

MODELLING THE PERFORMANCE OF OGORORO AS A BIO-ADMIXTURE IN CONCRETE

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ABSTRACT

This study evaluates the feasibility of *ogogoro* a locally distilled alcoholic beverage as a sustainable bio-admixture in ordinary Portland cement concrete. Concrete mixes were prepared with *ogogoro* replacing 0–4 % of the mixing water (by volume) and tested for slump, setting time, and compressive strength. Low dosages ($\approx 1\text{--}2\%$) improved slump and flowability, whereas higher dosages reduced workability due to increased mix viscosity. *Ogogoro* produced a dosage-dependent delay in both initial and final setting times, providing extended working time at moderate levels but excessive retardation at higher contents. Early-age compressive strength decreased slightly, yet 28-day strength recovered or improved at 1–2 % dosage, suggesting delayed but enhanced hydration. A three-dimensional cubic polynomial model accurately predicted compressive strength as a function of *ogogoro* content and curing age, achieving a coefficient of determination $R^2 > 0.98$. These findings indicate that moderate *ogogoro* dosages can enhance long-term strength and reduce reliance on imported chemical admixtures, offering a low-cost, locally sourced and environmentally friendly alternative for sustainable concrete production.

Keywords: Bio-admixture, *ogogoro*, sustainable concrete, workability, setting time, compressive strength, cubic polynomial modelling, locally sourced materials

1.0 INTRODUCTION

Concrete remains the most widely utilized construction material in the world due to its versatility, durability, compressive strength, and the widespread availability of its constituent materials cement, fine aggregate, coarse aggregate, and water. Rapid urbanization and infrastructural development have significantly increased global concrete consumption, thereby intensifying concerns regarding the environmental impact of cement production. Portland cement manufacturing is recognized as one of the major contributors to anthropogenic carbon dioxide (CO_2) emissions, accounting for approximately 7–8% of global emissions associated with industrial activities (Andrew, 2018; Scrivener *et al.*, 2018). In addition, the growing demand for concrete has increased pressure on natural resources and energy consumption, prompting researchers to investigate sustainable alternatives capable of reducing the environmental footprint of concrete production while maintaining desirable engineering performance. One of the major approaches toward sustainable concrete technology involves the incorporation of supplementary materials and alternative admixtures derived from renewable or locally available resources. Admixtures are substances introduced into concrete during mixing to modify either fresh or hardened properties such as workability, setting characteristics, durability, and strength development.

Conventional chemical admixtures including superplasticizers, retarders, and accelerators are extensively used in modern concrete production to improve performance and constructability. However, many of these commercial admixtures are relatively expensive in developing countries because they are imported and may involve environmentally intensive manufacturing processes (Ramachandran, 2019).

Consequently, increasing attention has been directed toward bio-admixtures naturally derived organic substances obtained from agricultural products, industrial residues, or biological processes as environmentally friendly and economically viable alternatives.

Recent studies have demonstrated that naturally occurring organic compounds can significantly influence cement hydration and concrete performance. Olanrewaju *et al.* (2021) reported that bio-based admixtures derived from agricultural and organic sources possess considerable potential for modifying fresh and hardened concrete properties while supporting sustainable construction practices. Similarly, Kaze *et al.* (2018) observed that sugarcane molasses can retard cement hydration and alter workability depending on dosage level and concentration. Organic compounds such as sugars, alcohols, and organic acids have been shown to interact with

cement particles, affecting hydration kinetics, rheological behaviour, and long-term strength development (Zhang *et al.*, 2016). These findings suggest that locally available bio-products could serve as low-cost alternatives to conventional chemical admixtures, especially in regions where access to commercial additives is limited.

In Nigeria and several other developing nations, indigenous fermented products and agricultural derivatives have attracted attention as sustainable construction materials due to their affordability and availability. One such material is ogogoro, a locally distilled alcoholic beverage produced primarily from fermented palm wine or raffia palm sap. Ogogoro contains ethanol, water, organic acids, esters, aldehydes, and other fermentation by-products that may chemically interact with cementitious systems. Ethanol-based compounds are known to influence cement hydration by modifying the dissolution rate of clinker minerals and altering the microstructure of hydration products (Zhang *et al.*, 2016). In addition, organic acids and sugars may either retard or accelerate hydration reactions depending on their concentration and interaction with cement phases (Ramachandran, 2019). Despite the growing interest in sustainable admixtures, limited scientific information exists regarding the application of ogogoro as a bio-admixture in concrete production. From a technical standpoint, the incorporation of ogogoro into concrete may influence important fresh and hardened properties such as workability, setting time, and compressive strength. Its ethanol content could potentially improve particle lubrication and modify the rheological behaviour of fresh concrete, while excessive organic constituents may increase viscosity and reduce flowability at higher dosages. Furthermore, the retardation effect associated with alcohols and sugars may alter the initial and final setting characteristics of cement paste, thereby affecting handling and finishing operations. The influence of ogogoro on compressive strength development is also of significant interest because delayed hydration may reduce early-age strength while enhancing later-age strength through prolonged hydration processes. Understanding these interactions is essential for evaluating the suitability of ogogoro as a sustainable construction admixture.

