• Concrete target strength determination:

Himsworth constant for 5% risk factor = 1.65 and standard derivation (Institution, I.S. 2000).

For M20 = 4.0 (Institution, I. S. (2009).

$f_{target} = f_{ck} + 1.65 \times S$ = 20 + 1.65 x 4 = 26.6N/mm^2.

• Water cement ratio (w/c) determination (IS 456: (page 20), table 5) (Institution, I.S. 2000)

Max w/c taken for plain concrete under severe exposure = 0.5

• Selection of water content for concrete mix (Institution, I.S. 2009).

Max water content = 186kg (for max aggregate size of 20mm)

Correction in water content (Institution, I.S. 2009).

Slump of 75mm

Corrected water content at slump of 75mm = 186 + (3% of 186) = 191.6kg/m3.

• Cement content for the concrete mix (Institution, I.S. 2000).

w/c = 0.5

Corrected water content = 191.6kg/ m^3.

Cement content calculated = $\frac{corrected\ water\ content}{w/c} = \frac{191.6}{0.5}$ = 383.2kg/ m^3

From Table 5 of IS: 456-2000 (Aldea et al. 2000).

383.2kg/ m3> 250kg/ m3 OK this value need to be checked for durability requirement (Institution, I.S. 2000).

• Estimation of C.A. Proportion of the Concrete Mix (Institution, I.S. 1970).

Zone of fine aggregate = Zone II

w/c =0.5

Nominal max aggregate size = 20mm

Volume of C.A. per unit volume of concrete = 0.62

Hence volume of F.A =1-0.62 = 0.380

• Materials Estimation

Volume of concrete = 1 m^3

Volume of cement = $\frac{cementweight}{cementSG} \times \frac{1}{100} = \frac{383.2}{3.15} \times \frac{1}{100} =$ 0.121 m^3

Volume of water = $\frac{waterweight}{waterSG} \times \frac{1}{1000} = \frac{191.6}{1} \times \frac{1}{1000} =$ 0.1916 m^3

Volume of aggregates = $a-(b+c)=1-(0.121+0.1916)=0.6874\ \mathrm{m}^3$

Weight of C.A = 0.6874 x 2.84 x 1000 = 1307.98kg/ m^3

Weight of F.A = 0.6874 x 0.380 x 2.64 x 1000 = 689.59kg/ m^3

• Concrete Mix Proportion for Cement Trial

Cement: 383.2kg/ m^3

Water: 191.6kg/ m^3

F.A: 689.59kg/ m^3

C.A: 1307.98 kg/ m^3

W/C: 0.5

Ratio obtained: 1:1.80:3.32

DATA PROCESSING TECHNIQUE

Statistical analysis technique (Analysis of variance) is utilized for the processing of the experimental data obtained to assess the mechanical strength characteristics of the concrete mixed and cured with water of varying quality characteristics. Using statistical software, Minitab 18, the data sets were analyzed to derive the statistically significant difference to enable the acceptance of the null or alternate hypothesis. Dunnet multiple comparison test is also carried out after the ANOVA on the data to obtain the level of statistical significance for the compared water sources with respect to the control or referenced source of absolute quality (DW) (Alaneme et al. 2020). Based on mathematical expression, the Dunnet test is similar to Tukey's test except in the following respects; instead of testing:

$$\bar{x}_{\max} - \bar{x}_{\min} > q_{crit}\sqrt{\frac{MS_w}{n}} \quad (1)$$

We test whether $|\bar{x}_i - \bar{x}_0| > t_d\sqrt{\frac{2MS_w}{n}}$ (2)

Where $\overline{x_0}$ is the control mean group, n is the sample size, t_d is the two critical value of Dunnet and $\overline{x_i}$ is the mean of the other group.

The Dunnet test can also be used for unequal group with mathematical expression present in Eqn. 3

$$|\bar{x}_i - \bar{x}_0| > t_d\sqrt{MS_w\left(\frac{1}{n_i}+\frac{1}{n_0}\right)} \quad (3)$$

For the experimental methods, the mix-ratio of the concrete ingredients is first designed using Indian code following specified procedure so as to ensure optimal utilization of the concrete materials (Dunnett, 1985).

