doi.org/10.54473/IJTRET.2025.10106
International Journal of Trendy Research in Engineering and Technology
Volume 10 Issue 1 February 2026
ISSN No. 2582-0958

ASSESSMENT OF THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF CONCRETE ADMIXED WITH CASSAVA PEEL ASH

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Received 15 Feb' 2026 Received in revised form 18 Feb' 2026 Accepted 20 Feb'2026
Available Online 23 Feb'2026

ABSTRACT

This study investigates the utilization of cassava peel ash (CPA) as a partial substitute for cement in concrete production, aiming to create more environmentally friendly construction materials while maintaining structural integrity. CPA was incorporated as a partial cement replacement at levels ranging from 0% to 15%, increasing in 5% increments. The results of the slump test for the admixed concrete showed that at 0% (control), slump was 51 mm, 5% was 54 mm, 10% was 57 mm, 15% was 64 mm, and 20% was 68 mm. The density of the CPA-Concrete is within the range of 2.4 to 2.54 kg/m^3. The highest compressive strength was recorded as 26.4 N/mm^2 with 5% CPA at 56 days, this is higher than the control strength of 22.5 N/mm^2. The highest flexural strength was recorded at 3.4 N/mm^2 with 5% CPA at 56 days of curing, higher than the control flexural strength of 3.1 N/mm^2. The optimization function of Design-Expert software version 13 indicates that the optimal values of the factors as 5.4% CPA at 50 days. The microstructural analysis of the control appears to be loosely packed and thus porous, on the other hand, the SEM images of admixed concrete containing 5.4% CPA have few calcium hydroxide Ca $(OH)_2$ platelets and the pores are smaller and appear denser compared to the control image. The pozzolanic effect involving the consumption of calcium hydroxide $Ca(OH)_2$ to produce the secondary C-S-H gel is seen in admixed concrete. In conclusion, the study recommends 5.4% of CPA as partial replacement of cement in M20 grade concrete.

Keywords: Optimization, Cassava Peel Ash, Compressive Strength, Flexural Strength, Microstructural Analysis

1.INTRODUCTION

The recent introduction of wastes in concrete and mortar production has led to considerable improvements in their performance, saving costs and reducing the problems associated with the use of cement in building construction [1-4].

Cassava peel is one of the agricultural wastes which is a by-product of cassava processing, either for domestic consumption or industrial uses. High cost of portland cement has also made building construction very expensive. It is difficult for people to own houses due to rise in the price of building materials, most especially cement. Part of the challenges causing substandard constructions and collapse of building and structures is compromise in the mix ratio arising from the desire to save cost. This compromise is becoming more severe with the rise in cost of materials being experienced now, particularly in the developing world. There is the need therefore to prospect for cheap but competitive materials that could be used as replacement to cement [6]. This could lead to a reduction in its quantity use without compromising quality, and safety in concrete production.

The use of industrial and agricultural wastes as supplementary cementitious materials (SCMs) in concrete production is economical and suitable in term of strength, workability and durability [5-7].

The devastating effect of pollution due to agricultural waste generation requires a technological intervention for re-use and proper disposal which leads to a sustainable development, hence a partial replacement of cement with cassava peel ash tends to help in waste management [8 – 10].

2.LITERATURE REVIEW

2.1 Properties of Concrete Admixed with CPA

Amusan et al. [11] studied the effect of cassava peel ash blended cement (CPABC) on setting-time and density of concrete. The cassava peel ash partially replaced conventional cement within the range 0 to 12% in steps of 3 by weight of cementitious materials. Setting-time was determined and compared with conventional cement. 60 CPABC concrete cube samples were cast using grade 20 MPa and density tested at the hydration maturation age of 7, 14, 28 and 90 days. The experimental results showed that CPABC had satisfactory setting time and workability ranging from 22 to 51 minutes and 85 to 95 mm, respectively. The densities of CPABC concrete were comparable to the concrete, 2281.48 to 2548.15 kg/m^3. Density of the concrete increase with curing age and reduces with increase in CPABC content.

