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Performance Evaluation of Cassava Starch as Concrete Admixture

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Abstract: Concrete is a composite material and the most widely used construction material. It comprises cement, aggregates, and water for hydration purposes. Recently, rapid increases in the cost of construction and problems associated with the use of cement, a major constituent of concrete, have necessitated the search for supplementary cementitious materials in partial replacement of cement in construction works. Admixtures are integrated into concrete to solve problems and improve the properties of both fresh and hardened concrete. This research evaluates the performance of concrete containing cassava starch as a mineral admixture. A face-centered cubic central composite response surface design was used to investigate the effects of cassava starch on the compressive strength of concrete at 3, 14, and 28 days, respectively. The cassava starch admixture was varied in the range of 0.1 to 0.5% by weight of cement. The effect of cassava starch on the compressive strength of concrete was studied at a constant water-binder ratio of 0.5, using response surface generated by the Design- Expert software 13. The results indicate maximum compressive strengths of the admixed concrete at 0.1% of cassava starch content. It was presumed from a review of related literature that the compressive strength of concrete decreases with an increase in the cassava starch content of the concrete mix. The assumption was found to be correct based on the compressive strength test that was conducted on the cubes with varying cassava starch content (0%, 0.1%, 0.2%, 0.3%, 0.4% and 0.5%). Numerical optimization was conducted, and model equations were generated for concrete with starch as an admixture. 0.1% of cassava starch is recommended as an admixture in concrete production, and, certain admixtures such as air-entraining agents and superplasticizers should be used so as to improve the flow properties of concrete.

Keywords: *Admixture, Cassava Starch, Compressive Strength, Concrete, Optimization*

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Supporting agencies: None

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1. Introduction

Nigeria is the largest producer of cassava worldwide (IITA, 2019). Cassava, also known as Manihot esculenta, is a perennial crop with edible roots cultivated widely in tropical and subtropical regions of the world. Cassava roots are processed as value products such as gari, starch, fufu, sweeteners, glues, etc., and have become a staple food for over 300 million people globally (IITA, 2019). Efforts are geared towards using cassava starch as an admixture in concrete.

Admixtures are inorganic or organic chemicals added to concrete to improve some of its physio-mechanical properties so that the concrete can meet its intended design target mean strength (Akpokodje and Uguru, 2019 ; Afolayan et al., 2022). According to the Portland Cement Association (2019), the functions of admixtures include corrosion inhibition, shrinkage reduction, alkali-silica reactivity reduction, air entrainment and workability enhancement, bonding and strength development, damp proofing, and coloring, among others. Air-entraining admixtures are used to encourage the development of microscopic air bubbles in the concrete. In contrast, pozzolanic-based admixture helps to prevent alkali aggregate reactions and enhance further strength development in the concrete (PCA, 2019). Industrial by-products or agricultural waste materials such as granite dust, cassava peel ash, metakaolin, and rice husk ash are generally used as mineral admixtures in concrete (Abdullahi et al., 2024; Abubakar et al., 2023; Abubakar et al., 2018)

Recently, the cassava peel was burnt to ash under controlled incineration and used as a partial replacement of cement in concrete (Olonade et al., 2014; Adetoye et al., 2022). Concrete compressive, flexural, and tensile strengths can be improved upon by adding special admixtures to concrete constituents (Shetty, 2001; Yan and Chouw, 2014; Adetoye et al., 2023). The continuous utilization of non-renewable materials by the construction industry has become a major threat to the existence of these materials. In contrast, some of these materials have drastic effects on the environment, hence are contributing to the climate change effect (Akpokodje and Uguru, 2019 Agbi et al., 2020). Recently, the price of construction materials has been rapidly increasing at a geometric rate, so attention is now paid to traditional and sustainable construction materials (Atikpo et al., 2018; Akpokodje et al., 2019).

