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RESEARCH ARTICLE

Influence of Pulverized Animal Bone and Animal Bone Ash on the Mechanical Properties of Normal Strength Concrete using Response Surface Method

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ABSTRACT - Global warming, improper solid waste and environment degradations are the major challenges facing humankind. One way to lower the effect global warming is to use less energy intensive materials optimally in construction and proper solid waste disposals to protect the environment from it harmful effects. In this study, the mechanical properties of Pulverized Animal Bone (PAB) and Pulverized Animal Bone Ash (PABA) as cement replacement in concrete were examined and the mechanical properties of concrete containing PAB/PABA optimised using response surfaces methodology (RSM). Central composite Design (CCD) method of experimental design of RSM was used to design the experiment using the key variables in the mechanical properties of Pulverised Animals Bone Ash concrete (PABC) and Pulverised Animals Bone Concrete Ash (PABAC). The variables considered in the model's development are Bone powders percentages replacement of cement in concrete at five levels (5, 10, 15, 20 and 25% levels) and curing age (3, 7, 28, 60 and 90-days). The Test conducted on fresh PABC/BAPAC was slump test while on hardened concrete were, Density, water absorption and compressive strength tests. Analysis of variance (ANOVA) indicates that the variables PAB/PABA and curing age influence the variability in the generated models and all the models are statistically significant at 95% level in all the factors levels. Numerical method of optimisation was applied to determine optimum mix proportions for PABC/PABAC. The optimum mix for PABC was obtained by addition of 5.00% PAB after curing for 42.24-days with 0.736 desirability. In PABAC, 5.00% PABA and 44.87-days curing with desirability 0.736 was the optimum.

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1.0 INTRODUCTION

The need to meet the demand for shelter and other infrastructure in the construction industry has led building engineers to start exploring alternative materials for construction; this is as a result of the high cost of conventional construction materials. Concrete being the most widely used construction material has proven to meet the demands of the construction industry and this is due to the ease by which structural elements are produced to desired shape and size. Alternative materials such as mineral and chemical admixtures have been used in the production of concrete to improve its structural and physical properties. Along this line, building engineers have been exploring the possibilities of using industrial and agricultural waste as additives or replacements for concrete constituents in concrete production.

These studies attempt to utilize industrial and agricultural wastes to reduce environmental pollution that may arise as a result of too many wastes and also reduce the cost of concrete production, in the process minimizing greenhouse gas emission and energy consumption. Due to high cost of cement, energy consumption and greenhouse gas emission, the use of supplementary cementitious materials have been a focus for research lately. Animal bones are dumped in large quantities at disposal yards as wastes creating air pollution due to its bad odour and could eventually lead to outbreaks of illnesses.

2.0 RELATED WORK

Studies into the application of alternative materials in the production of concrete have shown that concrete strength development is determined not only by the water cement ratio, but also influenced by the content of other ingredients, as in the case of a study carried out by Elinwa [1]. Findings show that strengths recorded at 10% replacement of cement with calcined termite mound material (CTMM) at 60 days supersede that of the reference mix. Elinwa [1] posited that up to 40% replacement of cement with CTMM produces concrete of good quality when cured for 90 days. In the same vein, Siddique and Klaus [2] found that metakaolin helps in enhancing the early age mechanical properties as well as long term properties of cement-concretes with replacements levels between 10 to 15% of cement with metakaolin.

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Industrial and agricultural wastes such as rice husk ash [3], sugarcane bagasse ash [4], glass waste powder [5], ceramic waste [6], and marble waste [7] have been utilized in concrete production as partial replacement for cement. Metakaolin was also utilized as a partial replacement for cement for concrete production [8].

This study considers an effective way of disposal for these animal bones by utilizing them in concrete production and optimised the properties of bone powder/Ash in mortar and concrete. Response surfaces methodology (RSM) was used to obtained response surface models for Density, Water absorption and compressive strengths.

3.0 RESPONSE SURFACE METHODOLOGY (RSM)

Montgomery [9] defined response surface methodology as a collection of mathematical and statistical techniques used for modeling and analyzing of problems in which a response of interest is influenced by several variables and the objective is to optimize the response. RSM is highly effective tool for models development, data analysis and interpretation, in an efficiency and economy in the experimental process and scientific objectivity in the conclusions.

RSM have been used as an effective method for improving the characteristics of concrete by many researchers. Montgomery [9] have used RSM to developed a model for prediction of mechanical properties of recycled coarse aggregate and Bone China fine aggregate. Recycled construction waste (RCA) as coarse and bone china fine aggregate (BCA) as fine aggregate, RSM Central Composite Design approach in RSM was used to design the experiment with alpha=1.4142. Analysis of variance test (ANOVA) was utilised in access statistical significance of the developed mathematical models. Based on ANOVA all the models were statically significant at 95% level of significant and it was concluded that percentage of BCA and percentage of RCA can describe the mechanical properties of Recycled coarse aggregate and Bone China fine aggregate concrete. The results of numerical optimisations indicate the optimum utilization of RCA and BCA was at 40% and 60% as coarse and fine aggregate replacement in concrete respectively. It was concluded that use of RCA and BCA in concrete can helps to reduce costs and is sustainable.

