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Investigating the Pozzolanic Properties of *Canarium schweinfurthii* ('Atili') Seed Shell Ash as Partial Replacement for Cement in Concrete

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***Abstract**: Ethnomedicinal, insecticidal, biological and other non-engineering uses of Canarium seed have been identified but little or no engineering uses have been explored. This research investigates the effect of Canarium schweinfurthii Seed shell Ash (CSSA) on the mechanical properties of concrete. CSSA was obtained after calcination of Canarium schweinfurthii seed shell at 400^0C, 700^0C and 1000 ^{0}C. X-ray Florescence (XRF) analysis carried out revealed the best sample of CSSA to be used for this work, and found to be a Class C pozzolana, which contains 51.21% of (SiO_2 + Al_2O_3 + Fe_2O_3). The compressive and flexural strengths were determined at 7, 14, 21 and 28 days. The workability of the concrete was found to have dropped with the increment in the percentage of CSSA in the concrete. The compressive strength and flexural strength of the concrete cubes declined with the increment in the percentage of CSSA in the concrete. The compressive strength of the CSSA concrete after each curing age for the control and all the different percentages of CSSA replacement all met the minimum requirement for the characteristic strength (20 N/mm^2). From the result, the reduction in compressive strength of the concrete at 28 days is between 0% and 5%, with the optimal increment in the strength achieved at 10% CSSA. The flexural strength of the CSSA concrete reduces drastically with increment in the CSSA content across all the curing ages, having an optimal replacement at 5% CSSA replacement.*

***Keywords:** Concrete, Compressive Strength, Flexural Strength, Canarium Schweinfurthii Seed Shell Ash (CSSA), X-ray Florescence.*

1. INTRODUCTION

According to [1] concrete is the oldest construction material in the world essentially owing to its durability, low cost, and resistance to harsh environmental conditions. Concrete is a heterogeneous mixture of cement, aggregate and water. It is more common and less expensive when compared to other construction materials. Though it is brittle and has high compressive strength, concrete usually requires reinforcement (e.g. steel), in order to resist tensile stress [2]. In concrete technology, the constituent materials of concrete can be altered to enable the use of unconventional materials. This is due to the highly increasing demand for conventional construction materials and their low cost of production. Furthermore, the purpose for adopting these unconventional materials arises also from the need for utilizing alternative materials such as industrial wastes, thereby ensuring a cleaner environment [3]. These wastes constitute a very large portion of the landfills which when utilized, reduces the environment's susceptibility to pollution. These pollutions often spoil the land and affect the aesthetics of urban communities. Poutos and Nwaubani informed that the influence of global environment is fast forcing the construction industry to review the conventional methods of concrete and cement production. This is due to the fact that these methods lead to large release of hazardous gases [4]. Martos, M. A. & Sousa-Coutinho also recorded that Portland cement production is responsible for 5% of the global CO_2 anthropogenic emission worldwide. Its industry is also very energy intensive, hence begging the need for sustainable alternatives [5].

In the context of cement replacements, the use of processed agricultural and industrial wastes namely fly ash, slag, rice husk ash, silica fume has proven very constructive [6]. Other materials such as groundnut shell ash [7], raffia palm ash [8] and white cowpea husk ash [9] have proved to be adequate safe replacements cements. For the purpose of this research, *Canarium schweinfurthii* ("*Atili*") shell ash is being proposed for the replacement of cement in concrete. Atili plant has a widespread distribution across Africa and it is known for its multipurpose economic and cultural value [10]. Its shell which is usually disposed of as agricultural waste would undergo burning. The pozzolanic property of the ash extracted after burning would be determined, and then experimental partial replacement of cement will be conducted.

2. METHODOLOGY

The constituents employed in this study are as follows:

2.1 *Canarium Schweinfurthii* (Atili) Seed Shell Ash (CSSA)

The Atili seed shell ash which was sourced from a farm site in Jos, Plateau State of Nigeria was first crushed to a smaller particle size before incineration. The incineration was controlled in a closed electronic oven at dissimilar temperatures of 400^0C, 700^0C and 1000^0C at Chemical Engineering Department Laboratory of Ahmadu Bello University, Zaria. The burning at 400^0C gave a rather rough mixture of charcoal and ashes, but became finer as the temperature was increased to 1000^0C. It was observed that the higher the temperature, the finer the ashes obtained as shown in Plate 1a-c

Plate 1a: Ashes obtained at 400^0C

Plate 1b: Ashes obtained at 700^0C

Plate 1c: Ashes obtained at 700^0C

2.2 Cement

Ordinary Portland cement (OPC); grade 42.5R which conforms to [11] is the cement used for casting the concrete samples for the research.