Oluwabusayo et al. (2019) investigated the workability of cassava starch-modified concrete using slump and compacting factors. In their study, they added cassava starch by weight of cement at 0.4, 0.8, 1.2, 1.6, and 2.0%. They found that the workability of concrete reduced as the percentage of cassava starch increased. This was attributed to its viscosity-modifying properties. Suhad et al. (2016) investigated concrete workability and compressive strength with corn starch as an admixture. Corn starch was added at 1%, 3%, and 5% with cement. It was observed that the addition of corn starch admixtures increased the workability of concrete, while the compressive strength of concrete increased with the addition of 1% of corn starch, and further addition of corn starch reduced the compressive strength. Akindahunsi and Uzoegbo (2015) investigated the strength and durability properties of concrete made with starch and maize starch. The study revealed that the admixtures delayed the cement's setting time but improved the concrete's strength and durability.

There is limited exploration of the optimal proportions of cassava starch required to maximize compressive, flexural, and tensile strengths, as well as insufficient studies on its long-term durability and environmental impacts. Comparative studies evaluating the performance of cassava starch against other agricultural-based admixtures, such as corn starch and cassava peel ash, remain sparse. This research aimed to evaluate and model the effect of cassava starchy components on the compressive strength of concrete.

2. Materials and methods

Ashaka brand of cement was used in this research with a specific gravity of 3.15. Bulk density of 1470 kg/m3. It exhibited all the qualities of good cement by touch, visual, and hydration and also met the NIS 444 specifications. The cassava starch used for the study was dried, milled, and sieved with a 75µm screen to obtain the required sizes. The fine aggregate used was sourced from Bayara River. Bauchi. The coarse aggregate used was crushed rock purchased at Yelwa in Bauchi. The aggregates were inert, hard, non-porous, and free from excessive dust and splinters. The aggregates with a maximum size of 20mm and retained on a 16mm sieve were used for the study. The water that is fit for drinking was used in the study; no test was conducted.

2.1. Starch activation

Cassava starch was activated with hot water at 90 to 100 °C. Therefore, the required dosage was prepared separately and allowed to cool down to not contribute to temperature rise in the mix in which it is going to be used. The quantity of water used in the starch activation was deducted from the total required in a mix.

2.2. Concrete Mix Design

Mix design is the process of selecting materials and determining their relative quantity with the objective of producing a product of the desired quality. Table 1 shows the mix proportion content for a single cube. Hence, for 3 cubes, each content was multiplied by 3.

Table 1: Mix proportion of concrete

Mix No	Starch (g)	Cement (g)	w/c	Fine aggregate(g)	Coarse aggregate(g)
control	0	327.13	0.55	745.87	1122.07
C.S 0.1%	0.33	327.13	0.55	745.87	1122.07
C.S 0.2%	0.65	327.13	0.55	745.87	1122.07
C.S 0.3%	0.98	327.13	0.55	745.87	1122.07
C.S 0.4%	1.31	327.13	0.55	745.87	1122.07
C.S 0.5%	1.64	327.13	0.55	745.87	1122.07

2.3. Mixing, Casting and Curing of Test Specimen

To facilitate easy demoulding, molds were oiled during the mix. The moulds were filled in three layers, with each being vibrated and compacted by striking with a rammer 25 times, which is the minimum number of strokes stipulated by BS 1881.P111. The cubes were then cast for each mix with the conventional concrete to serve as a control concrete. After

24 hours, the cubes were molded and placed in the curing tanks containing water for curing at room temperature until the testing day.

3. Results and discussion

Table 2 shows the results of tests conducted on aggregates. The specific gravity for fines is between 2.6 to 2.7. A value of 2.5 obtained is within the specification. The specific gravity of the coarse aggregate obtained was 2.82, which is within the generally acceptable standard of 2.6 to 2.9, while the specific gravity of cassava starch was 1.22, which is very low compared to that of cement. The aggregate impact value equal to or greater than 35% is considered bad for use in road construction; the obtained value of 5.71% is acceptable. The aggregate crushing value obtained was 31.89%. The bulk density of fine aggregate was 1410.26kgm-3, and the bulk density of coarse aggregate was 1550kgm-3; therefore, the values obtained fall within the range of accepted values.