CONCRETE MIXTURE DESIGN FLOW CHART FOR THE TEST

The flow chart showing the step by step procedure for the concrete mixture design and proportioning of the constituting ingredients consisting of cement, water, fine and coarse aggregates is presented n Figure 2. The processes involved starts from utilization of suitable or specified standard for the mixture design methodology; for this research study, suitable code was utilized to achieve the mix design. The concrete mix-design procedure starts with the determination and prescription of design parameters and specification such as characteristic strength determination at 28 days hydration period, selection of appropriate slump value, maximum aggregate size, cement type, and exposure condition requirement determination (Alaneme & Mbadike 2019a).

The next step involves the experimental testing of the concrete mixture ingredients to obtain the following; particle size distribution of aggregates, specific gravity of cement and aggregates, and classification of fine aggregates zone (Institution 1970).

The data generated from these first two steps are then utilized for the concrete mix design processes which starts from the determination of target compressive strength through the linear combination of the Himsworth constant for 5% risk factor and the standard deviation (Institution, I.S. 2000); with respect to the design concrete grade using the mathematical expression in Eqn. 2

$$F_{target} = f_{ck} + H \times S \quad (2)$$

Where f_{ck} is the characteristic compressive strength of concrete, H is the Himsworth constant and S is the standard deviation.

After determination of the target strength of the concrete, the water cement ratio (w/c) is obtained with respect to the concrete exposure condition. w/c is used for calculation of the water content required for the concrete through which the correction in water content required C_w is derived (Institution, I. S., 2009); from the formula presented in Eqn. 3

$$C_w = M_w + (3\% \times M_w) \quad (3)$$

Where M_w is the maximum water content with respect to aggregate maximum size.

The cement content required C_c for the concrete mix is then calculated from the specified w/c and the corrected water content C_w rom the mathematical expression presented in Eqn. 4

$$C_c = \frac{C_w}{w/c} \text{ (Kg/m}^3\text{)} \quad (4)$$

As specified by the code, the computed cement content is then compared with the minimum cement content required for plain concrete with respect to the specified exposure condition and if the computed value is less than the minimum cement content value, the minimum is then selected but if it's greater, we choose the higher value calculated for the cement content. This check is required to check the concrete durability requirement (Institution 2000).

The next stage will involve the calculation of fine aggregate quantity using fresh concrete estimated weight and already derived quantities of coarse aggregate, water and cement. After that comes the adjustments for the aggregates moisture content which is carried out carefully before the trial mix and finally, estimation of the concrete ingredient materials from which the effective mix ratio is then derived (Aldea et al. 2000).