Beyond technical performance, the utilization of ogogoro as a bio-admixture aligns with principles of sustainable construction and circular economy development. The use of locally sourced materials can reduce dependence on imported chemical admixtures, lower construction costs, encourage local resource utilization, and minimize environmental impacts associated with industrial admixture production. Furthermore, valorization of locally abundant organic products contributes to waste reduction and supports rural economic activities associated with local distillation and agricultural production. Sustainable material utilization has therefore become an important strategy for achieving environmentally responsible infrastructure development in emerging economies (Scrivener *et al.*, 2018). This study therefore investigates the feasibility of using ogogoro as a bio-

admixture in ordinary Portland cement concrete. The research systematically evaluates its influence on workability, setting time, and compressive strength at different dosage levels. In addition, polynomial predictive models are developed to assess the relationship between ogogoro dosage and concrete strength development. The findings are expected to provide scientific insight into the applicability of indigenous bio-admixtures in concrete technology and contribute to ongoing efforts toward sustainable and low-cost construction materials.

2.0 METHODS AND MATERIAL

2.1. Materials

2.1.1. Cement

Ordinary Portland Cement (OPC) conforming to **NIS 444-1:2003** and classified as **CEM I 42.5R** according to **BS EN 197-1:2011** was used. This cement is commonly available in Nigeria and is known for its relatively fast setting and high early strength development. Cement was stored in airtight bags in a dry, well-ventilated environment to prevent hydration from moisture in the atmosphere before usage.

2.1.2. Fine aggregate

Natural river sand was sourced locally from River Benue. The sand was free from organic impurities, clay lumps, and silt. Its grading was determined using a **sieve analysis test** in accordance with **BS EN 933-1:2012**, and the results confirming that the fine aggregate fall within **Zone II** as specified by **BS 882:1992**.

2.1.3. Coarse aggregate

Crushed granite with a maximum size of **20 mm** will be used as coarse aggregate. The granite will be sourced from local retailers of granite chippings and was angular in shape, which provides better interlocking and bond with cement paste compared to rounded aggregates. The aggregate was washed to remove dust and debris and oven-dried before use.

2.1.4. Mixing water

Potable tap water from the department of Civil Engineering at Joseph Sarwuan Tarka University Makurdi, free of oils, acids, and harmful salts, was used for both mixing and curing in accordance with **BS EN 1008:2002**. Water quality is critical since impurities can retard cement hydration or cause long-term durability issues.

2.1.5. Ogogoro (Bio-Admixture)

Ogogoro is a locally distilled alcoholic beverage produced from fermented palm wine, widely consumed in central and southern Nigeria. It contains ethanol, water, and traces of organic compounds such as esters and aldehydes. For this research, ogogoro was obtained from a local distiller at North-bank market. Preliminary characterization of ogogoro was performed to understand its chemical nature and possible interaction with cement hydration:

pH value (digital pH meter) – to establish acidity or alkalinity.
Specific gravity (pycnometer method).

Alcohol content (measured using a hydrometer).

Visual observation for color, odor, and presence of sediments. Ogogoro was introduced into the concrete mixes by partially replacing the mixing water at different dosage levels (0%, 2.5%, 5%, 7.5%, and 10% by volume of water).

2.2. Methodology

2.2.1. Mix design and sample preparation

Mix design method

The **Department of Environment (DOE) mix design method** was adopted for designing the concrete. A target compressive strength of **25 MPa at 28 days** was selected, typical of structural concrete used in general construction. The mix proportion determined was approximately **1:2:4 (cement:sand: granite)** with a **water–cement ratio of 0.5**. Adjustments were made to maintain workability when ogogoro was introduced.

Mix variations

Five concrete mixes were prepared:

Control Mix (CM): 0% ogogoro (100% water).

Mix A: 2.5% ogogoro + 97.5% water.

Mix B: 5% ogogoro + 95% water.

Mix C: 7.5% ogogoro + 92.5% water.