Table 2: Result of Preliminary Studies

S.N.	Responses	Value
1	Specific gravity of fine aggregates	2.5
2	Specific gravity of coarse aggregates	2.82
3	Specific gravity of starch	1.22
4	Aggregate Impact value (%)	5.71
5	Aggregates crushing value (%)	31.89
6	Bulk density of fine aggregates (kg/m^3)	1410
7	Bulk density of coarse aggregates (kg/m^3)	1550

3.1. Consistency, Setting Time Test and Fine Aggregates Gradation

The result of consistency test conducted on cement paste is presented in the Figure 1 while the result of setting time test is shown in Figure 2.

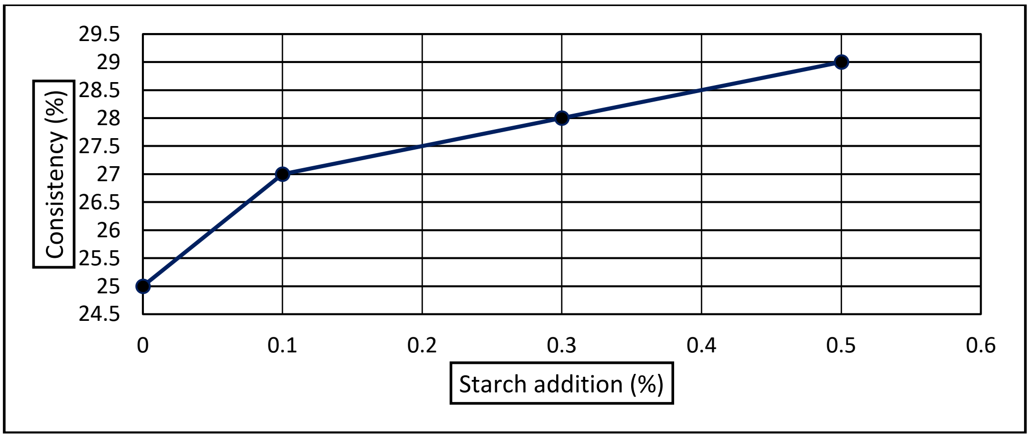

Figure 1: Consistency of Admixed Cement Paste

It is clearly shown that the maximum consistency of the cement paste is achieved by adding 25% water. Subsequently, at 0.1%, 0.3%, and 0.5% cassava starch content, it gives 27%, 28%, and 29%, respectively. An increase in cassava starch content significantly increases the percentage of water required to make a cassava starch-admixed paste.

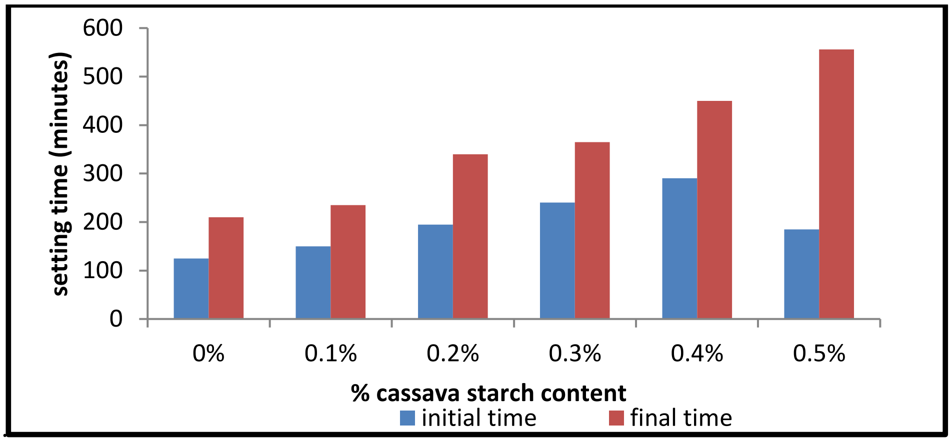

Figure 2: Graph of Setting Time against Cassava Starch Content

It is observed from Figure 2 that the control (%) exhibited the least initial and final setting time, but an increase in the concentration of starch caused an increase in both initial and final setting time. Cassava starch delayed the setting time of cement which may be an advantage for use where a longer period of time is required for casting of concrete. The gradation of fine aggregates is shown in Figure 3.