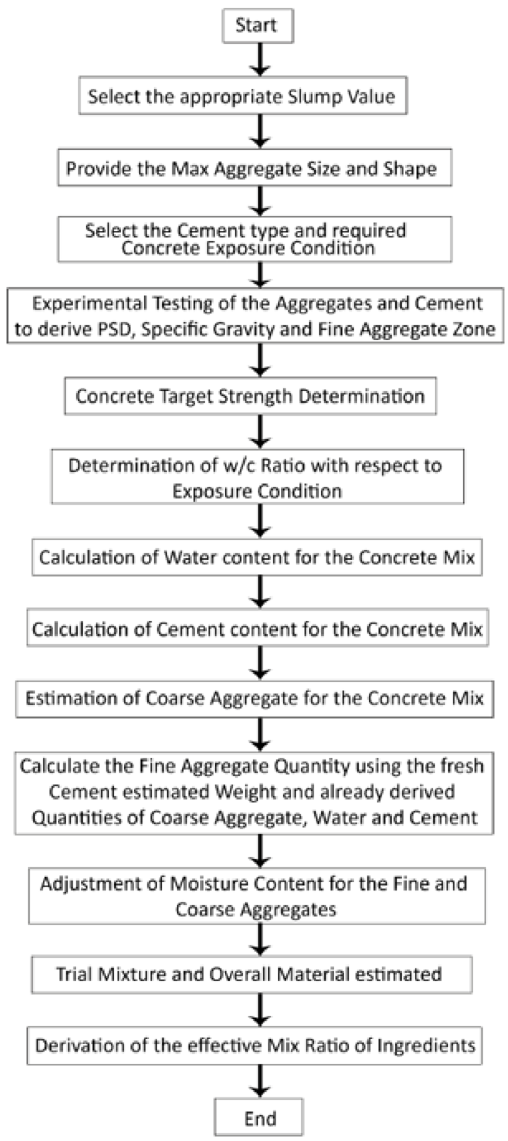

FIGURE 2. Concrete Mix Design Flow chart

RESULT DISCUSSION AND MODEL DEVELOPMENT

MATERIALS CHARACTERIZATION

TEST WATER PROPERTIES

The water samples (secondary waste water (SWWT), tertiary waste water (TWWT), borehole water (BW), and distilled water (DW)) investigated in this study were assessed to characterize its physiochemical properties such as solid analysis, temperature, pH, chemical oxygen demand (COD), and turbidity characteristics as shown in Table 1. From the results, solid analysis (total suspended solid (TSS), volatile suspended solid (VSS) and total volatile solid (TVS)) produced a higher value for SWWT and decreased slightly for TWWT while small value was observed for BW and none for DW. The pH value indicated alkaline value of 7.98 and 7.75 for SWWT and TWWT respectively while lower alkaline results were obtained for BW at 7.36 and DW produced a near neutral pH value of 7.04. The concentration of sulphate, Nitrate, chloride, ammonium, sulphide and COD also tend to produce higher results for SWWT and TWWT while the corresponding results decreased to minimum for BW and almost absent for DW which signifies little or no concentration of the chemical impurity concentrations (Uddin et al. 2012; Alaneme & Mbadike 2021b).

TEST AGGREGATES PROPERTIES

The sieve analysis experimental result of the fine and coarse aggregates which enables the assessment of the particle

TABLE 1. Physicochemical Properties of Test Water for the Concrete Production

Parameter	Secondary Wastewater	Tertiary Wastewater	Borehole Water	Distilled Water
Temperature (°C)	27.15	26.98	25.55	24.84
Conductivity(μ S/cm)	78.3	71.44	63.5	55.22
pH	7.98	7.75	7.36	7.04
Turbidity (NTU)	0.39	0.35	0.26	0.12
TSS (mg/l)	12.07	9.46	9.12	0
VSS (mg/l)	11.14	9.17	8.58	0
TVS (mg/l)	135	118	105	100
Sulphate (mg/l)	188	150	15	0.08
Nitrate (mg/l)	2.42	1.68	0.15	0
Chloride (mg/l)	286.7	217.12	96.2	25.4
Ammonium (mg/l)	45.68	35.33	0.25	0
COD (mg/l)	66.81	32.64	5.5	0.13
Alkalinity (mg/l)	69.73	51.62	22.14	4.25
sulfide (mg/l)	0.38	0.1	0	0

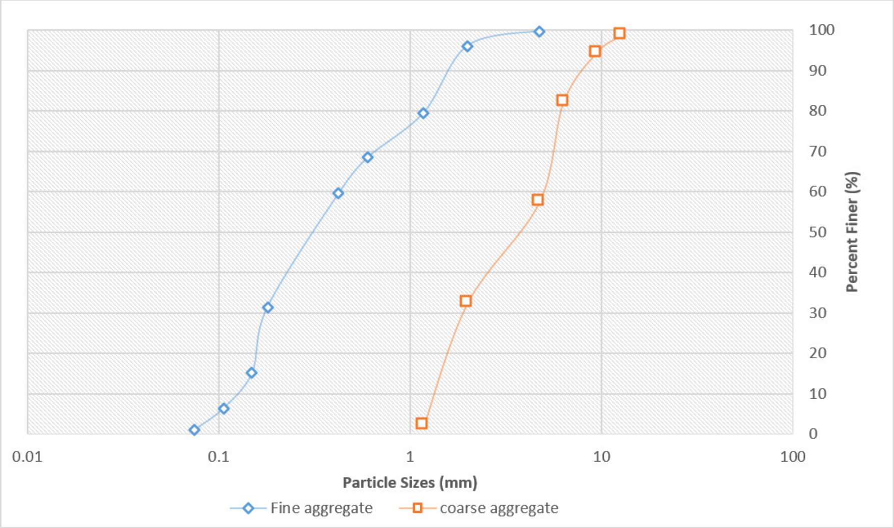

FIGURE 3. Concrete aggregate particle size distribution

size distribution (PSD) is presented in Figure 3. From the results, 98.66 % and 32.51 % is passing through sieve size 12.7 mm and 2 mm respectively for the coarse aggregates while 96.12 % and 1.12 % is passing through sieve size 2 mm and 75 μm respectively for the fine aggregates.