Ogbonna et al. [12] evaluated the physicochemical properties of CPA and mechanical properties of the CPA concrete mix at fresh or hardened state. The results of compressive strength for 5%-replacement range from 12.56N/mm^2 to 33.26N/mm^2 for the varying hydration periods as against 13.93 N/mm^2 to 35.23 N/mm^2 for the control test (0% replacement). The result of flexural strength for 5% replacement ranged from 3.33 N/mm^2 to 15.17 N/mm^2 for the varying hydration periods as against 4.67N/mm^2 to 16.80 N/mm^2 for the control. The mechanical properties results indicated that lower strength is obtained at early hydration periods but the strength increased with longer hydration period; while the strength decreased with increased ratio of the CPA. From the results, the optimum combination level of 5% - 10% replacement of the cement by CPA can be used to produce more desirable concrete.

Usman et al. [10] evaluated 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 results indicated maximum compressive strengths of the admixed concrete at 0.1% of cassava starch content. Numerical optimization was conducted, and model equations were generated for concrete with starch as an admixture.

Ofutayatan et al. [3] partially replaced cement with CPA in concrete at varying ratio from 5 % to 25 %. The properties of the CPA concrete were determined after curing from 7 days to 180 days. Compressive strength, flexural strength, slump, water absorption and shrinkage were determined. The results showed that 10 % CPA produced the optimal results for the response parameters.

Raheem et al. [13], in their study replaced cement in concrete by CPA of varying proportions from 0% to 20% by cement weight at 5% interval using a mixture ratio of 1:2:4 and cured for 7 days to 28 days. The strength development and slump were determined and it was concluded that the concrete strength increases with increased hydration period but decrease with increase quantity of the CPA.

Olonade et.al. [14] revealed that concrete made from blended cement-cassava peel ash possesses relatively low compressive strength, when cured in sulphuric acid and that the sulphuric acid solution inhibits pozzolanic reaction between Cassava Peel Ash (CPA) and calcium hydroxide to take place. They recommended that more studies be carried out on the effect of sulphuric acid solution on cement-CPA concrete cured in fresh water for longer period to allow pozzolanic reaction to take place.

Abdulwahab and Uche [5] studied the durability properties of SCC produced with cassava peel ash (CPA) at 5 %, 10 %, 15 %, 20 % and 25 % replacement level of cement. An optimum of 5% cement replacement was recommended for grade 35 compressive strength of CPA-SCC. However, the rate of water absorption reduced to a minimum when CPA is used in SCC as a result of an improved pore structure of the CPA-SCC specimen.

3.0 METHODOLOGY

3.1 Cassava Peel Ash (CPA)

The cassava peel used for the production of CPA was collected from Garri processing industries in Bauchi. The cassava peel was burnt at a temperature of 700°C under control temperature. On completion of burning, the ash was allowed to cool before grinding using pestle and mortar to a very fine texture. The resulting ash was required to pass through sieve of size 150µm to obtain the required fineness. It was used in this study to partially replace cement.

The properties of CPA were carried out in accordance with ASTM [15] while the chemical composition of the ash was determined by X-ray fluorescence in accordance with specifications [16] at Ahmadu Bello University, Zaria.

3.2 Concrete Mix Design

The concrete of 20 N/mm^2 target strength at 28 days was designed using a concrete mix ratio of 1:1.5:3 and water-cement ratio of 0.50 for 100 mm x 100 mm x 100 mm cube. Cement was blended with cement peel ash at 0%, 5%, 10% and 15% respectively. Three sets of cubes of dimension 100 mm x 100 mm x 100 mm were cast, cured and tested at 3, 28, 56 and 90 days to determine compressive strength, flexural strength and water absorption. The materials were then thoroughly mixed at ambient temperatures within the laboratory and the cubes were cured by soaking completely in water until the curing ages. Cement was partially replaced by CPA.

3.3 Analysis by Central Composite Design

CCD of response surface methodology was adopted in the design of experimental combinations. Experimental runs were created by Design-Expert software 13 for M20 grade concrete. It was used to quantify the relationship between the controllable input parameters as shown in Table 3 and the obtained response surfaces. The design was used to optimise the responses and also generate a mathematical model for them. The factor level for CCD is shown in Table 1

Table 1: Factor and Factor Levels of Mixture for CCD

Name	Units	Low	Middle	High
CPA	%	5	10	15
CA	days	3	28	56

4.RESULTS AND DISCUSSION

4.1Properties of Cassava Peel Ash and Cement

The oxide composition of cement and CPA is presented in Table 2.

