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OPTIMIZATION OF CONCRETE CONTAINING LIMESTONE DUST AND LOCUST BEAN POD ASH BY CENTRAL COMPOSITE DESIGN.

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ABSTRACT
The over-reliance on concrete produced from cement had kept the cost of construction high and also prevented people from building modern and cost-effective houses most especially by rural dwellers in the developing nations. Emission of carbon footprint during cement production depletes the ozone layer which is a major concern to researchers all over the world. This investigation focused on the partial replacement of cement with Locust Bean Pod Ash (LBPA) and Limestone Dust (LSD) with a characteristic strength of 20 N/mm^2. Tests were conducted on slump, compressive, and flexural strength. The results of the physical properties showed that cement had a specific gravity of 3.14, LSD and LBPA had 2.72 and 2.61 respectively. The result of the slump test for the admixed concrete containing LSD/LBPA showed that they were workable and the higher the replacement of cement with LBPA/LSD, the higher the slump value. Optimization of the admixed concrete properties was done by numerical method. Limestone dust was kept at 5% for all the runs, and LBPA ranged from 5% to 25% at curing ages of 28, 60, and 90 days. The analysis of variance showed that the model developed was significant. The optimal value obtained was 5% LSD and 5.4% LBPA at 90 days with compressive strength of 26.9 N/mm^2 and flexural strength of 3.5 N/mm^2. Model equations were developed for both compressive and flexural strengths. This research recommends 5% LSD and 5.4% LBPA as cement replacements in the production of concrete.
Keywords: Limestone Dust, Locust Bean Pod Ash, Compressive Strength, Flexural Strength. Optimization.

1. INTRODUCTION
Concrete is the most widely used construction material all over the world [1]. It is desired for its durability, fire resistance, relative water impermeability, cost efficiency, energy efficiency and ability to be produced on-site. Cement is the main binder in concrete. Its production requires a huge amount of natural material, approximately 1.5 tons of raw materials are required for the production of each ton of cement [2]. The cement industry is the third-largest energy consumer worldwide and second-largest carbon dioxide (CO_2) emitter, it emits about 7% of global CO_2 emissions [3], [4].
Agricultural and industrial waste materials such as rice husk, granite dust, metakaolin, Saw Dust Ash, Eggshell Powder, and cassava peel ash have pozzolanic properties and many studies have been conducted on their effects on engineering properties concrete [5], [6] and [7].
Limestone dust (LSD) is a by-product of the quarry industry, while LBPA is an agricultural waste. These wastes have been shown to have pozzolanic properties. Limestone dust has a high Calcium Oxide (CaO) content, while LBPA has a high Silica Oxide (SiO_2) content. Both CaO and SiO_2 are essential chemicals in the hydration of cement and the production of cementitious materials or as binding aggregates in concrete [8]. The performance of different types of concrete required the analysis of the impact of the binder material on concrete parameters [9].

2. MATERIALS AND METHODS
2.1 Materials
Portland Limestone Cement used was bought from an open market in Bauchi, and kept in a dry place. Sample of the cement was then subjected to various standard tests to check its quality and ensure its conformity with the specifications for Cement. River sand was sourced locally as fine aggregate and used for the research. The limestone dust used was obtained from freshly deposited heaps of waste at a cement factory located in Ashaka, Gombe State. The limestone dust was sieved through BS No 200 and stored in an air-tight container before usage. Locust bean pod is an agricultural by-product that was obtained during the processing of its fruit after harvesting. The locust bean pod ash was obtained from Tafawa Balewa LGA of Bauchi State. Locust bean pod samples collected were burnt in open air, and afterward calcined in an oven at 700ºC for 2 hours to produce the ash. The ash was then allowed to cool before grinding to a very fine texture and then allowed to pass through the No. 200 (75µm) sieve. The aggregate was obtained at Bauchi and sieved through a BS 4.75mm sieve to remove larger aggregates and the following tests were performed to determine the suitability of the material for concrete; silt content, specific gravity, and particle size distribution (sieve analysis). Crushed coarse aggregates were obtained in Bauchi. The aggregates of the maximum size of 20mm were used. The university water supply was used for preparing concrete mix and the concrete specimens produced were cured according to BS [10].

2.2 Experimental Design
Central composite design response surface methodology was used for the design of experimental combinations. Experimental runs were created by Design-Expert software 13 for M20 grade concrete. It was also used to quantify the

relationship between the controllable input parameters and the obtained response surfaces. The central composite design (CCD) was used for analysis, and optimization and also generated model equations for compressive strength and flexural strength.

3.RESULTS AND DISCUSSIONS

3.1 Physical and Chemical Composition of Binders

Table 1: Physical Properties of Binders

S/N	Material/binder	Specific gravity	Colour
1	Cement	3.14	Grey
2	LBPA	2.61	Grey
3	LSD	2.72	White grey

Table 2: Oxide compositions of LBPA, LSD and OPC.