4.0 MATERIALS AND METHODS

Materials

4.1 Cement

The cement used was Ashaka Portland cement having a specific gravity of 3.15. The physical and oxide composition of Ashaka cement are shown on Tables 1 and 2 respectively.

4.2 Aggregates

The coarse aggregate was obtained from local suppliers in Bauchi, Bauchi State. It is a normal weight aggregate with nominal size of 20 mm, specific gravity of 2.63, bulk density of 1485 kg/m^3, aggregate crushing value (ACV) of 15.52% moisture content of 0.56%. The tests conform to BS EN 1097 [10] and were conducted in the Structures and Soil Mechanics Laboratories of the Department of Civil Engineering, Abubakar Tafawa Balewa University Bauchi.

The fine aggregate (sand) was sourced from local suppliers in Bauchi with a specific gravity of 2.64, bulk density of 1528 kg/m^3 and moisture content of 0.42%. The fine aggregate was tested in conformity with BS EN 1097 [10]. The specific gravity test was carried out in the structures laboratory, while the bulk density was carried out in the soil mechanics laboratory of the Department of Civil Engineering in Abubakar Tafawa Balewa University, Bauchi.

Table 1. Physical properties of Ashaka Portland Cement

Parameters	Values
Bulk density (kg/m^3)	1475
Moisture content (%)	0.9
pH	12.40

Source: AshakaCem Plc (2019).

Table 2. Oxide composition of Ashaka Portland cement, PAB and PABA

Compounds	Values (%)		
	Cement	PAB	PABA
SiO_2	19.258	7.03	4.02
Al_2O_3	5.728	0.91	2.00
Fe_2O_3	2.380	0.15	0.02
CaO	62.238	70.87	66.00
Mn_2O_3	0.161	0.03	0.01

Table 2. (cont.)

Compounds	Values (%)		
	Cement	PAB	PABA
Na_2O	0.129	1.67	1.00
MgO	0.569	2.58	1.00
K_2O	0.955	0.51	0.01
SO_3	2.194	0.54	0.01
TiO_3	0.283	--	0.01
P_2O_5	0.193	--	25.41
Cl	0.006	--	--
LOI	--	2.14	0.35

PAB=Pulverized Animal Bone: PABA=Pulverized Animal Bone Ash

4.3 Water

Potable tap water suitable for drinking was used for the work. No test was conducted on the water.

4.4 Pulverized Animal Bone (PAB)

Animal bones were collected from abattoir disposal yards in Bauchi metropolis and environs. Meat residue and tissues were properly removed and the resulting bones were sun dried, pulverized and sieved through 150µm sieve to obtain PAB. The specific gravity of the PAB was determined as 2.23. The oxide composition of PAB is shown on Table 2.

4.5 Pulverized Animal Bone Powder (PABA)

The collected bones from the abattoir are calcined in a kiln at temperature range of between 600 and 800 ºC over a period of approximately one hour. The resulting ash is pulverized and sieved through 150µm sieve to obtain PABA. The specific gravity of the PABA was measured as 2.36. The oxide composition of PABA is shown on Table 2.

5.0 METHODS AND EXPERIMENTAL RESULTS

5.1 Consistency and Setting Times Tests

The consistency and setting times tests were conducted using the Vicat apparatus with PAB replacing cement at 0 %, 5 %, 10 %, 15 %, 20 % and 25 % by weight of cement. The same procedure was repeated for cement and PABA. Water-cementitious ratios of 0.28 to 0.31 and 0.28 to 0.323 were used to attain normal consistency for cement/PAB and cement/PABA pastes respectively at replacement levels from 5% to 25 %. The results for normal consistency and setting times are shown on Table 3.

Table 3. Consistency and setting times of cement-PAB and PABA pastes

Replacement (%)	Pulverized Animal Bone (PAB)			Pulverized Animal Bone Ash (PABA)		
	Consistency (%)	Initial (min)	Final (min)	Consistency (%)	Initial (min)	Final (min)
0	28.0	118	235	28.0	118	235
5	28.7	156	300	29.1	150	295
10	29.6	200	350	29.8	195	330
15	30.0	240	420	31.0	230	380
20	30.6	204	390	31.7	193	382
25	31.0	194	380	32.3	180	385

5.2 Concrete Preparation

The concrete mix was designed using grade 20 (f_{cu} 20 N/mm^2) and the batching was carried out using the absolute volume method conforming to ACI 211.1 [11]. The summary of the mix proportions are shown in Table 4 and 5. Six mixes were used for concrete production, the control mix contained 0% PAB or PABA while other mixes contained PAB or PABA replacing the cement by weight at replacement levels from 5% to 25% at 5% interval. The concrete mix ratio of 1: 1.9: 2.6 at water-cementitious ratio of 0.45 was obtained from the design.