SETTING TIME RESULTS

The water quality effects on the initial and final setting time characteristics of the concrete mixes is presented in Figure 4; showing the results with respect to the water quality sources under investigation. From the results, shorter setting time for the distilled water (DW) and borehole water (BW) mixture paste samples was observed compared to the secondary (SWWT) and tertiary waste water treatment source mixture paste (TWWT). This is due to higher chemical oxygen demand (COD) concentration in STTW and TWWT samples which consequently results in concrete with longer setting time properties which is in agreement with the research findings of Terro et al. (2003) and Chimmaobi et al. (2020)

CONCRETE COMPRESSIVE STRENGTH CHARACTERISTICS VS. PERIOD OF CURING

The concrete compressive strength property results obtained from crushing test in the laboratory plotted against the curing period (days) with respect to the different sources of water of varying quality namely; SWWT, TWWT, BW and DW were presented in Figure 5. From the results, it is observed the double effect of water quality and hydration period on the concrete compressive strength. The details derived from the plot indicates that concrete mixed with DW produced the best strength performance followed by BW, TWWT and then lastly SWWT which clearly outlined a setback in the concrete strength due to water quality ratings. The strength development of the test concrete samples were further observed to improve with longer period of hydration which shows a direct proportionality between the two variables of curing age and strength property. This is possible due to the formation of cementitious products obtained from cement hydration reaction; the increment rate at the initial curing period is

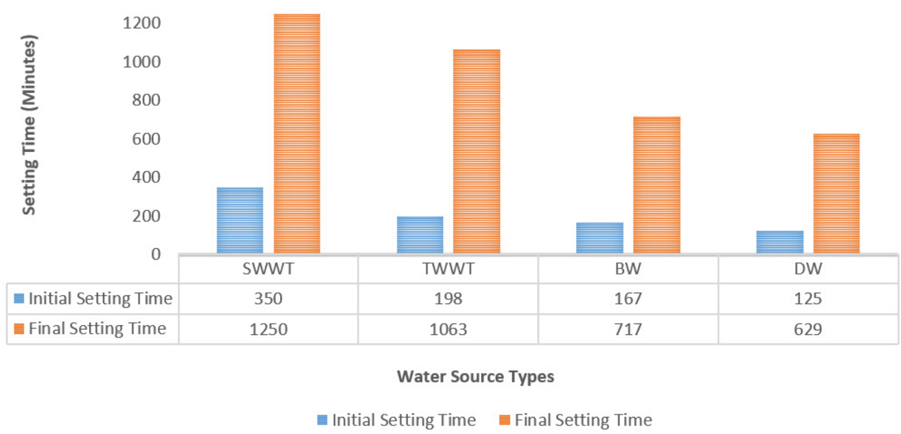

FIGURE 4. Setting time results

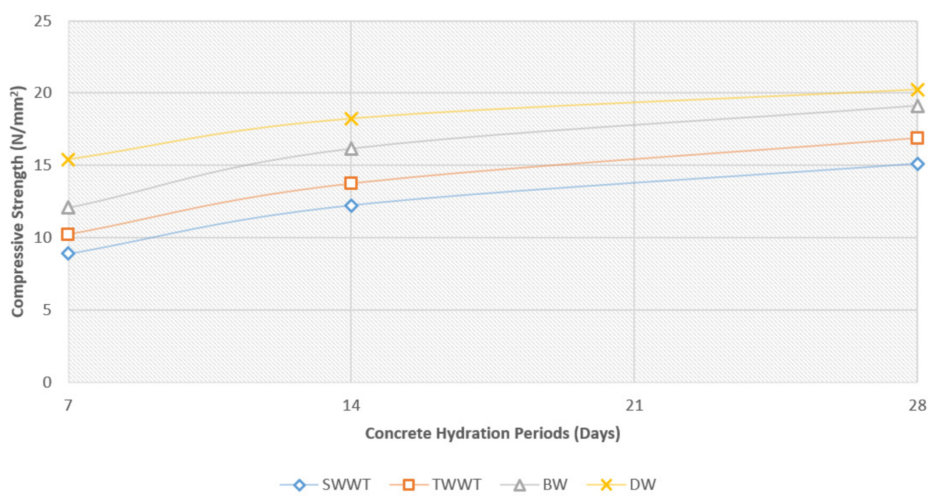

Figure 5. Concrete Compressive Strength vs. Curing Period

moderate but this rate increases after the first week till the 28th day of hydration (Neville 2012; Ogbonna et al. 2020). This research study shows the importance of water characterization so as to ascertain its impurity level before utilization for concrete production as it was observed that water with less impurity (distilled water) produced higher strength performance than the concrete mixed and cured with water of questionable impurity levels (Safiuddin et al. 2007; Shoba & Raju 2005).