2.3 Aggregate

Fine aggregate (particularly natural river sand) that passed through sieve 4.75 mm and coarse aggregate (crushed stone) of maximum size of 19 mm was used and both were found to be in conformity with [12]. Several control concrete cubes of 100 x 100 x 100 mm size were cast with a design mix of concrete grade M20 according to IS-456. The design calculation consequently revealed the water-cement ratio and the quantity of fine and coarse aggregate. Also, a corresponding 'Atili' seed shell ash-replaced concrete cubes were also cast. The replacements would vary depending on the material in focus. When green, portions of the various categories of mix was set aside for the workability testing and other fresh state characterization. The cubes' compressive and flexural strength tests were scheduled at 7 days, 14 days, 21 days and 28 days curing ages.

3. RESULTS AND DISCUSSION

3.1 Preliminary Tests on CSSA, OPC and Aggregate

The primary tests carried out include XRF analysis, specific gravity, fineness, particle size distribution. The tests were carried out in accordance with the provision of [13], [14], [15], [16] respectively. The results obtained are illustrated in the Tables 1 to 5.

Table 1: Oxide composition

Content	Percentage (400^0C)	Percentage (700^0C)	Percentage (1000^0C)
SiO_2	40.031	45.549	43.251
Al_2O_3	2.366	2.976	2.134
Fe_2O_3	2.423	2.685	2.290
CaO	1.269	1.135	1.563
K_2O	3.782	3.920	4.012
SO_3	0.893	0.557	1.001
MgO	1.990	1.890	1.786
P_2O_5	4.609	4.901	3.992

Table 1 shows different samples of CSSA burned at different temperature, in order to pick the best sample that meets the [13] for a material to be classified as pozzolan, the summation of all the chemical oxide compounds (SiO_2, Al_2O_3, Fe_2O_3) should have a minimum of 50% for class C or 70% for class F. The CSSA burnt at 700°C was observed to be 51.21%.

Table 2: Characterization of the CSSA

Test	Result	Code Specification	Code
Fineness	0.06	0.01 – 0.06	BS 12: 1990
Specific Gravity	2.40	2.3-2.9	BS 12: 1990

Table 2 confirms that the CSSA used met the requirement of fineness and specific gravity to be used as a concrete material.

Table 3: Properties of the used fine aggregate

Test	Result	Code Specification	Code
Fineness Modulus	2.47	2.3 – 3.1	ASTM C33 (ACI)
Specific Gravity	2.45	2.3-2.9	BS 12: 1990

The result in Table 3 also shows that the properties of the aggregate used met the [17] and [18] code requirements in terms of fineness modulus and specific gravity to be used as fine aggregates having tested to be some way in-between values specified by the relevant codes.