Oxide	LBPA (%)	LSD (%)	Cement (%)
CaO	15.71	40.32	64.45
SiO_2	39.01	11.71	21.55
Al_2O_3	3.05	2.55	5.28
Fe_2O_3	11.51	1.78	3.95
MgO	2.01	1.27	1.85
K_2O	26.8	-	-
Na_2O	0.12	0.15	1.2

3.2 Aggregate Crushing Value and Aggregate Impact Value

Table 3: Result of Aggregate Crushing Value (ACV)

Description	Test 1 (kg)	Test 2 (kg)
Wt. of empty mould = C'(g)	10.45	10.45
Wt. of material in mould = D '(g)	14.15	14.13
Wt of aggregate (W_1) =D-C (g)	3.7	3.68
Wt of aggregate passing (W_2)	0.576	0.643
ACV = (W_2/W_1) X 100	15.57	17.47
Average ACV	16.52	

Table 4: Result of Aggregate Impact Value (AIV)

Description	Test 1 (kg)	Test 2 (kg)
Wt. of empty mould = C'(g)	2.8	2.8
Wt. of material in mould =D'(g)	3.5	3.5
Wt of aggregate (W1) =D-C (g)	0.7	0.67
Wt of aggregate passing (W2)	0.032	0.045
AIV = (W_1/W_2) X 100	4.57	6.7
Average AIV	5.64	

The result of the aggregate impact value is shown in Table 11. The AIV obtained was 5.64%.

3.3 Consistency and Setting-time Results

Table 5: Consistency for cement / LSD/LBPA paste

% Replacement	Consistency (%)	Initial setting time (mins)	Final setting time (mins)
0 LSD/LBPA	28	65	145
5 LSD/LBPA	31	70	195
10 LSD/LBPA	34	74	210
15 LSD/LBPA	35	79	235
20 LSD/LBPA	38	83	265

Table 5 shows the consistency and setting time (Initial and final) of LSD/LBPA. The consistency value of the cement was lower than the values of blended cement with LSD/LBPA. The consistency of cement was 28% and increased with increasing percentages of LSD/LBPA. At 5, 10, 15, and 20% replacement, the values were 31, 34, 35, and 38%. The results stated that cement consistency is less than that of cement with LSD/LBPA. At higher replacement level, the initial setting time increased which shows that LSD/LBPA retards the setting time of cement.

3.4 Slump Test Result

Table 6: Result of Slump test

Percentage Replacement	Slump Height (mm)
Control	38
LSD 5%, LBPA 0%	41
LSD 5%, LBPA 5%	45
LSD 5%, LBPA 10%	46
LSD 5%, LBPA 15%	51
LSD 5%, LBPA 20%	54
LSD 5%, LBPA 25 %	55

The result of the slump test showed that at 0% replacement (control), the result was 38 mm, 5% (5% LSD, 0% LBPA) was 41mm, 10% (5% LSD, 5% LBPA) was 45 mm, 15% (10% LSD, 5% LBPA) 46mm, 20% (15% LSD, 5% LBPA) was 51mm, 25% (20% LSD, 5% LBPA) was 54mm and 30% (25% LSD, 5% LBPA)was 55mm. All replacements showed that concretes made with LSD and LBPA were workable. The higher the replacement of cement with LBPA, the higher the slump value. This shows that the LBPA absorbs more water. The slump result indicates a true slump mean it is workable.

3.5 Compressive Strength Result

The result of the compressive strength is shown in Table 7.

Table 7: Compressive strength result for CCD

Run	Factor 1 A:LBPA %	Factor 2 B:Curing Age days	Response 1 Compressive strength N/mm^2
1	15	60	22.66
2	15	60	22.66
3	15	60	22.66
4	15	28	18.83
5	25	60	14.85
6	5	90	26.59
7	25	90	15.95
8	15	90	23.57
9	15	60	22.66
10	5	60	26.36
11	5	28	24.45
12	25	28	13.58
13	15	60	22.66

Limestone dust was kept at 5% for all the runs, LBPA varied at 5% to 25% at curing ages of 28, 60 and 90 days. At ages 28-90 days, LSD/LBPA addition increased the strength of concrete possibly due to an improved transition zone. At these ages, more calcium hydroxide is being removed from the system and accelerates cement hydration.