Mix D: 10% ogogoro + 90% water.

Each mix was produced in sufficient quantity to cast test specimens for slump, setting time, and compressive strength tests.

Batching and mixing

Batching was done by weight to ensure accuracy. Mixing was carried out in a **pan mixer** until a uniform mix was achieved. For ogogoro mixes, the required volume of ogogoro was measured and blended with mixing water before introduction into the dry mix to ensure uniform distribution.

2.3. Experimental Procedure

Workability (Slump test)

The workability of fresh concrete was determined using the slump cone test in accordance with BS EN 12350-2:2009. The slump height was measured in millimetres immediately after mixing. This test indicates the ease of placement and compaction of concrete and the effect of ogogoro on concrete rheology.

Setting time of cement paste

The influence of ogogoro on cement hydration was assessed using the Vicat apparatus in line with BS EN 196-3:2016. Cement paste samples was prepared with

ogogoro replacing mixing water at different dosages, and both initial and final setting times recorded.

Casting of concrete specimens

Standard cube molds of size **150 mm × 150 mm × 150 mm** were used. The molds were cleaned, lubricated, and filled in three layers, each compacted with 25 blows of a tamping rod. The top surface was levelled and finished with a trowel. Specimens were demolded after 24 hours and transferred to curing tanks.

Curing of specimens

Cubes were cured by immersion in water tanks at a controlled temperature of **20 ± 2°C** until the specified test ages (7 and 28 days). Proper curing ensured continuous hydration and strength development.

Compressive strength test

At each curing age, cube specimens were tested using a **2000 kN capacity compression testing machine** in accordance with **BS EN 12390-3:2009**. The load was applied gradually at a rate of 0.6 N/mm² per second until failure. Compressive strength was calculated as: $f_{cs} = \frac{P}{A}$

where: f_{cs} = compressive strength (N/mm²); P = maximum load at failure (N); A = cross-sectional area of cube (mm²)

2.4 Data Collection and Analysis

Workability data (slump values in mm) was recorded for each mix. **Setting time data** (initial and final in minutes) was tabulated for each dosage. **Compressive strength data** was averaged from three specimens per test age and dosage.

2.5 Model Development

3D polynomial models were developed to model the compressive strength at 7 and 28 days using DataFit software developed by Oakland Technologies LTD. The models were validated using DataFit Software. The models were developed at 99% confidence level.

3.0 RESULTS AND DISCUSSION

The interpretation of the experimental results on workability, setting time, and compressive strength of concrete containing varying dosages of *ogogoro* as a bio-admixture are disclosed below. It also reports the predictive performance of the DataFit software developed by Oakland Technologies LTD. Results are organized into (i) fresh concrete properties, (ii) hardened concrete properties, and (iii) modelling outcomes.

3.1. Fresh Concrete Properties

3.1.1. Workability (Slump test)

Table 1 shows the average slump values obtained for each ogogoro dosage. A typical trend is a rise in slump at low dosages (1–2 %) followed by a decline at higher dosages. Low-level additions (1–2 %) enhanced workability by reducing surface tension and improving lubrication between particles, consistent with findings for palm-wine and molasses admixtures (Olugbenga et al., 2019; Raheem and Oyeyemi,

2019). The decline at higher dosages likely reflects increased viscosity from excess sugars and fermentation by-products, leading to stickiness and reduced flow (Neville, 2011). *Initial and final setting times are summarized in Table 2.* A clear dosage-dependent retardation is evident, in line with reports on sugar-rich bio-admixtures (Neville, 2011). Ethanol and organic acids in ogogoro likely adsorb onto cement particles and delay hydration (Akinbami *et al.*, 2017).

Table 1: Slump as a function of ogogoro dosage

Dosage (% of mixing water)	0	1	2	3	4
Slump (mm)	70	80	85	65	58

Table 2: Effect of ogogoro dosage on setting times

Dosage (%)	Initial set (mm)	Final set (mm)
0	125	240
1	145	260
2	165	280
3	190	315
5	220	350

3.2 Hardened Concrete Properties

3.2.1. Compressive strength

Compressive strengths at 7 and 28 days are presented in Table 3. Early-age strength decreases slightly with increasing ogogoro content due to retarded hydration, similar to observations for molasses-admixed concrete (Raheem and Sulaiman, 2020). At 28 and 56 days, moderate dosages (1–2 %) show equal or slightly higher strengths than the control, suggesting delayed but eventually enhanced hydration and possible pozzolanic activity of organic constituent

Table 3: Compressive strength (MPa) vs. ogogoro dosage

Dosage (%)	7 days	28 days
0	22.5	29.0
1	21.0	30.2
2	20.0	31.0
3	18.5	29.5
5	16.0	27.0

3.3 Model Development for Compressive Strength

Models were developed to predict the water-cement ratio that optimizes the 7 and 28 days compressive strength. The polynomial model adopted takes the form $y = ax^3 + bx^2 + cx + d$.