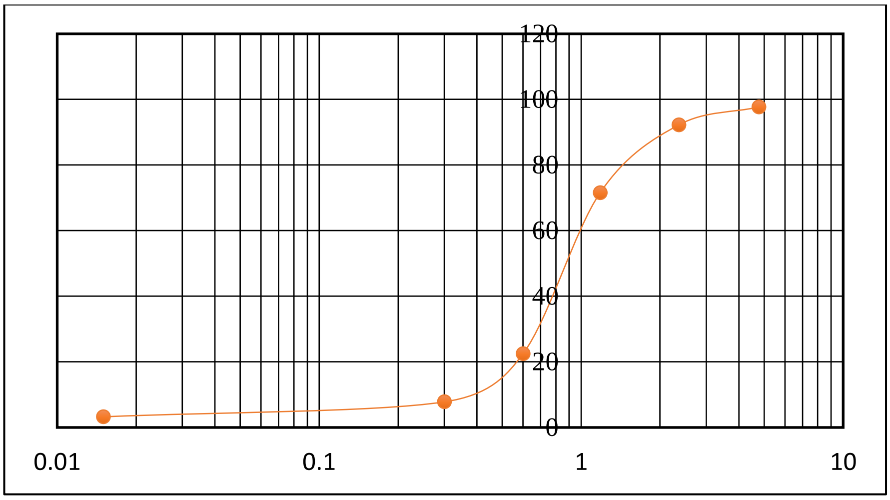

Figure 3: Sieve Size Analysis of Fine Aggregates

3.2. Slump Test

The result of the slump test is shown in Table 3.

Table 3: Slump Test Result

% replacement	Slump Value (mm)
0%	300-270=30
0.1%	300-272=28
0.2%	300-273=27
0.3%	300-275=25
0.4%	300-277=23
0.5%	300-278=22

Slump test results showed that the values obtained for all replacements were within the range of (25-50) mm for all the percentages of cassava starch (0%, 0.1%, 0.2%, 0.3%, 0.4%, and 0.5%) as shown in Figure 3. An increase in the percentage of cassava in concrete causes a decrease in slump value. This may be due to a strong affinity for water by starch in concrete.

3.3. Compressive Strength of Concrete Containing Starch as Admixture

Strength development was assessed by a compressive strength test after the concrete specimen was cured for 3 days, 14 days, and 28 days. The result of the compressive strength test of concrete containing cassava peel ash is presented in Figure 4.