Table 4. Mix proportion for Concrete Production Containing PAB

Replacement (%)	PAB (kg)	Cement (kg)	FA (kg)	CA (kg)	Water (kg)
0	0.00	7.02	13.32	18.36	3.24
5	0.36	6.66	13.32	18.36	3.24
10	0.72	6.30	13.32	18.36	3.24
15	1.08	5.94	13.32	18.36	3.24
20	1.44	5.58	13.32	18.36	3.24
25	1.80	5.22	13.32	18.36	3.24

Table 5. Mix proportion for concrete production containing PABA

Replacement (%)	PABA (kg)	Cement (kg)	FA (kg)	CA (kg)	Water (kg)
0	0.00	7.02	13.32	18.36	3.24
5	0.36	6.66	13.32	18.36	3.24
10	0.72	6.30	13.32	18.36	3.24
15	1.08	5.94	13.32	18.36	3.24
20	1.44	5.58	13.32	18.36	3.24
25	1.80	5.22	13.32	18.36	3.24

Mixing was carried out using the tilting drum mixer, constituents are measured and poured inside the concrete mixer and mixed until the mix is uniform in appearance. Mold of size 100 mm x 100 m x 100 mm was used for casting while mechanical vibrator used to expunge air bubbles from the molds to achieve adequate compaction.

5.3 Slump Test

The slump test was carried out using the slump cone and conducted in accordance with BS EN 12350-2 [12]. It was conducted to determine the workability of the concrete mixes at the replacement levels of 0 % to 25 % of PAB or PABA by weight of cement. At each replacement level, two slump samples were measured and the average recorded. The results are shown on Table 6.

Table 6: Slump test result

Replacement (%)	Slump (mm)	
	PAB	PABA
0	71	71
5	65	60
10	57	49
15	50	37
20	38	22
25	25	15

5.4 Density, Water-Absorption and Compressive Strength Tests

Specimens were cast using cement replacement levels of 0 to 25 % PAB/PABA contents by weight of cement and cured from 3 to 90 days. Three cubes were weighed for density test at the end of each curing regime using a digital weighing machine and the average recorded. The test was carried out in accordance with BS EN 12390:7 [13] and the results are shown on Table 7.

Similarly, for the water absorption test, the concrete cubes were cured by complete immersion in water at curing age between 3 and 90 days before the test. The concrete specimen were dried to a constant mass at 105^o for 72 hours, they were then weighed before and after immersion for thirty minutes and the values recorded. Three cubes were weighed before and after immersion and the average recorded. The test was carried out in accordance with BS 1881:122 [14] and results shown on Table 7.

For compressive strength test, specimens were crushed to failure using COMPTEST digital compression machine. The load was applied at the rate of 3kN/s until failure. At the end of each curing regime three cubes were tested and the average recorded. The test was conducted in accordance with BS EN 12390:3 [15] and results shown on Table 7.

6.0 RSM MODELLING AND OPTIMIZATION

6.1 Model Development

The properties of mortar and concrete incorporating PAB and PABA material were analyzed and the empirical relations developed based on central composite design (CCD) of the experiment (DOE) for RSM. Five replacement levels of PAB/PABA (0, 5, 10, 15, 20 and 25%) and curing age (3, 7, 28, 60 and 90-days) were combined as variables/factors and the combinations and the design of experiment matrix is shown in table 8 with PAB coded as A and PABA coded as B. Second order quadratic response surfaces model was used as empirical equation to analyze the responses using Design-Expert version 11.0 software shown as Equation (1).

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_{12} AB + \beta_{11} A^2 + \beta_{22} B^2 \quad (1)$$

where
Y is predicted response; β_0 is intercept; β_1, β_2 are linear effect coefficients; β_{11}, β_{22} are quadratic effect coefficients; and β_{12} is interaction effect coefficient.

Table 7: Details variables combinations and the responses density (Kg/m3), water absorptions WAs (%) and compressive strength CSs (N/mm2) PAB/PABA Concretes