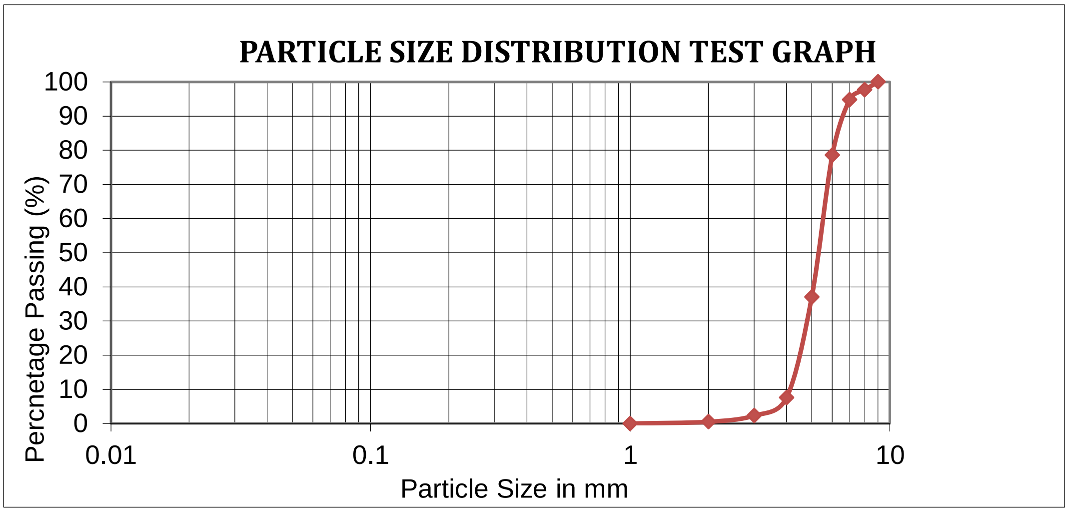


Figure 1: Sieve analysis for fine aggregate

The result in Figure 1 and Table 3 are reflective of the fact that all the tested properties on fine aggregate lie within limits specified by the respective codes as the fine aggregate particle indicates suitability for mortar and concrete works.

3.2 Workability Test of Fresh Concrete

The slump height values obtainable in Figure 2 showed that workability declined as the proportion of *Canarium schweinfurtti* ('Atili') Shell Ash increased in the concrete mix owing to the absorbent nature of CSSA. [19] and [20] obtained similar result with different cement replacement.

3.3 Compressive Strength Test

The compressive strength of the CSSA concrete after each curing age for the control and all the different percentages of CSSA replacement all met the minimum requirement for the characteristic strength (20 N/mm^2) [21]. From Table 4 and Figure 3, it is obvious that the compressive strength of the concrete at 28 days decreased between 0% and 5%, with an increment in the strength at 15% replacement, followed by reduction in strength till 25. The 10% CSSA replacement can be regarded as the optimal CSSA quantity however, depending on the target strength or grade of interest, the result shows that as much as 20 MPa of concrete can be achieved by as high as 20% replacement of cement with CSSA. Similar results were obtained by [7], [8] and [9] which have used different pozzolanic materials to replace cement in concrete.

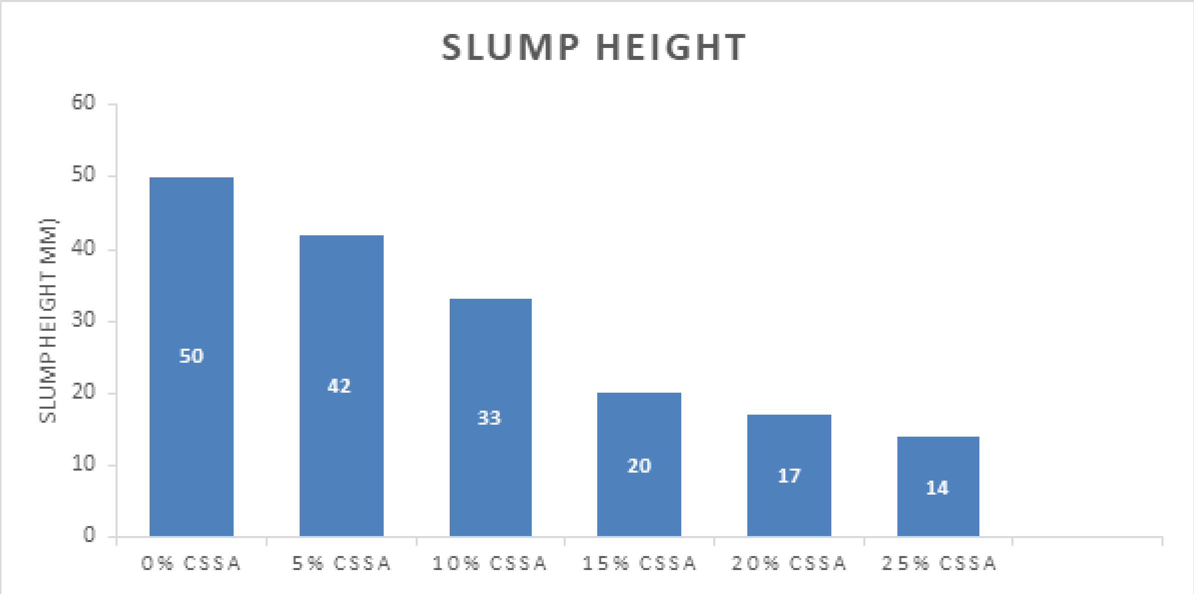
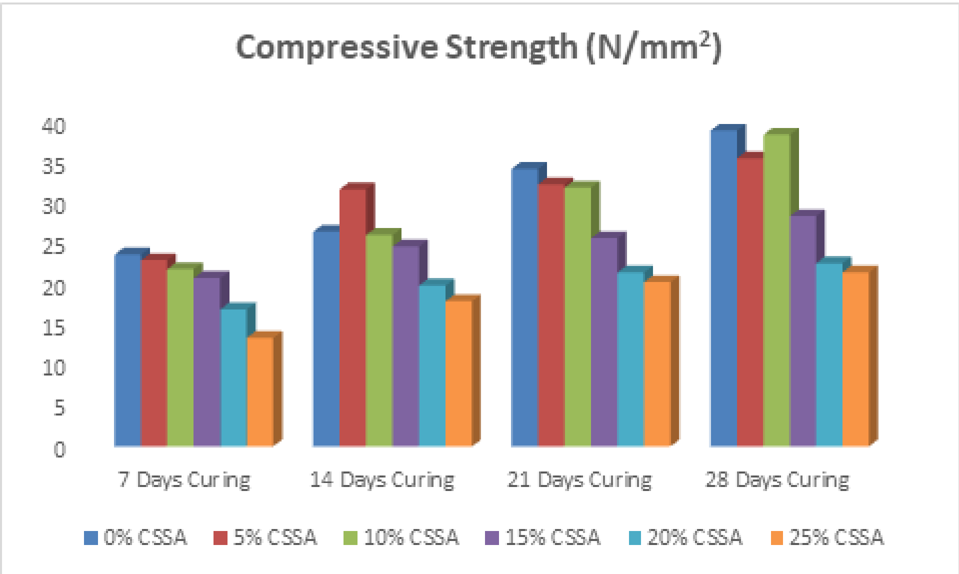