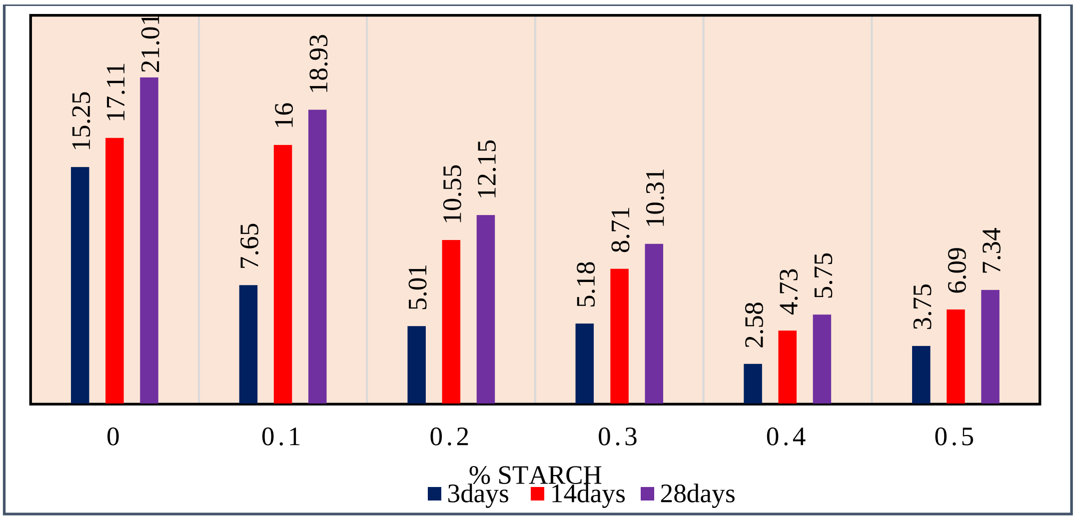

Figure 4: Graph of Compressive Test against Various % of Cassava Starch

It can be seen that in all curing periods used, the use of cassava starch concrete results in decreased compressive strength with the highest percentage of cassava starch content. The compressive strength test was carried out using the following percentage (0%, 0.1%, 0.2%, 0.3%, 0.4%, and 0.5%) of cassava starch by mass of cement in the mix, maximum compressive strength of concrete 18.93N/mm^2 was achieved at 0.1% of cassava starch at 28days.

3.3.1 Analysis of Compressive Strength Test

Table 4: Factors and Response of Compressive Strength.

Factor 1 A:Starch content %	Factor 2 B:Curing age days	Response 1 compressive strength N/mm^2
0.5	3	3.75
0.3	14	8.71
0.5	14	6.09
0.3	14	8.71
0.3	3	5.18
0.3	28	10.31
0.1	3	7.65
0.3	14	8.71
0.1	28	18.9
0.5	28	7.34
0.1	14	16
0.3	14	8.71
0.3	14	8.71

Table 5: ANOVA for Quadratic Model for Compressive Strength

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	199.74	5	39.95	64.00	< 0.0001	significant
A-Starch content	110.82	1	110.82	177.56	< 0.0001	
B-Curing age	66.47	1	66.47	106.49	< 0.0001	
AB	13.94	1	13.94	22.34	0.0021	

A^2	11.18	1	11.18	17.91	0.0039
B^2	7.82	1	7.82	12.52	0.0095
Residual	4.37	7	0.6241		
Lack of Fit	4.37	3	1.46		
Pure Error	0.0000	4	0.0000		
Cor Total	204.11	12			

The Model F-value is 64 which implies that the model is significant. Also, P-values of significant model terms are A, B, AB, A^2, and B^2.

Table 6: Fit Statistics for Compressive Strength

Parameters	**Value**
R^2	0.9786
Adjusted R^2	0.9633
Predicted R^2	0.7946
Adeq Precision	28.4364

The Predicted R^2 of 0.7946 is in reasonable agreement with the Adjusted R^2 of 0.9633. Adeq Precision measures the signal-to-noise ratio. The ratio of 28.436 indicates an adequate signal. This model equation for compressive strength is given in the equation below.

$$Compressive\ strength\ = 9.98 - 40.14 * A + 0.83 * B - 0.745 * AB + 50.3 * A^\wedge 2 - 0.011 * B^\wedge 2$$