	A	B	PAB Concrete			PABA Concrete		
Run	(PAB/PABA) %)	(CAs days)	Density (Kg/m^3)	WAs (%)	CSs (N/mm^2)	Density (Kg/m^3)	WAs (%)	CSs (N/mm^2)
1	0	3	2650	1.03	15.72	2650	1.03	15.72
2	5	3	2580	1.42	15.51	2588	1.48	15.59
3	10	3	2575	1.57	14.45	2578	1.62	14.56
4	15	3	2570	1.49	11.08	2573	1.52	12.02
5	20	3	2566	1.60	9.56	2567	1.63	9.99
6	25	3	2460	1.70	7.16	2562	1.73	8.20
7	0	7	2660	1.13	20.50	2660	1.13	20.50
8	5	7	2590	1.53	19.19	2595	1.55	19.58
9	10	7	2585	1.60	18.47	2588	1.64	18.98
10	15	7	2577	1.53	17.62	2583	1.58	18.02
11	20	7	2571	1.65	15.68	2579	1.68	15.92
12	25	7	2568	1.73	13.79	2573	1.76	14.21
13	0	28	2690	1.26	25.27	2690	1.26	25.27
14	5	28	2687	1.60	23.09	2686	1.63	23.97
15	10	28	2689	1.63	22.71	2680	1.65	22.99
16	15	28	2679	1.71	21.55	2675	1.73	21.88
17	20	28	2676	1.74	19.63	2670	1.76	20.02
18	25	28	2672	1.75	15.69	2665	1.77	16.02
19	0	60	2680	1.29	25.45	2680	1.29	25.45
20	5	60	2676	1.67	24.22	2675	1.69	24.99
21	10	60	2673	1.70	23.83	2672	1.72	21.94
22	15	60	2669	1.67	21.57	2667	1.70	22.58
23	20	60	2665	1.71	20.20	2660	1.73	20.83
24	25	60	2659	1.80	19.15	2657	1.82	19.64
25	0	90	2680	1.42	25.57	2680	1.42	25.57
26	5	90	2677	1.69	24.99	2680	1.70	24.99
27	10	90	2675	1.71	23.50	2679	1.73	23.87
28	15	90	2670	1.70	21.95	2674	1.72	22.09
29	20	90	2668	1.74	21.29	2670	1.75	21.79
30	25	90	2663	1.81	20.09	2669	1.85	20.39

7.0 DISCUSSION

From results obtained for compressive strenght, the inclusion of PAB and PABA did not in any way cause the cement paste and concrete to undergo any chemical transformation with all the constituents it comes in contact with. This shows that both PAB and PABA are inert. PAB and PABA bahaves in a similar manner at all replacement levels for all responses performing less than the control mix [16]. The small differences in the values for consistency, setting times, density, water-absorption and compressive strength was accounted for due to the difference in fineness. PABA produced more fines than PAB because of the temperature the bones were subjected to during the ashing process [17].

7.1 Consistency and Setting Times

From the results shown in Table 3, it was observed that as the percentage replacement of PAB or PABA increases the quantity of water required to attain normal consistency increased. Normal consistency for cement (control) was attained at 28%, while for PAB and PABA normal consistency was attained at 28.7 to 31.0% and 29.1 to 32.3% respectively for 5 to 25% replacement levels. The increase in water content before attaining normal consistency was due to the fineness of the PAB or PABA particles (150 µm), also knowing that PAB and PABA have lower specific gravity than cement, more of their volume would be required for every weight of cement replaced. Furthermore, the resultant large volume of PAB or PABA will give rise to larger surface area that would be in contact with water, this will increase the water demand of the cement-PAB/PABA blended paste to attain normal consistency. The ash content of PABA is responsible for the increase in water demand because it has finer particles than PAB. In conclusion the material would lead to high affinity for water when used as a partial replacement of cement. Figure 1 shows the relationship between water content and cement replacement with PAB/PABA for attaining normal consistency.