Table 2: Composition of Cement and CPA

Composition %	Cement	CPA
SiO_2	22.5	55.7
Al_2O_3	6.2	5.91
Fe_2O_3	4.2	3.29
CaO	60.5	22.7
MgO	1.4	3.39
SO_3	2.88	0.22
K_2O	0.7	13.9
Na_2O	0.13	0.17
LOI	3.5	8.20

The percentage contents of the major oxides of cement are SiO_2 as 22.5%, Al_2O_3 as 6.2%, Fe_2O_3 as 4.2% and CaO as 60.5% whereas the percentage contents of the minor oxides were: MgO as 1.4% SO_3 as 2.88 and the alkalis (Na_2O and K_2O) as 0.13% and 0.7%. The loss of ignition as 3.5. This shows that the cement used for this research work conforms to the Nigeria Industrial Standard. The chemical test results for oxide composition of CPA is presented shows that the major oxides of CPA are SiO_2 as 55.7%, Al_2O_3 as 5.91, Fe_2O_3 as 3.29% and CaO as 22.7%. This shows that CPA has enough silica oxide and calcium oxide which enhance better strength development of concrete. The sum of SiO_2 +Al_2O_3 + Fe_2O_3 exceeds 70% and can be classified as a pozzolana according to ASTM C 618 [17].

4.2 Consistency and Setting Time Properties of Admixed Paste

The consistency result, initial and final setting time of paste is shown in Figure 1

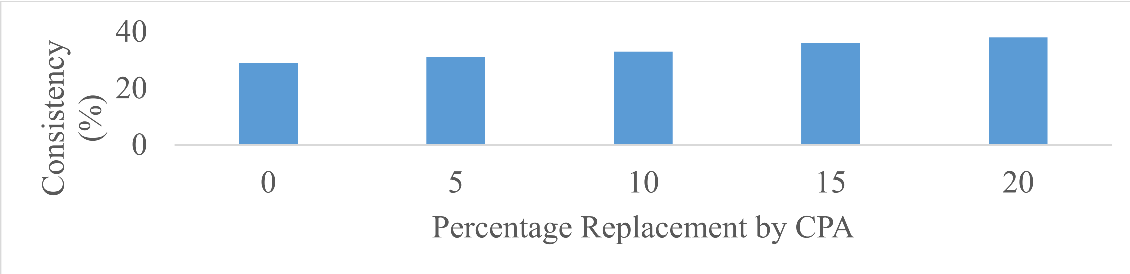

Figure 1: Consistency Result

In Figure 1, the consistency value of the cement is lower than the values of blended cement with CPA. The consistency of cement is 29% and increased with increasing CPA content. At replacement of cement by CPA at 5, 10, 15 and 20%, the consistency values were 31, 33, 36 and 38%. This trend may be due to the finer particles of CPA which are finer than those of cement and consequently increase the surface area available for contact with water thereby increasing the water demand of the CPA blended Paste.