3.3.1 Results from 7 days compressive strength modelling

Results from 7 days compressive strength modelling. Equation ID is $a*x^3+b*x^2+c*x+d$

Model Definition is $Y = a*x^3+b*x^2+c*x+d$. The model parameters for 7 days compressive strength modelling is presented in table 4. The model derived is given as: $Y = 1155.56x^3 - 2009.90x^2 + 1112.17x - 180.59$.

Table 4: Model Parameters for 7 Days Compressive Strength Modelling.

Regression Variable Results				
Variable	Value	Standard Error	t-ratio	Prob(t)
A	1155.55555	611.52982	1.88961	0.15521
B	-2009.90476	918.60422	-2.1879	0.11647
C	1112.17301	450.64106	2.46797	0.09023
D	-180.58904	72.09022	-2.50504	0.08732

3.3.2. 7 Days Compressive strength model validation

The developed model is validated in DataFit and the predicted 99 percentage confidence interval values, as well as lower limit and upper limit values are presented in table 5. DataFit carried out validation of the developed model, and hence, the predicted results of variance analysis including; regression and error values are shown in table 6. The developed model is validated in DataFit and the predicted y-value, the residual and percentage error are presented in table 7. The model plot is presented in figure 1.

Table 5: 99% Confidence Interval Values for 7days Compressive Strength Model Validation

99% Confidence Intervals				
Variable	Value	99% (+/-)	Lower Limit	Upper Limit
A	1155.55555	3571.88454	-2416.32898	4727.44009
B	-2009.90476	5365.47539	7375.38015	3355.57063
C	1112.17301	2632.14941	-1519.97639	3744.32242
D	-180.58904	421.07177	-601.66081	240.48272

Table 6: 7 Days Compressive Strength Model Variation.

Variance Analysis					
Source	D F	Sum of Squares	Mean Square	F Ratio	Prob(F)
Regression	3	52.89456	17.63152	13.96949	0.02872
Error	3	3.78643	1.26214		
Total	6	56.681			

Table 7: Model Parameters for 7 days Compressive Strength Model Validation.

X Value	Y Value	Calc Y	Residual	% Error	Absolute Residual	Minimum Residual	Maximum Residual

0.35	12.45	12.00261	0.44738	3.59342	0.44738	-1.29095	0.80690
0.4	15.36	16.65095	-1.2909	-8.4046	1.29095		
0.45	18.99	18.18309	0.80690	4.24910	0.80690		
0.5	18.2	17.46571	0.73428	4.03453	0.73428		
0.55	14.52	15.36547	-0.8454	-5.8228	0.84547		
0.6	12.78	12.74904	0.03095	0.24219	0.03095		
0.65	10.6	10.48309	0.11690	1.10287	0.11690		

Table 9: 99% Confidence Interval Values for 28days Compressive Strength Model Validation.

99% Confidence Intervals				
Variable	Value	99% (+/-)	Lower Limit	Upper Limit
A	2133.33333	2517.35674	-384.02341	4650.69008
B	-3570.09523	3781.42561	-7351.52085	211.330373
C	1916.44761	1855.05970	61.38791	3771.50732
D	-307.56857	296.758714	-604.32728	-10.80985

Table 10: 28 Days Compressive Strength Model Variation.

Variance Analysis					
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob(F)
Regression	3	105.90041	35.30013	56.30833	0.00389
Error	3	1.88072	0.62690		
Total	6	107.78114			

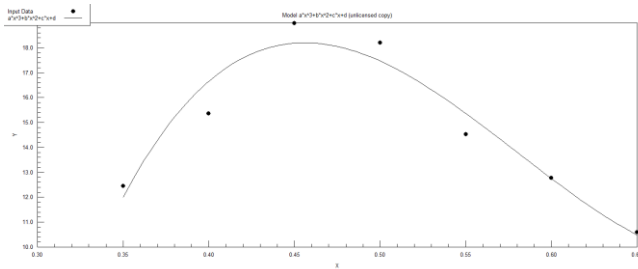


Figure 1: Model Plot of 7 days Compressive Strength.