Figure 2: Slump height of CSSA concrete

Table 4: Summary of Mean Compressive Strength of CSSA Concrete

Replacement (%)	Mean Compressive Strength (N/mm^2)			
	7 Days	**14 Days**	**21 Days**	**28 Days**
0% CSSA	23.6	26.4	34.1	38.8
5% CSSA	22.9	31.6	32.2	35.4
10% CSSA	21.8	26	31.8	38.3
15% CSSA	20.7	24.6	25.6	28.3
20% CSSA	16.8	19.8	21.4	22.5
25% CSSA	13.3	17.8	20.2	21.4



3.4 Two-

Figure 3: Mean compressive strength of concrete cubes

Two-way analysis of variance tests (Two-Factor without replication) was carried out on the compressive strength result to determine the level of significance of the percentage replacement of CSSA on the compressive strength of the concrete. The results are presented in Table 5.

Table 5: ANOVA result for CCSA concrete cubes

SUMMARY	***Count***	***Sum***	***Average***	***Variance***		
7 Days Curing	6	119.1	19.85	16.019		
14 Days Curing	6	146.2	24.36667	24.63067		
21 Days Curing	6	165.3	27.55	35.647		
28 Days Curing	6	184.7	30.78333	60.98167		
0% CSSA	4	122.9	30.725	48.68917		
5% CSSA	4	122.1	30.525	28.6225		
10% CSSA	4	117.9	29.475	51.4225		
15% CSSA	4	99.2	24.8	9.913333		
20% CSSA	4	80.5	20.125	6.1425		
25% CSSA	4	72.7	18.175	12.8025		
ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	391.4846	3	130.4949	24.07864	5.5E-06	3.287382
Columns	605.0988	5	121.0198	22.33031	1.85E-06	2.901295
Error	81.29292	15	5.419528			
Total	1077.876	23				

From the result, it is deduced that the effect of curing age and CSSA replacement on the compressive strength was statistically significant, (F_{CAL} = 24.08 > F_{CRIT} = 3.29) for curing days while (F_{CAL} = 22.33 > F_{CRIT} = 2.90) for CSSA replacement. Thus, the effect of curing age on compressive strength is more pronounced than that of CSSA replacement.

3.5 Flexural Strength Test

The flexural strength of the CSSA concrete reduced drastically with increment in the percentage of cement replacement across all the curing age, the optimum replacement falls at 5% CSSA replacement, which is different with the trend of the compressive strength of the same replacement with optimum at 10% CSSA replacement.