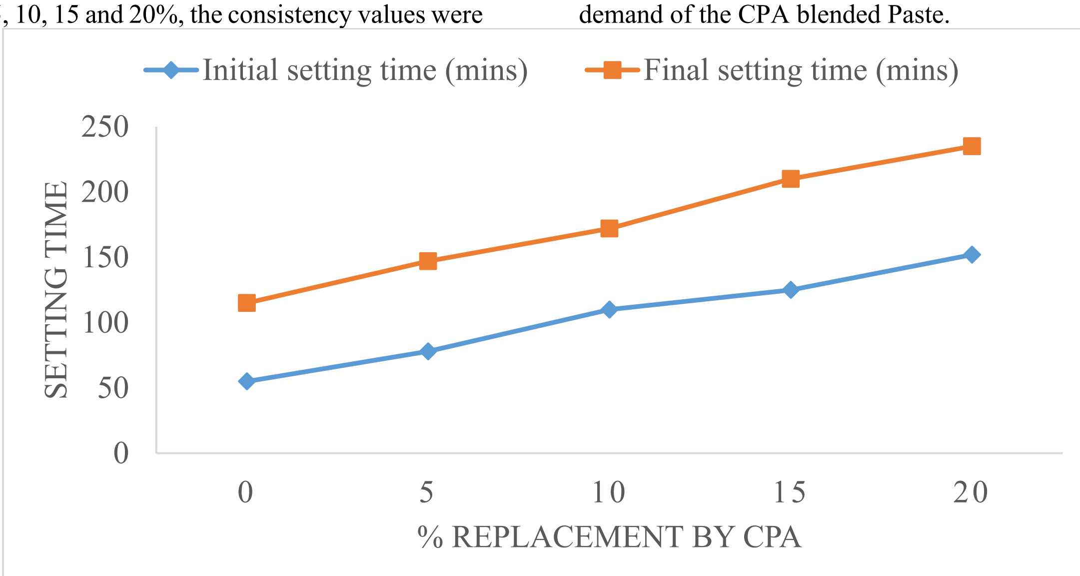

Figure 2: Setting-time of Concrete

Results from Figure 2 shows that increase in percentage of CPA causes increase in the initial and final setting time of cement. CPA acts as retarding agent for concrete.

4.3 Workability of Concrete by Slump test

Workability of concrete was tested by slump test. The result of the slump test is presented in the Figure 3.

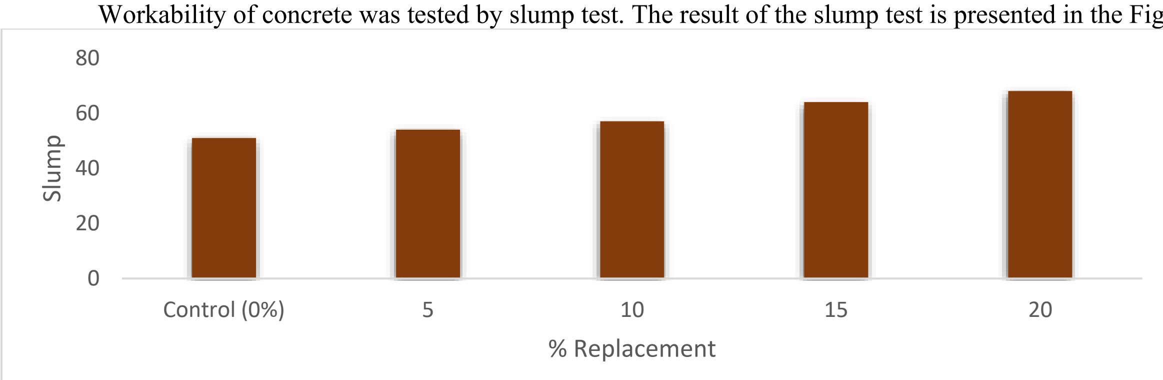

Figure 3: Slump Test Result

The result of the slump test for the concrete with CPA replacement showed that at 0% (control), the result was 51 mm, 5% was 54 mm, 10% was 57 mm, 15% was 64 mm, and 20% was 68 mm. At all replacements, admixed concretes made with CPA were workable with true slump. The higher the replacement of cement with CPA, the higher the slump value. This shows that the CPA absorb more water. The increase in the water consistencies could be attributed to the diminution of C_3S in cement, the unburnt carbon present in the ashes coupled with the porous nature of CPA and the narrower particle size distributions of the cement blends

4.4 Analysis and Modelling of Admixed Concrete with CPA

The results of all the responses are shown in Table 3.

Table 3: Result of All the Responses

Run	Factor 1 A:CPA %	Factor 2 B:C.Age days	Response 1 Density kg/m^3	Response 2 Compressive str. N/mm^2	Response 3 Flexural Str. N/mm^2
Control	0	56	2.42	22.5	3.1
1	15	28	2.43	18.8	2.9
2	10	28	2.48	20.2	3.1
3	10	28	2.48	20.2	3.1
4	5	56	2.54	26.4	3.4
5	5	28	2.53	24.5	3.3
6	10	28	2.48	20.2	3.1
7	5	3	2.50	14.3	3
8	10	3	2.49	11.7	2.7
9	10	56	2.53	23.6	3.3
10	15	3	2.40	10.1	2.7
11	10	28	2.48	20.2	3.1
12	10	28	2.48	20.2	3.1
13	15	56	2.44	20.4	3.2

The density of the CPA-Concrete is within the range of 2.4 to 2.54 kg/m^3 and higher than the control density 2.42 kg/m^3. The highest compressive strength was recorded as 26.4 N/mm^2 with 5% CPA at 56 days, this is higher than the control strength of 22.5 N/mm^2. The highest flexural strength was recorded at 3.4 N/mm^2 with 5% CPA at 56 days of curing, it is higher than the control flexural strength of 3.1N/mm^2.