STATISTICAL ANALYSIS AND VALIDATION OF RESULTS

ANALYSIS OF VARIANCE (ANOVA)

Analysis to evaluate statistical significance between the compared data sets is carried out using Minitab 18 statistical software; so as to determine when to accept or reject the proposed statistical hypothesis which are presented in Table 2;

TABLE 2. Analysis to evaluate statistical significance between the compared data sets

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	α = 0.05

Equal variances were assumed for the analysis

FACTOR INFORMATION

The factor information which constitutes the dependent and independent variables; for this research study, we have two factor levels presented in Table 3.

TABLE 3. Factor Information

Factor	Levels	Values
Factor	4	DW, BW, SWWT, TWWT

ANOVA RESULTS

The result output of the analysis of variance (ANOVA) is shown in Table 4. Which is carried out using F-statistics to compute a P-value of 0.190; this result indicates that there is significant difference between the compared data sets and we hope to conduct a post hoc test using Dunnet statistical tests to determine the level of statistical significance between the compared factor levels (Alaneme et al. 2020a).

TABLE 4. Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Factor	3	59.24	43.05%	59.24	19.747	2.02	0.190
Error	8	78.38	56.95%	78.38	9.798		
Total	11	137.62	100.00%				

MODEL SUMMARY

The computed model summary is presented in Table 5. Which presents the coefficient of determination of 43.05% and predicted error sum of residual (PRESS) of 176.359 indicating poor prediction accuracy based on the input-output variables (Alaneme & Mbadike 2019a). The mean of the compared data sets as obtained from descriptive statistics and at 95% confidence interval computed as presented in Table 6.

TABLE 5. Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
3.13013	43.05%	21.69%	176.359	0.00%

TABLE 6. Means

Factor	N	Mean	StDev	95% CI
DW	3	17.96	2.44	(13.79, 22.13)
BW	3	15.80	3.54	(11.63, 19.97)
SWWT	3	12.09	3.10	(7.92, 16.25)
TWWT	3	13.61	3.33	(9.44, 17.78)

Pooled StDev = 3.13013

The computation summary of the mean comparison is presented in the interval plot graph of the distilled and borehole water shown in Figure 6;

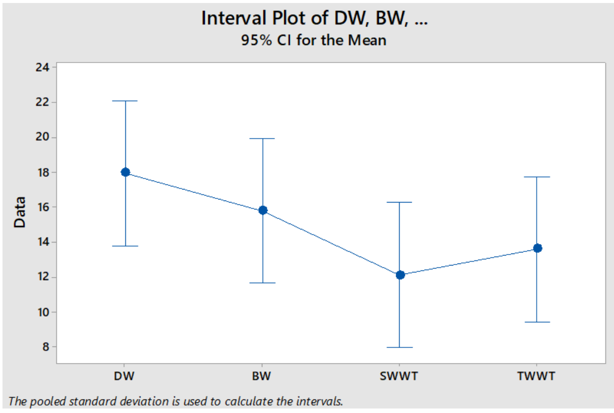

FIGURE 6. Interval Plot of Distill, borehole

RESIDUAL PLOTS FOR THE INPUT-OUTPUT VARIABLES

The statistical analysis output plots showing the fitted value vs. residual, the normal probability plot and the residual vs. frequency histogram chart which shows the regression assumption compliances is presented in Figure 7.

DUNNET PAIRWISE COMPARISON

Grouping information using the Dunnett Method and 95% Confidence; the control is the response with respect to distilled water and it is compared statistically with the lab response for concrete produced with borehole water [26]. The result summary is presented in Tables 7 and 8.