Table 6: Summary of mean flexural strength of CSSA concrete

Replacement (%)	**Mean Flexural Strength (N/mm^2)**			
	7 Days	**14 Days**	**21 Days**	**28 Days**
0% CSSA	3.6	3.85	4.25	4.65
5% CSSA	3.2	3.58	3.86	4.25
10% CSSA	2.95	3.23	3.35	4.05
15% CSSA	2.5	2.7	3	3.5
20% CSSA	2.35	2.58	2.75	3.29
25% CSSA	2.21	2.41	2.58	2.85

The effect of curing age and CSSA replacement on the flexural strength was statistically significant, (F_{CAL} = 77.1 > F_{CRIT} = 3.29) for curing days while (F_{CAL} = 120.88 > F_{CRIT} = 2.90) for CSSA replacement. Thus, the effect of curing age on flexural strength is more pronounced than that of CSSA replacement.

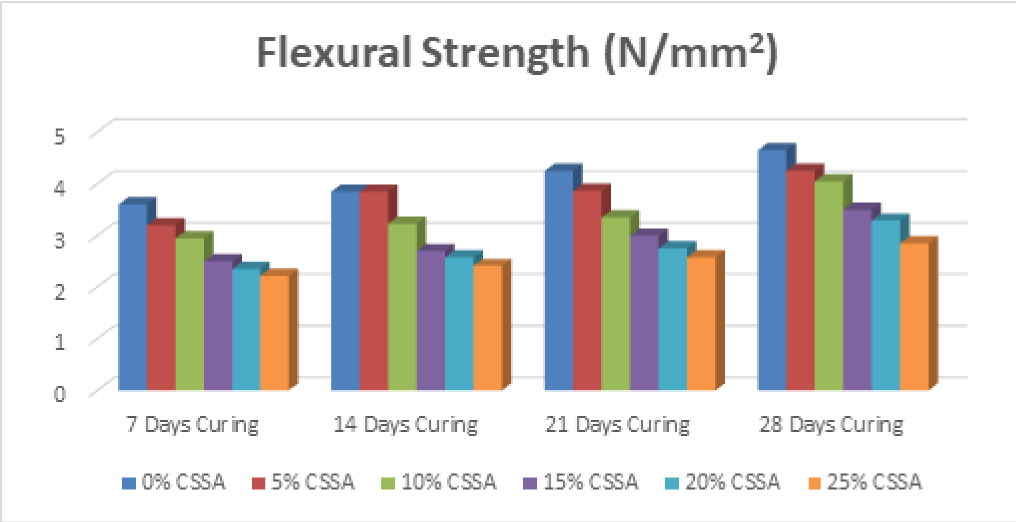


Figure 4: Mean Flexural strength of concrete Beams

Table 6: ANOVA result for CCSA concrete beams

SUMMARY	***Count***	***Sum***	***Average***	***Variance***		
7 Days Curing	6	16.81	2.801667	0.292617		
14 Days Curing	6	18.62	3.103333	0.409667		
21 Days Curing	6	19.79	3.298333	0.425897		
28 Days Curing	6	22.59	3.765	0.44655		
0% CSSA	4	16.35	4.0875	0.212292		
5% CSSA	4	15.16	3.79	0.1894		
10% CSSA	4	13.58	3.395	0.218767		
15% CSSA	4	11.7	2.925	0.189167		
20% CSSA	4	10.97	2.7425	0.160092		
25% CSSA	4	10.05	2.5125	0.073492		
ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	2.938946	3	0.979649	77.06521	2.43E-09	3.287382
Columns	7.682971	5	1.536594	120.878	1.43E-11	2.901295
Error	0.190679	15	0.012712			
Total	10.8126	23				

4. CONCLUSION

In the context of this research work, the investigation was centred on the feasibility of incorporating CSSA in concrete as a partial replacement. It can be deduced that there is a general reduction in the compressive strength and slump value of all concrete cubes made with CSSA and hence 10% is regarded as the optimal CSSA replacement. However, a grade 30 concrete can be satisfactorily achieved by as much 20 % CSSA replacement of cement by weight at a curing age of 28 days. CSSA satisfies the requirement for class C pozzolana as provided by ASTM C618. It is recommended that further studies be embarked upon in the use of CSSA for higher grades of concrete as well as investigating its performance with various grades/classes of cement.

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