4.5 Analysis of Density of Concrete

The result of the density conducted on admixed concrete at 3 days, 28 days and 56 days are presented in Table 8. The ANOVA is presented in Table 4.

Table 4: ANOVA for Density

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.0174	2	0.0087	40.53	< 0.0001
A-CPA	0.0150	1	0.0150	69.80	< 0.0001
B-C.Age	0.0024	1	0.0024	11.26	0.0073
Residual	0.0021	10	0.0002		
Lack of Fit	0.0021	6	0.0004		
Pure Error	0.0000	4	0.0000		
Cor Total	0.0196	12			

The Model F-value of 40.53 implies the model is significant. P-values less than 0.05 indicate model terms are significant. In this case A, B are significant model terms. Values greater than 0.1 indicate the model terms are not significant. The Fit statistics for density is presented in Table 5.

Table 5: Fit Statistics Table

Parameters	Values
Std. Dev.	0.0147
Mean	2.48
C.V. %	0.5907
R^2	0.8902
Adjusted R^2	0.8682
Predicted R^2	0.7741
Adeq Precision	19.8994

The Predicted R^2 of 0.7741 is in reasonable agreement with the Adjusted R^2 of 0.8682; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Ratio of 19.899 indicates an adequate signal. This model can be used to navigate the design space. The 3-D response surface graph of curing age and CPA and their effect on density is shown in Figure 4. The model equation is presented in Equation 1.

$$\text{Density} = 2.55981 - 0.01A + 0.00076B \quad \dots (1)$$

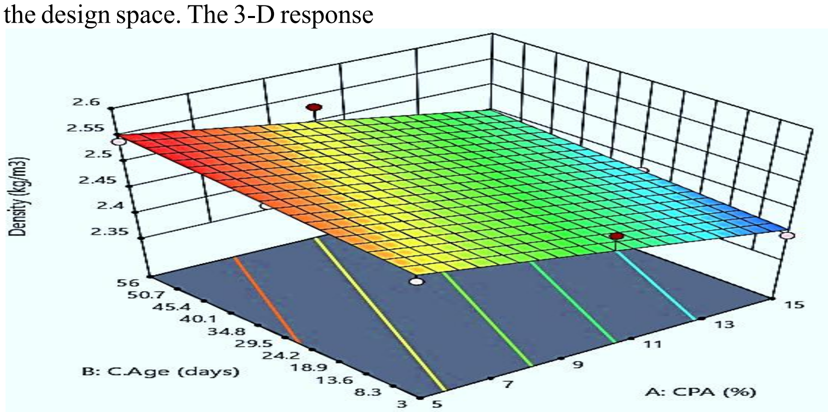

Figure 4: 3D Response Graph of CPA, Curing and Density of Concrete

In Figure 4, the higher the percentage increase in CPA, the lower the density and as the curing age increases, there is slight increase in density of concrete.

4.6 Analysis of Compressive Strength of Concrete

The analysis of variance for compressive strength is presented in Table 6

Table 6: ANOVA for Compressive Strength

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	267.38	5	53.48	254.66	< 0.0001
A-CPA	42.38	1	42.38	201.81	< 0.0001
B-C.Age	196.08	1	196.08	933.76	< 0.0001
A^2	1.87	1	1.87	8.90	0.0204
B^2	33.81	1	33.81	160.99	< 0.0001
Residual	1.47	7	0.2100		
Lack of Fit	1.47	3	0.4900		
Pure Error	0.0000	4	0.0000		
Cor Total	268.85	12			

The Model F-value of 254.66 implies the model is significant. P-values less than 0.05 indicate model terms are significant. In this case A, B, A^2, B^2 are significant model terms. The model equation is presented in Equation 2.

$$\text{Compressive strength} = 17.6 - 1.09A + 0.544B - 0.0033AB + 0.033A^2 - 0.01B^2 \quad .. (2)$$

The Fit statistics for compressive strength is shown in Table 7.