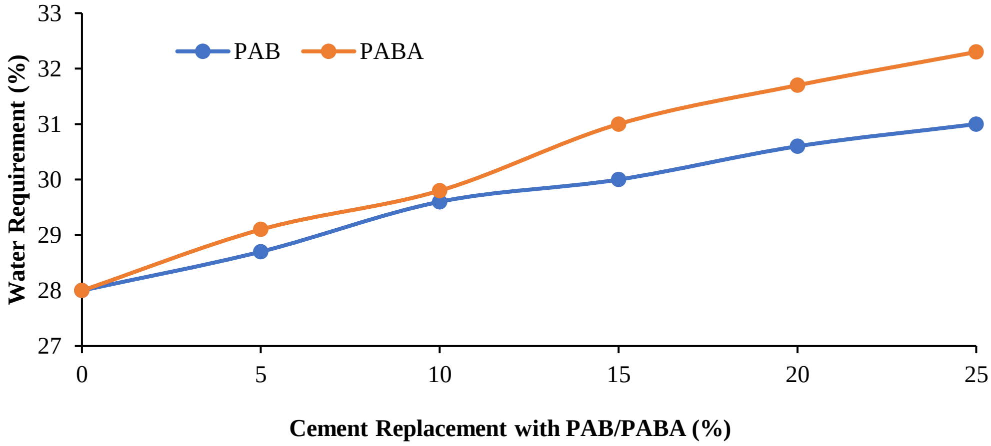


Figure 1: Consistency of PAB and PABA

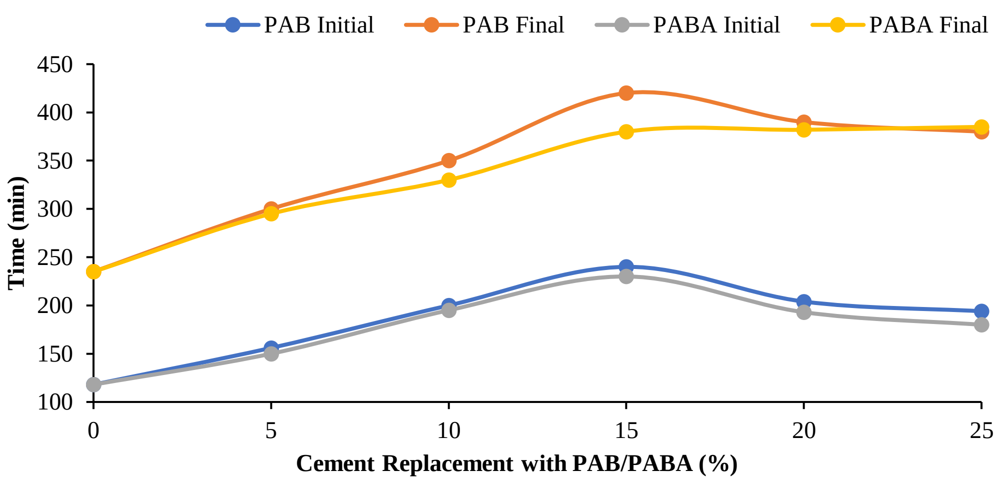


Figure 2: Setting times of PAB and PABA

From Figure 2, it was found that as the percentage replacement of cement with PAB/PABA increases, the initial and final setting times increases up to 15% replacement level and starts decreasing thereafter. According to BS EN 196-3, the initial setting time of cement should not be less than 40 minutes while the final setting time should not be more than 600 minutes. The results conform to the condition stipulated in the code. In practical application when carrying out concrete work in hot weather, quick setting of cement due to excessive evaporation as a result of the hot weather causes cracks.

Replacement of cement with PAB or PABA by 15% will result in delaying the setting of cement up to a reasonable time to allow for the reaction process to complete. PAB and PABA are therefore recommended as setting time decelerators in concrete production.

7.2 Slump

The results obtained are presented in Table 6. The maximum value of slump was recorded at 0% replacement of cement with PAB and PABA (reference mix). The slump starts decreasing as the percentage replacement increases giving an inverse relationship. The increment in percentage replacement turns the fresh concrete into an inconsistent and stiff matrix. Concrete mixes with percentage replacement of cement with PAB ranging from 0 to 15% are classified as 'S1' (slump ranging from 10 mm to 40 mm), while 20 and 25% are classified as 'S2' (slump ranging from 50 mm to 90 mm) according to EN206-1. Similarly conforming to the same code, Concrete mixes with percentage replacement of cement with PABA ranging from 0 to 10% are classified as 'S1', while 15 to 25% are classified as 'S2'. These class of mixes are suitable for normal reinforced concrete placed with vibration.

7.3 Density

From results shown on Table 7, densities of the concrete decrease with increase in PAB or PABA contents. The densities of the specimens containing PAB or PABA are less when compared to the reference mix. The specimens containing PABA have densities higher than that containing PAB and this is because PABA has higher specific gravity than PAB.

From Table 7, the mean density recorded for each mix after 28 days of curing lies within the range of 2200 to 2600 kg/m^3 which is specified as the density for normal weight concrete (EN 206-1:2000). Since the density of concrete depends primarily on the amount and densities of the aggregates, entrapped air, the concentration of the binders and size of aggregate used for the production of concrete [18], it is then deduced that the increase in PAB or PABA contents in the matrix are majorly responsible for the decrease in density obtained [19,20]. The influence of PAB/PABA replacements and curing age on concrete density was study using RSM.

The results of analysis of variance (ANOVA) of the responses, density of PABC and PABAC are shown in Table 8. The Fisher test (F-value test), P-value test and coefficient of determinations for the developed models indicate the models are statistically significant. The coefficient of determination (R^2) and adjusted coefficient of determination ($adjR^2$) are close to each other and close to unity (1) as showed in table 8 and the final model equations for PABC and PABAC are designated as Eq2 and Eq3 respectively.

The three dimensional response surfaces plot for both PABC and PABAC are shown as Figure 3 and 4. It could be deduced from the figures, at all levels of PAB/PABA replacement density of PABC and PABAC increases with increase in curing age and decreases with increase in PAB and PABA replacements.

7.4 Water Absorption

The result for water absorption is given on Table 7. Water absorption increase with percentage replacement of cement with PAB and PABA. At 25% of PAB/PABA replacing cement, a significant increase was recorded when compared with the reference mix.

RSM Models were developed to depict the behaviours of PABC and BAPAC and the effect of percentage replacement of PAB and PABA on water absorption. Analysis of variance shows the developed models are statistically significant at 95% confidence interval as shown in Table 8. From Table 9, the models coefficient of determination (R^2) and adjusted coefficient of determination ($adjR^2$) for PABC and PABAC density are close to each other and close to unity (1). The model equations are presented in Eq3 and Eq6.