Table 8: ANOVA for Compressive strength

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	210.9	5	42.17	100	< 0.001
A-LBPA	181.7	1	181.73	433	< 0.001
B-Curing Age	14.26	1	14.26	34	0.006
A^2	6.84	1	6.84	16.3	0.005
B^2	2.38	1	2.38	5.68	0.049
Residual	2.94	7	0.419		
Lack of Fit	2.94	3	0.979		
Pure Error	0.00	4	0.000		
Cor Total	213.8	12			

In Table 8, the Model F-value of 100.54 implies the model is significant. P-values less than 0.0500 indicate model terms are significant. A, B, A^2, B^2 are the significant model terms

Table 9: Fit Statistics for compressive strength

Parameters	Value
Std. Dev.	0.648
Mean C.V. %	21.34 3.03
R^2	0.9863
Adjusted R^2	0.9765
Predicted R^2	0.8677
Adeq Precision	32.02

Adeq Precision of 32.02 indicates an adequate signal. It is seen from the analysis that R^2 = 0.9863 showing that the correlation between the actual and predicted values is very good and the regression model coincides with the test data. The Predicted R^2 of 0.8677 is in reasonable agreement with the Adjusted R^2 of 0.9765. The model equation for compressive strength.

$$Compressive\ strength = 21.04 - 0.089 * LBPA + 0.16 * C.A + 0.0002 * LBPA\,(C.A) - 0.016 * (LBPA)^2 - 0.00097 * (C.A)^2 \quad \ldots(1)$$

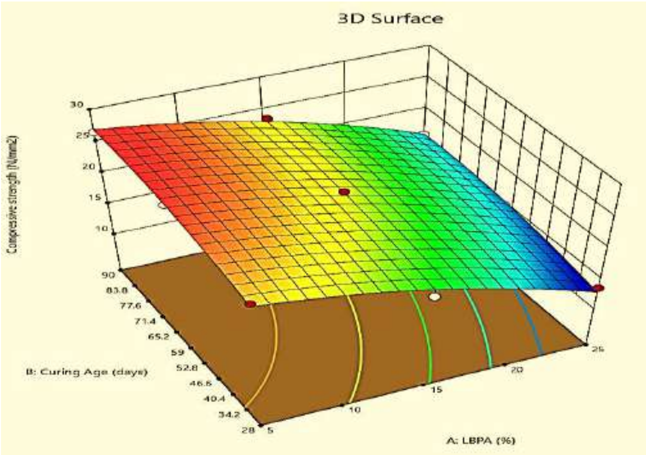

Figure 1: 3D graph of LBPA and C.A and compressive strength.

Figure 1 shows 3D response surface graph shows the influence of LBPA and curing age on compressive strength. The 3-D surface elucidates correlation between dependent variables (responses) and the independent variables (factors). The graph shows that increase in LBPA and C.A causes a decrease in compressive strength. Figure 5 shows the interaction of C.A and LBPA on compressive strength of concrete. The higher the curing age, the higher the compressive strength while the higher the percentage of LBPA replacement, the lower the compressive strength.

3.6 Flexural strength result by CCD

Limestone dust was kept at 5% for all the runs, LBPA ranged from 5% to 25% at curing ages of 28, 60, and 90 days.

Table 10: Flexural strength result.

Run	Factor 1 A:LBPA %	Factor 2 B:Curing Age days	Response 2 Flexural strength N/mm^2
1	15	60	3.2
2	15	60	3.2
3	15	60	3.2
4	15	28	2.9
5	25	60	2.5
6	5	90	3.5
7	25	90	2.6
8	15	90	3.3
9	15	60	3.2

10	5	60	3.4
11	5	28	3.3
12	25	28	2.3
13	15	60	3.2

Table 11: ANOVA for flexural strength.

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1.64	5	0.3277	188.7	< 0.001
A-LBPA	1.31	1	1.31	753	< 0.001
B-Curing Age	0.1350	1	0.1350	77.7	< 0.001
AB	0.0026	1	0.0026	1.47	0.265
A^2	0.1262	1	0.1262	72.67	< 0.001
B^2	0.0096	1	0.0096	5.52	0.051
Residual	0.0122	7	0.0017		
Lack of Fit	0.0122	3	0.0041		
Pure Error	0.0000	4	0.0000		
Cor Total	1.65	12			

The Model F-value of 186.66 implies the model is significant. P-values less than 0.0500 indicate model terms are significant. In this case A, B, A^2 are significant model terms.