Table 7: Fit Statistics for Quadratic Model of Compressive Strength

Parameters	Values
Std. Dev.	0.4582
Mean	19.29
C.V. %	2.38
R^2	0.9945
Adjusted R^2	0.9906
Predicted R^2	0.9572
Adeq Precision	53.8037

The Predicted R^2 of 0.9572 is in reasonable agreement with the Adjusted R^2 of 0.9906; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 53.804 indicates an adequate signal. The 3D response graph of CPA, curing age and compressive strength is presented in Figure 5.

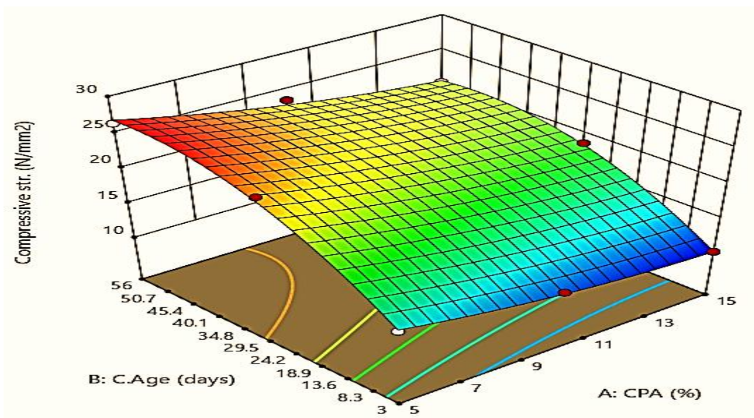

Figure 5: 3D Response Graph of CPA, Curing and Compressive Strength.

Figure 7 shows the influence of CPA and curing age on compressive strength of admixed concrete. The higher the curing age, the higher the compressive strength while slight improvement was witnessed as the CPA increased from 5 to 10%. Cassava peel ash slightly improved the compressive strength of concrete within the limits and the higher the curing age, the higher the compressive strength.

4.7 Flexural strength properties

The flexural strength property of the admixed concrete produced was determined after curing at 3, 28 and 56 days. The ANOVA result in shown in Table 8 and the Fit statistics in Table 9.

Table 8: ANOVA for Flexural Strength

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.5048	2	0.2524	65.95	< 0.0001
A- CPA	0.1350	1	0.1350	35.27	0.0001
B- C.Age	0.3698	1	0.3698	96.62	< 0.0001
Residual	0.0383	10	0.0038		
Lack of Fit	0.0383	6	0.0064		
Pure Error	0.0000	4	0.0000		
Cor Total	0.5431	12			

The Model F-value of 65.95 implies the model is significant. P-values less than 0.05 indicate model terms are significant. In this case A, B are significant model terms.

Table 9: Fit Statistics for Flexural Strength

Parameters	Values
Std. Dev.	0.0619
Mean	3.08
C.V. %	2.01
R^2	0.9295
Adjusted R^2	0.9154
Predicted R^2	0.8662
Adeq Precision	26.7874

The Predicted R^2 of 0.8662 is in reasonable agreement with the Adjusted R^2 of 0.9154; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 26.787 indicates an adequate signal. The 3D response graph of CPA, curing age and flexural strength is presented in Figure 6.

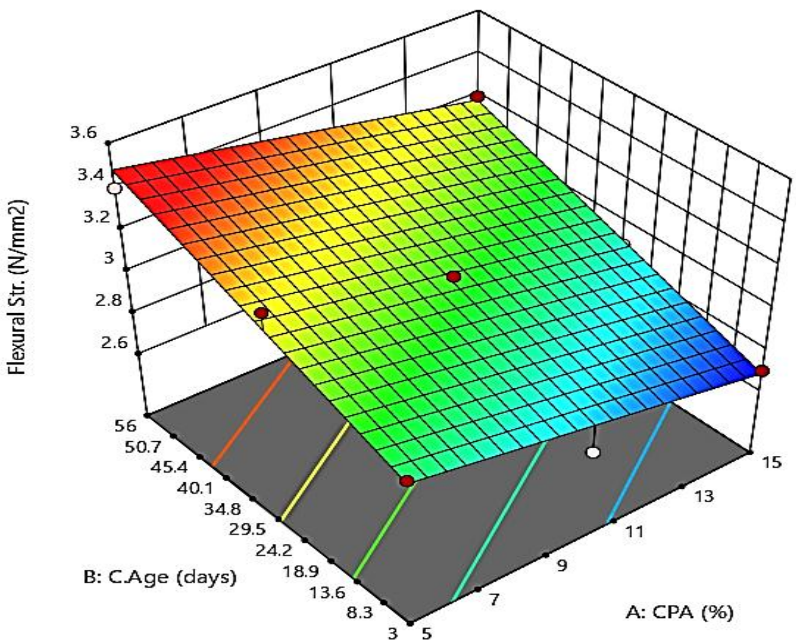

Figure 6: 3D Response Graph of CPA, Curing Age and Flexural Strength

4.8 Optimization of Admixed concrete containing CPA

The goals set for responses in numerical optimization are presented in Table 10.