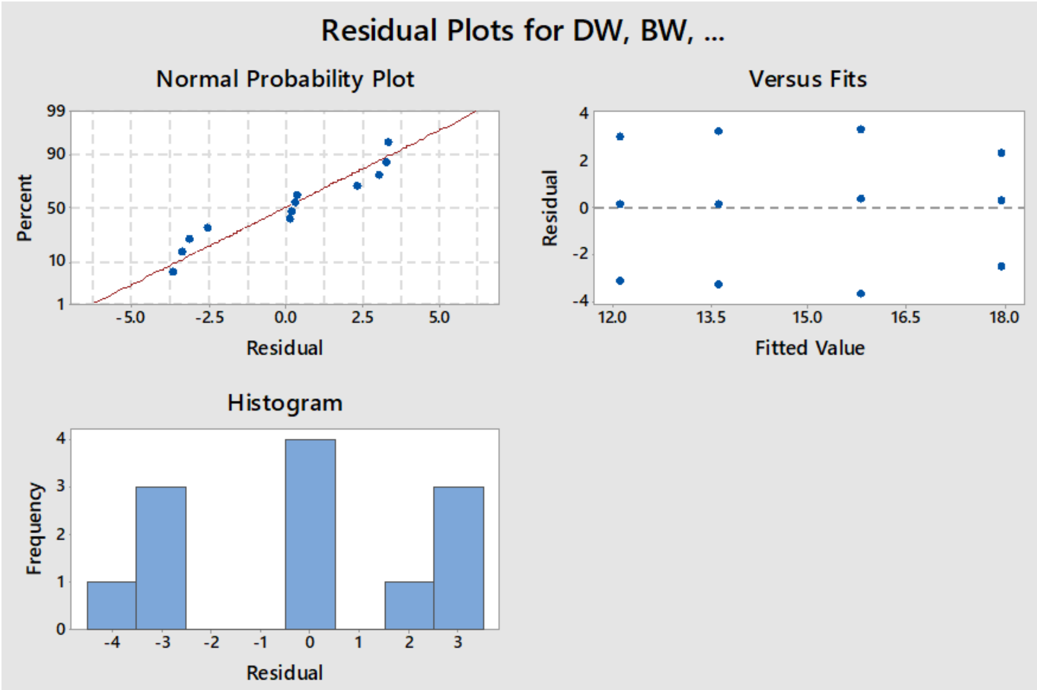

FIGURE 7. Residual Plots for Distill, borehole

TABLE 7. Dunnett Multiple Comparisons with a Control

Factor	N	Mean	Grouping
DW (control)	3	17.96	A
BW	3	15.80	A
TWWT	3	13.61	A
SWWT	3	12.09	A

Means not labeled with the letter A are significantly different from the control level mean.

TABLE 8. Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
BW - DW	-2.16	2.56	(-9.52, 5.20)	-0.85	0.741
SWWT - DW	-5.87	2.56	(-13.23, 1.49)	-2.30	0.118
TWWT - DW	-4.35	2.56	(-11.71, 3.01)	-1.70	0.278

Individual confidence level = 97.95%

From the results obtained from the Dunnet pairwise comparison test, the difference of means of -2.16, -5.87 and -4.35 for BW, SWWT and TWWT to control comparison respectively with a constant sum of errors difference of 2.56 as shown in Figure 8. From the presented results, we can observe the statistical rating of the performance with respect to water effect in the concrete samples and it shows the closest performance to the control (distilled water source) in the following order; borehole water source, tertiary treated water source while the secondary wastewater treated sample source produced the worst performance (Alaneme & Mbadike 2021a; Upton & Cook 2006).

CONCLUSION

Based on the research findings and evaluations of the water quality effect on the mechanical strength properties of the concrete produced, the following conclusions can be drawn;