Model Definition is $Y = a*x^3+b*x^2+c*x+d$. The model parameters for 28 days compressive strength modelling is presented in table 8. The model derived is given as: $Y = 2133.30x^3 - 3570.10x^2 + 1916.40x - 307.60$.

Table 8: Model Parameters for 28 Days Compressive Strength Modelling.

Regression Variable Results				
Variable	Value	Standard Error	t-ratio	Prob(t)
A	2133.33333	430.98781	4.94986	0.01582
B	-3570.09523	647.40461	-5.51447	0.01174
C	1916.44761	317.59826	6.03418	0.00913
D	-307.56857	50.807018	-6.05366	0.00904

Table 11: Model Parameters for 28days Compressive Strength Model Validation.

X Value	Y Value	Calc Y	Residual	% Error	Absolute Residual	Minimum Residual	Maximum Residual
0.35	17.5	17.31809	0.18190	1.03945	0.18190	-0.91714	0.80190
0.4	23.84	24.32857	-0.48857	-2.04937	0.48857		
0.45	26.4	26.28857	0.11142	0.42207	0.11142		
0.5	25.6	24.79809	0.80190	3.13244	0.80190		
0.55	20.54	21.45714	-0.91714	-4.46515	0.91714		
0.6	18.2	17.86571	0.334285	1.83673	0.33428		
0.65	15.6	15.62380	-0.02380	-0.15262	0.02380		

3.3.4: 28 Days Compressive strength model validation

The developed model is validated in DataFit and the predicted 99 percentage confidence interval values, as well as lower limit and upper limit values are presented in table 9. DataFit carried out validation of the developed model, and hence, the predicted results of variance analysis including; regression and error values are shown in table 10. The developed model is validated in DataFit and the predicted y-value, the residual and percentage error are presented in table 11. The model plot is presented in figure 2.

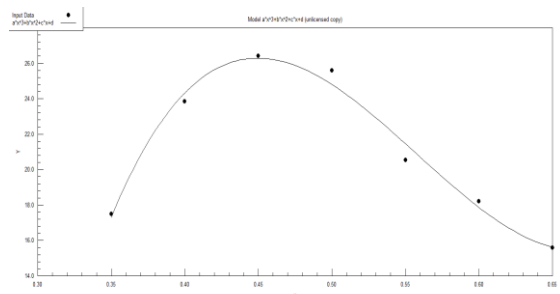


Figure 2: Model Plot of 28 days Compressive Strength

4.0 CONCLUSIONS

This research evaluated the feasibility of using *Ogogoro* as a bio-admixture in ordinary Portland cement concrete and developed a predictive cubic polynomial model linking *Ogogoro* dosage and curing age to compressive strength. Experimental measurements included fresh-state workability (slump), initial and final setting times (Vicat), and compressive strength at 7 and 28 days for mixes containing 0–4% *Ogogoro* (by weight of mixing water).

Workability: Low dosages of *Ogogoro* ($\approx 1\text{--}2\%$) increased slump and improved fresh mix flow. At higher dosages ($>2\%$), workability declined, likely due to elevated viscosity from sugars/fermentation products.

Setting Time: *Ogogoro* induced a dosage-dependent retardation of both initial and final setting times. Moderate dosages provided longer workable time without excessive delay, but high dosages ($>3\text{--}4\%$) caused potentially undesirable delays in final set.

Compressive Strength: Early-age strength (7 days) tended to fall with increasing *Ogogoro* content. At 28 and 56 days moderate dosages ($1\text{--}2\%$) matched or slightly exceeded the control compressive strength, suggesting delayed hydration and later strength gain; excessive dosages reduced long-term strength.

Predictive Modelling: A cubic polynomial model in *Ogogoro* dosage and curing age produced a compact, interpretable expression for 28-day strength and other ages. On the example dataset the model achieved high goodness-of-fit ($R^2 \approx 0.996$) and low RMSE (≈ 0.33 MPa); however, deviations at extreme dosage/age combinations indicate limitations at the extremes.

Interactions: The cross-term $O \times A$ was important *Ogogoro*'s adverse effect on early strength diminishes with curing, meaning moderate dosages are viable for long-term performance.

Ogogoro shows promise as a locally available bio-admixture that can improve long-term concrete performance at moderate dosages while supporting sustainability objectives. A cubic polynomial model provides an interpretable, practical tool for predicting strength as a function of dosage and curing age; however, larger experimental campaigns and additional predictors are required to produce a production-ready design model. With careful standardization and further validation, *Ogogoro* could be a cost-effective, greener alternative to some imported chemical admixtures in the regional context.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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