Table 10: Goals for Numerical Optimization.

Name	Goal	Lower Limit	Upper Limit
A: CPA	is in range	5	15
B: C. Age	is in range	3	56
Density	maximize	2.4	2.54
Compressive strength	maximize	10.1	26.4
Flexural Strength	maximize	2.7	3.4

The automatic optimization function of Design-Expert software version 13 indicates that the optimal values of the factors as 5.4% CPA at 50 days of curing with combined desirability of 1 as presented in Figure 7.

International Journal of Trendy Research in Engineering and Technology
Volume 10 Issue 1 February 2026
ISSN No. 2582-0958

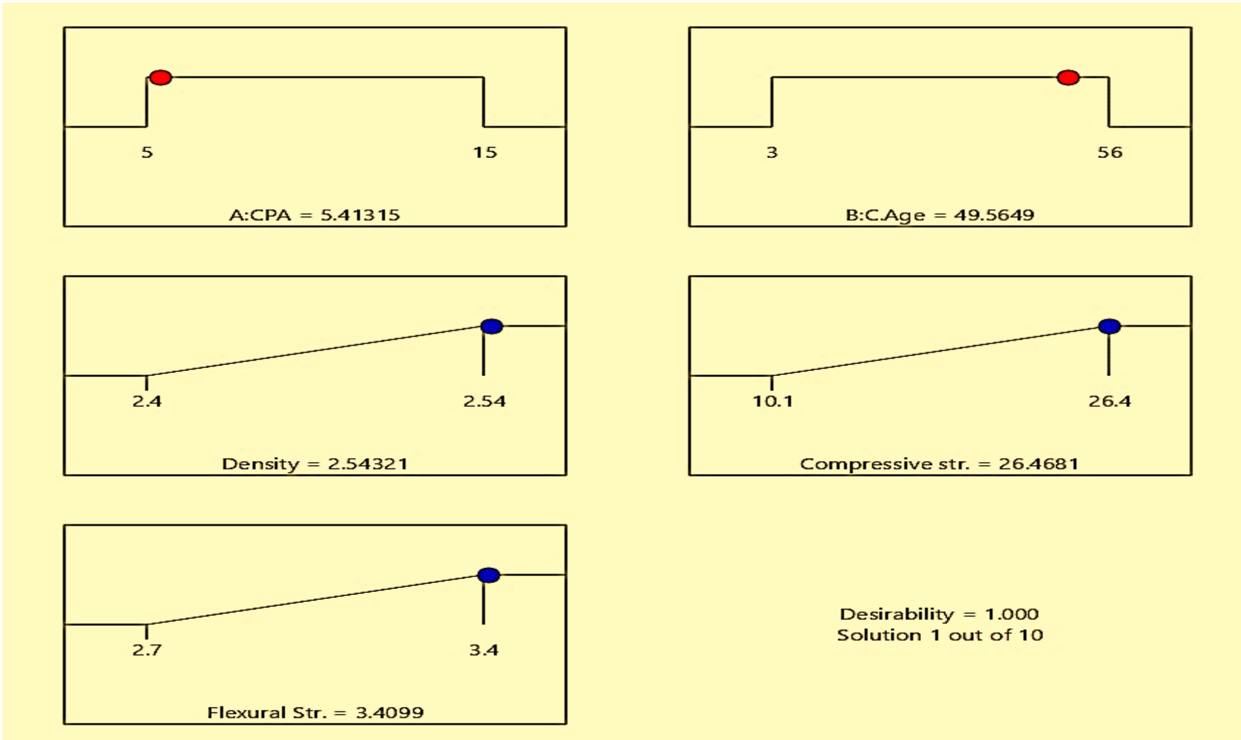

Figure 7: Ramp Plot Showing the Optimal Values for Responses

4.9 Analysis of Concrete Microstructure

Scanning electron microscopy (SEM) and energy-dispersive X-ray (EDX) analysis were used to examine the nature of the hydrated binder and the binder-aggregate interfacial zones at 28 days of curing. They are useful in the studies of hydration processes, the formation of the CSH and CH components, and any other situation where the microstructural characteristics of the concrete need to be examined.