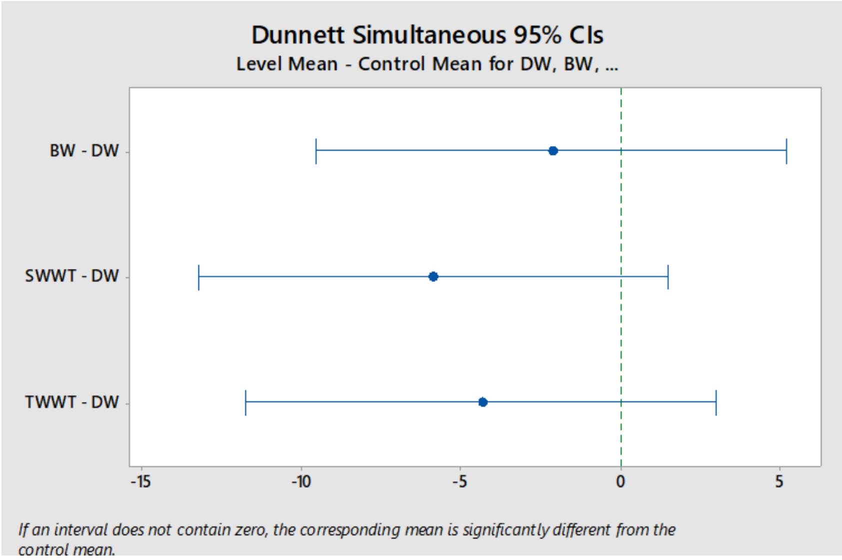

FIGURE 8. Dunnett Simultaneous 95% CIs

1. The concrete strength increases with prolonged period of hydration which was observed from the experimental results and the increment gets higher after the initial of days of curing. This is due to the rate of formation of cementitious products. As a result the compressive strength continues to increase with prolonged hydration period.

2. Water quality used for mixing and curing of the concrete had significant effect on the strength development, setting time and its overall performance. A distilled water mixed concrete which contains very little or insignificant level of impurity in it performs better than concrete produced with borehole water and wastewater treated sources. This is due to the presence of impurities in the form of dissolved salts, oil or grease which retards the hydration reaction and in turn reduces the compressive strength of the concrete.

3. The water sources evaluated in this study were characterized in the laboratory to ascertain their physicochemical properties and the level of concentration of impurities before mixing with the cement and from the result, the waste water treatment sources possessed higher level of impurities compared to borehole water with the distilled water possessing little or no impurity concentrations.

4. The concrete mixture ingredients were perfectly designed for M20 concrete using Indian code specifications to provide the appropriate ratios for the constituents in accordance with the required slump and exposure condition. The outcome of the design mix was utilized for the mixing of the concrete after which the fresh concrete was then placed in the cube mould, compacted and vibrated adequately to eject air bubbles.

5. The setting time results indicates a shorter setting time for distilled water (DW) and borehole water (BW) mixture paste samples compared to SWWT and TWWT. This is due to higher chemical oxygen demand concentration in the waste water treatment sources which consequently results in concrete with longer setting time properties. The averaged compressive strength for 7 to 28 days curing period produced a maximum result of 17.96 N/mm2 for distilled water source (DW), while SWWT produced the minimum result of 12.09N/mm2. BW and TWWT produced a compressive strength result of 15.8N/mm2 and 13.61N/mm2 respectively.

6. The obtained experimental results that were used to evaluate the water quality effect on the concrete strength property were analysed statistically using ANOVA to determine if there is statistical significance between the experimental datasets. Dunnet statistical pairwise-comparison test was utilized to assess the level of significance between the control sample (DW) and the compared water sources after the ANOVA test result. A 95% Confidence intervals of (-9.52, 5.20), (-13.23, 1.49) and (-11.71, 3.01) for BW-DW, SWWT-DW and TWWT-DW respectively was computed with sum of errors difference of 2.56 and Individual confidence level of 97.95%.

7. The statistical results indicated that the BW produced the best performance using the pairwise comparison tests

with respect to the control (DW) with a difference of means of -2.16, while -4.35 and -5.87 were obtained for TWWT and SWWT respectively. This shows that SWWT produced the worst performance.

8. The results obtained from this research study indicates the negative impact of poor water quality in the compressive strength property of concrete and helps to enlighten engineers and professionals in the construction industries the importance of evaluating the quality of water used for concrete production.

DECLARATION OF COMPETING INTEREST

None.

ABBREVIATION

PSD – Particle Size Distribution
TSS – Total Suspended Solid
VSS – Volatile Suspended Solid
TVS – Total Volatile Solid
COD – Chemical Oxygen Demand
DW – Distilled Water Source
BW – Borehole Water Source
TWWT – Tertiary Wastewater Treatment Source
SWWT – Secondary Wastewater Treatment Source
ANOVA – Analysis of Variance

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