The response surfaces for Water absorption of PABC and PABAC are plotted in Figure 5 and 6. From the figures, it can be deduced that water absorption increase with increase in PAB and PABA percentage replacement and increases with curing age.

7.5 Compressive Sterngth

Results of compressive strength presented in Table 7 show that as the percentage replacement of cement with either PAB or PABA increases the compressive strength reduces for all specimens. Concrete specimens having quantities of PABA shows compressive strengths slightly higher than the specimen having quantities of PAB. This may be attributed to more surface area is form for pozzolanic reaction from calcined Pulverised Bone when compared with uncalcined pulverised Bone powder.

Table 8 displays the ANOVA values for compressive strength models of PABC and PABAC. The determination coefficient R^2 and the adjusted coefficient $adjR^2$ for compressive strength of PABC and PABAC are all near unity and the high degree of fitting was found by Lack of Fit p-value test. P-value less than 0.05 shows that the regression models are statistically significant 95% level of significant as presented in Table 8. The final models equations for PABC and PABAC are Eq4 and Eq7 respectively.

The regression equations for PABC and PABAC are graphically represented by the three dimensional response surfaces plots as shown in Figure 7 and 8. The impacts of the two variables on compressive strength of can be seen on the plots. Compressive strength increases with increase in curing age and decreases with increase in percentage levels of PAB and PABA replacement at all the curing age.

Table 8. ANOVA for Density of PABC and PABAC

	PABC					PABAC				
	Source	DF	F-value	P-value	Significance	Source	DF	F-value	P-value	Significance
Density	Model	4	25.37	<0.0001	Significant	Model	4	32.45	<0.0001	Significant
	A (%)	1	08.88	0.0063	Significant	A (%)	1	10.06	0.0004	Significant
	B (days)	1	50.52	<0.0001	Significant	B (days)	1	72.07	<0.0001	Significant
	AB	1	6.39	0.00181	Significant	AB	1	4.41	0.0459	Significant
	B^2	1	23.24	<0.0001	Significant	B^2	1	31.76	<0.0001	Significant
Water absorption	Model	3	38.45	<0.0001	Significant	Model	3	37.37	<0.0001	Significant
	A (%)	1	27.11	<0.0001	Significant	A (%)	1	25.90	<0.0001	Significant
	B (days)	1	18.48	0.0002	Significant	B (days)	1	15.32	0.0006	Significant
	A^2	1	15.00	0.0005	Significant	A^2	1	16.58	0.0004	Significant
Compressive strength	Model	3	60.47	<0.0001	Significant	Model	3	56.27	<0.0001	Significant
	A (%)	1	56.41	<0.0001	Significant	A (%)	1	49.36	<0.0001	Significant
	B (days)	1	84.56	<0.0001	Significant	B (days)	1	80.38	<0.0001	Significant
	B^2	1	28.58	<0.0001	Significant	B^2	1	27.71	<0.0001	Significant

$$\text{Density PABC (Kgm}^3\text{)} = +2682.18 - 17.92A + 48.56B + 19.31AB - 66.17B^2 \quad (2)$$

$$\text{WAs PABC (\%)} = +1.74 + 0.12A + 0.092B - 0.10A^2 \quad (3)$$

$$\text{CSs PABC (N/mm}^2\text{)} = +22.13 - 2.90A + 4.01B - 4.44B^2 \quad (4)$$

$$\text{Density PABAC (Kgm}^3\text{)} = +2677.31 - 13.93A + 42.36B + 11.72AB - 51.41B^2 \quad (5)$$

$$\text{WAs PABAC (\%)} = +1.74 + 0.12A + 0.085B - 0.11A^2 \quad (6)$$

$$\text{CSs PABAC (N/mm}^2\text{)} = +22.42 - 2.72A + 3.91B - 4.38B^2 \quad (7)$$

Table 9. Model statistics for response variables

	PABC				PABAC				
Responses	PredR^2	AdjR^2	F-value	P-value	PredR^2	AdjR^2	F-value	P-value	Remark
Density	0.8023	0.7707	25.37	<0.0001	0.8385	0.8127	34.45	<0.0001	Significant
Water absorp.	0.8161	0.7948	38.45	<0.0001	0.8117	0.7900	37.37	<0.0001	Significant
Compr.Strength	0.8746	0.8602	60.47	<0.0001	0.8665	0.8511	56.27	<0.0001	Significant