Table 12: Fit Statistics for flexural strength

Parameters	Value
Std. Dev.	0.0417
Mean	3.06
C.V. %	1.36
R^2	0.9926
Adjusted R^2	0.9874
Predicted R^2	0.9310
Adeq Precision	43.577

In Table 12, the Predicted R^2 of 0.9310 is in reasonable agreement with the Adjusted R^2 of 0.9874; i.e. the difference is less than 0.2. Adeq Precision measures the signal-to-noise ratio. A ratio of 43.577 is greater than 4 shows that it is desirable. It is seen from the analysis that R^2 = 0.9926 showing correlation between actual and predicted values is very good and the regression model coincides with the test data. The Predicted R^2 of 0.9310 is in reasonable agreement with the Adjusted R^2 of 0.9874. The model equation for flexural strength

$$Flexural\ strength = 2.98 + 0.013 * LBPA + 0.011 * C.A + 8.2e-05 * LBPA\,(C.A) - 0.002 * (LBPA)\char`^2 - 6.14e-05 * (C.A)\char`^2 \quad ..(2)$$

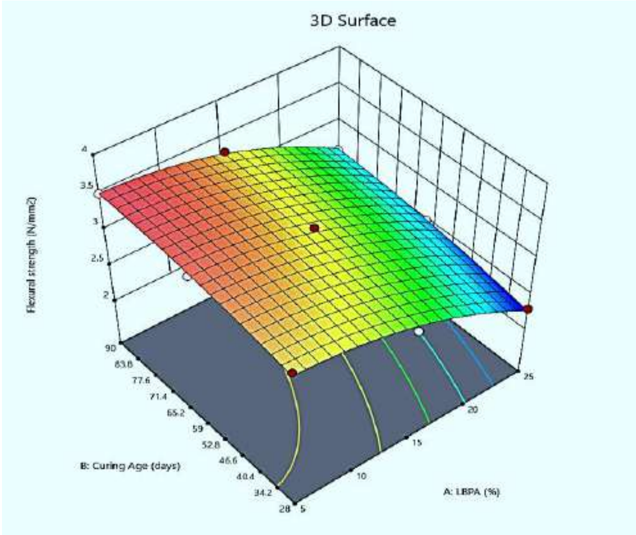

Figure 2: 3D surface graph showing the influence of LBPA and C.A on flexural strength.

The 3-D surface in figure 2 elucidates the correlation between the dependent variables (responses) and the independent variables (factors). The graph shows that an increase in LBPA causes decrease in flexural strength and increase in C.A causes increase in compressive strength.

3.7 Optimization of Mixtures by Numerical Method

The result of the optimization is shown in Figure 3.

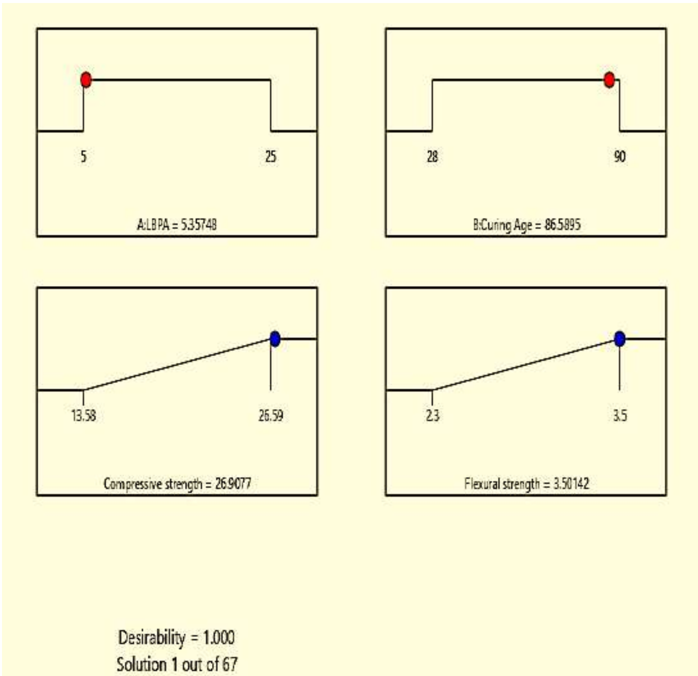

Figure 3: Ramp plot showing the optimal values

The optimal result showed 5% LSD and 5.4% LBPA at 90 days gave the maximum compressive strength of 26.9 N/mm^2 and flexural strength of 3.5 N/mm^2.

4.CONCLUSION

Based on the findings of this research, the following conclusions are made;

1. The results of the physical properties showed that cement had specific gravity of 3.14, LSD and LBPA had 2.72 and 2.61 respectively. The results of the oxide composition showed that LBPA can be classified as a class C pozzolana.

2. The consistency of cement was 28% and increased with increasing percentages of LSD/LBPA. At 5, 10, 15, and 20% replacement, the values were 31, 34, 35, and 38%. At higher the replacement level, increase in initial setting time shows that LSD/LBPA retards setting time of cement

3. All replacements showed that concretes made with LSD and LBPA were workable. The higher the replacement of cement with LBPA, the higher the slump value.

4 Optimization of compressive and flexural strength of the resulting concrete by Response Surface Methodology was done. The optimal result was 5% LSD and 5.4% LBPA at 90 days gave compressive strength of 26.9 N/mm^2 and flexural strength of 3.5 N/mm2. Model equations were developed for both compressive and flexural strengths.

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