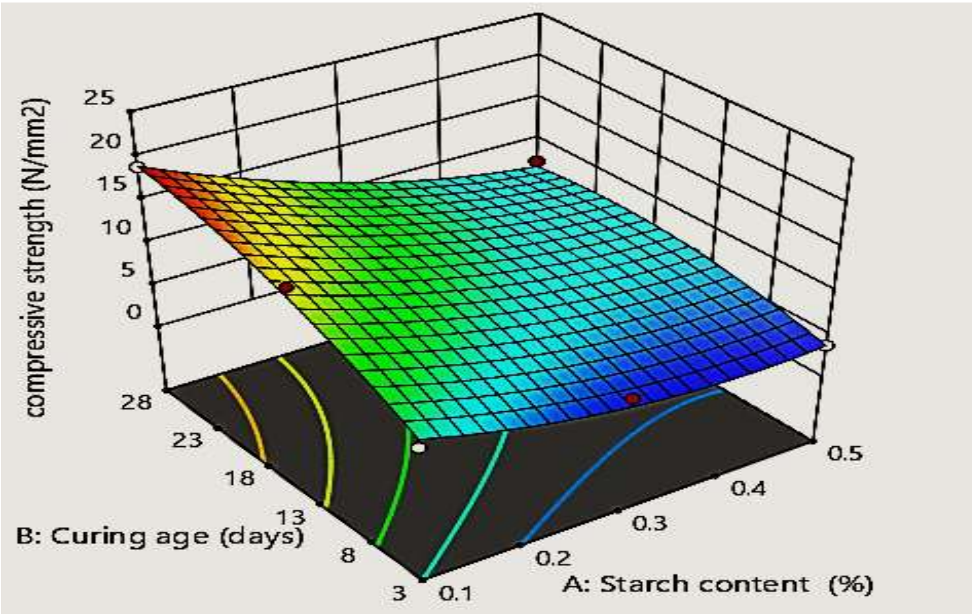

Figure 5: 3D Surface Graph of Starch Content, Curing Age and Compressive Strength

Figure 5 shows a 3D response surface graph of interactions between starch content and curing age and the influence on compressive strength of concrete. The 3-D surface elucidates the correlation between the dependent variables (responses) and the independent variables (factors). Figure 5 shows that an increase in starch content causes a decrease in compressive strength, while the increase in curing age causes a gradual increase in strength development.

3.3.2. Numerical Optimization of Compressive Strength Test

The automatic optimization function of Design-Expert software version 13 indicates that the optimal values of the factors for the highest concrete strength for starch-admixed concrete are presented in Figure 6.

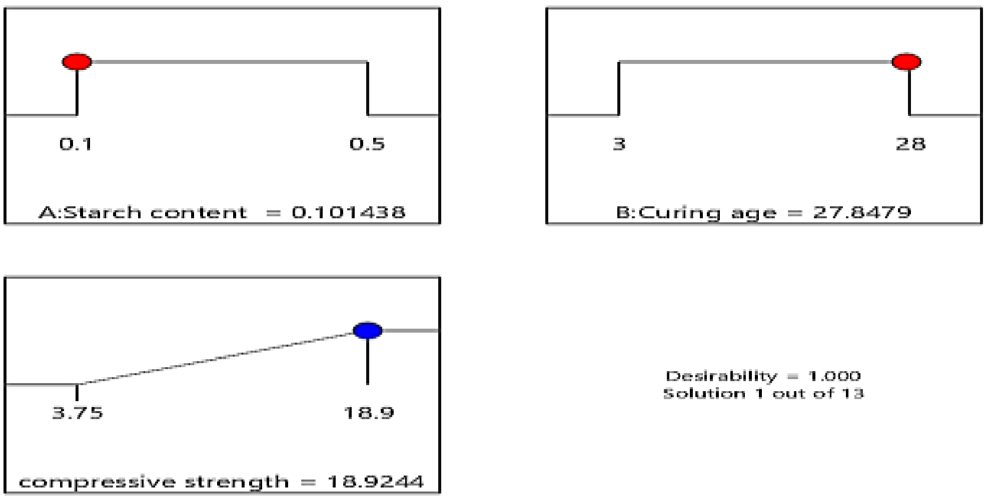

Figure 6: 3D Ramp Plot of Starch Content, Curing Age and Compressive Strength

4. Conclusion

In this experimental study, the cassava starch was added by weight of the cement at different percentages. The workability of the concrete with cassava starch was very great. Hence, it is suitable for use as an admixture in concrete production. The maximum compressive strength of the cassava starch concrete was achieved at 0.1% of cassava starch by weight as a replacement for cement in the mix. It was presumed from a review of related literature that the compressive strength of concrete decreases with an increase in the cassava starch content of the concrete mix. The assumption was correct based on the compressive strength test conducted on the cubes with varying cassava starch content (0%, 0.1%, 0.2%, 0.3%, 0.4% and 0.5%). From the result obtained after optimization, 0.1% of cassava starch is recommended as an admixture in concrete production cured for 28 days, producing a compressive strength of almost 19 MPa. It is recommended that certain admixtures, such as air-entraining agents and superplasticizers, should be used to improve the flow properties of concrete. The cassava starch produces light concrete. Therefore, it was recommended that cassava starch concrete be used to construct lightweight structures such as dome and shell structures.

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