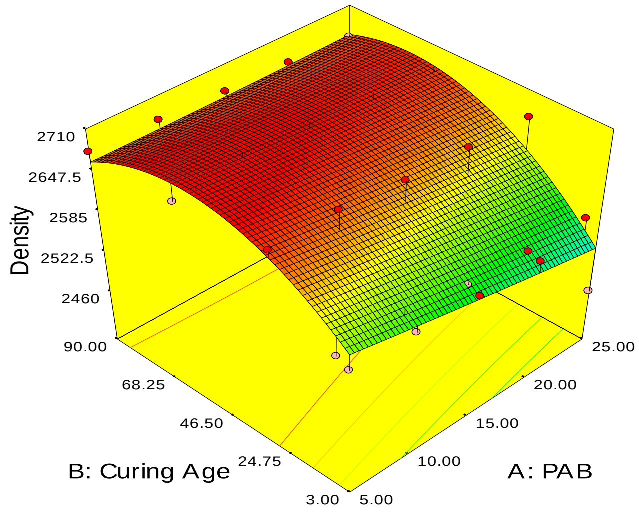


Figure 3. Response surface plot for PABC density

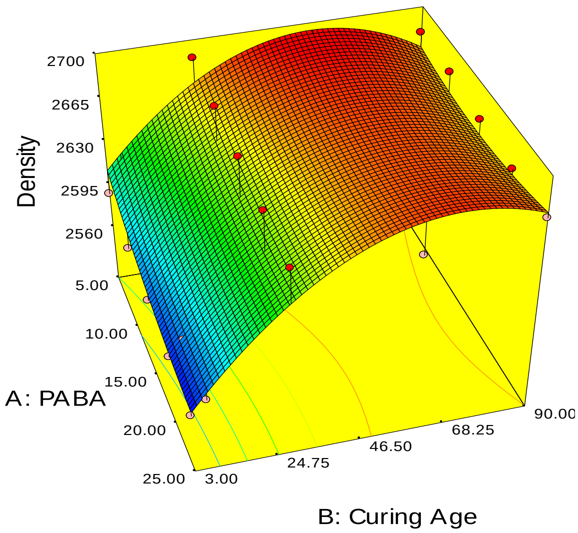


Figure 4. Response surface plot for PABAC density

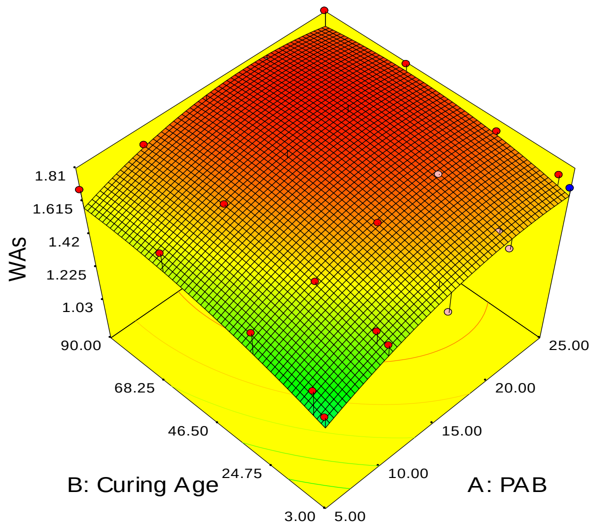


Figure 5. Response surface plot for PABC Water absorption

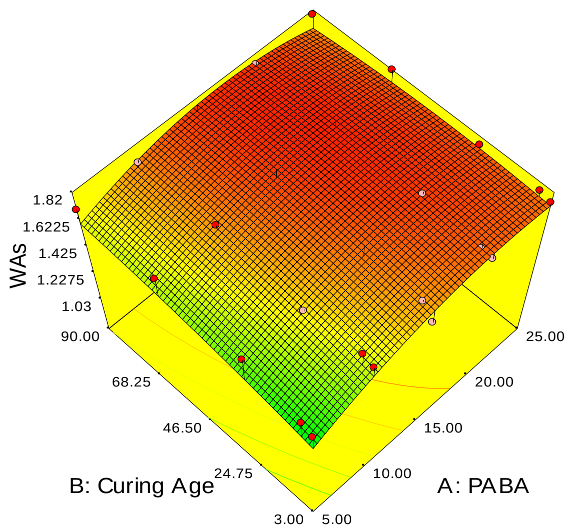


Figure 6. Response surface plot for PABAC water absorption

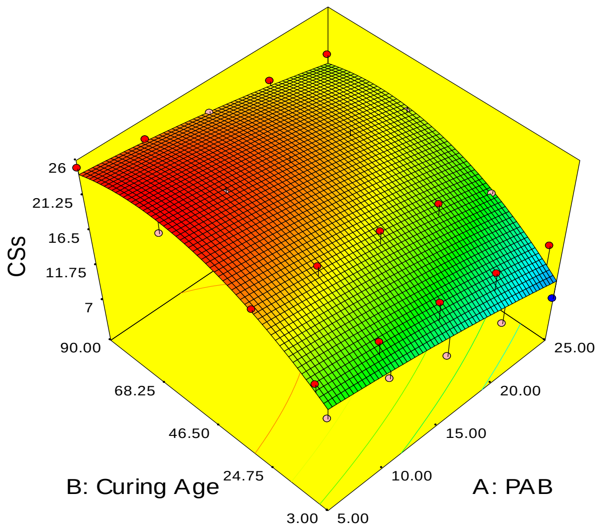


Figure 7. Response surface plot for PABC compressive strength

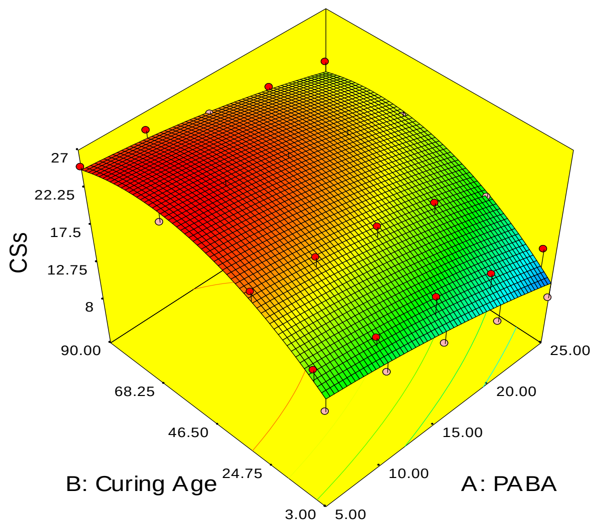


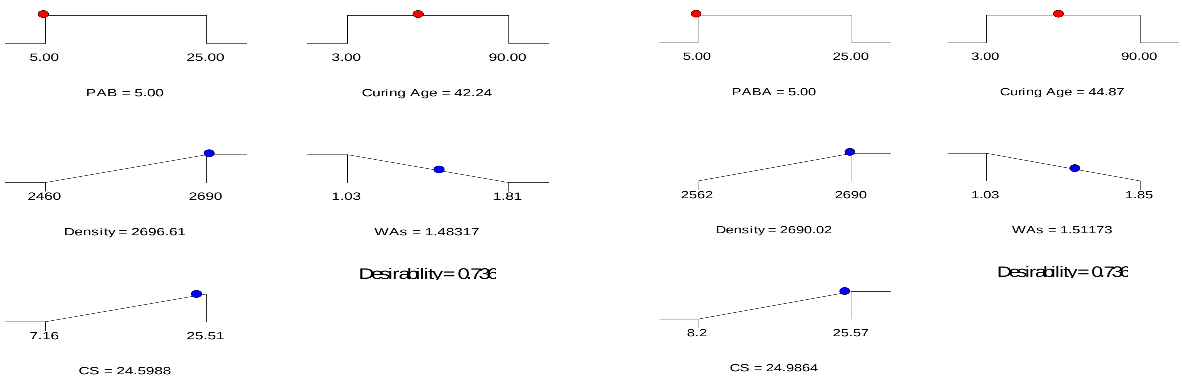
Figure 8. Response surface plot for PABAC compressive strength

8.0 OPTIMIZATION

Numerical optimization method was employed to optimize the variable of all the PABC and PABAC mixtures. The Optimization was performed by using Design Expert Software. The goals and limits of the optimisation for PABC and PABAC are shown in Table 10. The optimum mix for PABC was obtained by addition of 5.00% PAB after curing for 42.24-days with 0.736 desirability. In PABAC, 5.00% PABA and 44.87-days curing with desirability 0.736 was the optimum as shown in the Ramp plot of Figure 9 (a) and (b).

Table 10: Responses goal and limits for the optimization

Name of response	Goals	PABC		PABAC	
		Lower limit	Upper limit	Lower limit	Upper limit
Density	Maximize	2460	2690	2562	2690
Water absorption	Maximize	1.03	1.87	1.03	1.83
Compressive Strength	Maximize	7.16	25.51	8.20	25.57



(a) (b)

Figure 9. Ramp plot showing the optimum settings of PABC (a) and PABAC (b)

9.0 CONCLUSION

1) Pulverized animal bone whether in its natural or calcined form has proven to be a good cement replacement material in concrete properties other than strength. When concreting in hot weather it is recommended to add about 10 to 15% of either PAB or PABA for concrete elements while 20 to 25% for rendering to slow down the setting time to allow hydration reaction to complete. Though PAB or PABA does not improve the compressive strength, it acts as filler in concrete filling pores improving on the density and water absorption of concrete which are desirable properties in concrete.
2) With PAB and PABA the RSM showed is an effective tool for design improvement of PAB and PABA concretes.
3) All the regression models developed for Density, Water Absorption and Compressive strengths of PABC and PABAC were statistically significant at a 95% confidence levels.

10.0 AUTHOR CONTRIBUTIONS

Claudius Konitufe.: Conceptualization, Methodology, Investigation and Original draft preparation.

Abubakar Sabo Baba.: Software, Visualization and Validation.

Aliyu Abubakar.: Data curation, Reviewing, Editing and Supervision.

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12.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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14.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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