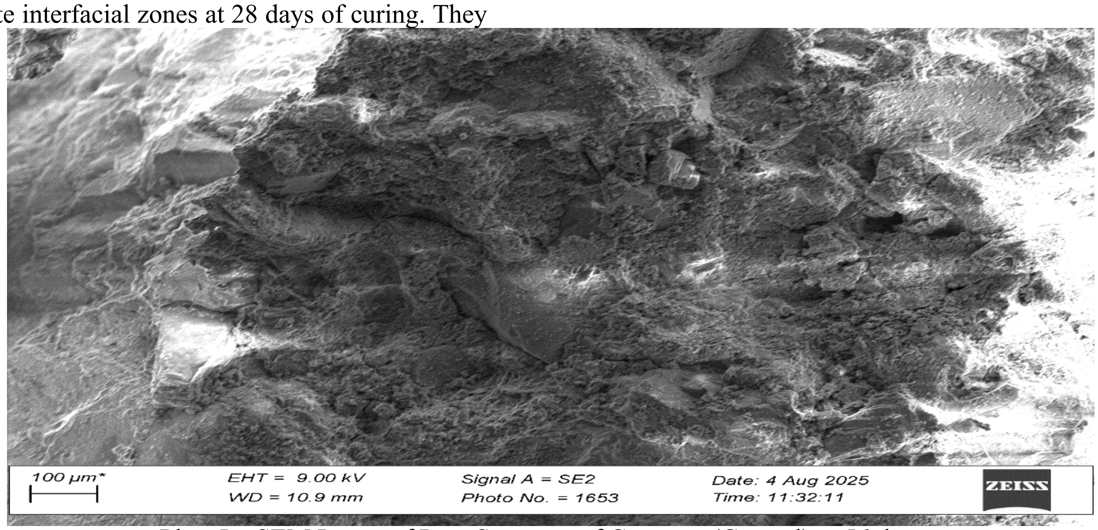

Plate I: SEM Image of Pore Structure of Concrete (Control) at 56 days.

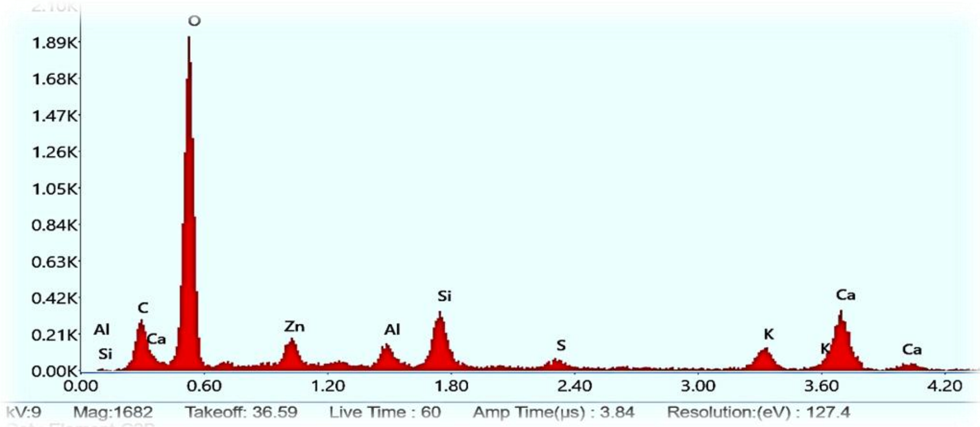

Figure 8: EDX Spectrum of Control at 28 Days of Curing.

Table 11: Quant Result - Analysis Uncertainty for Control

Element	Weight %	MDL	Atomic %
C K	7.14	1.51	12.43
O K	48.46	0.43	63.32
Al K	1.52	0.33	1.18
Si K	5.14	0.35	3.83
S K	0.90	0.44	0.59
K K	6.30	0.87	3.37
Ca K	27.34	2.16	14.26
Zn L	3.19	0.84	1.02

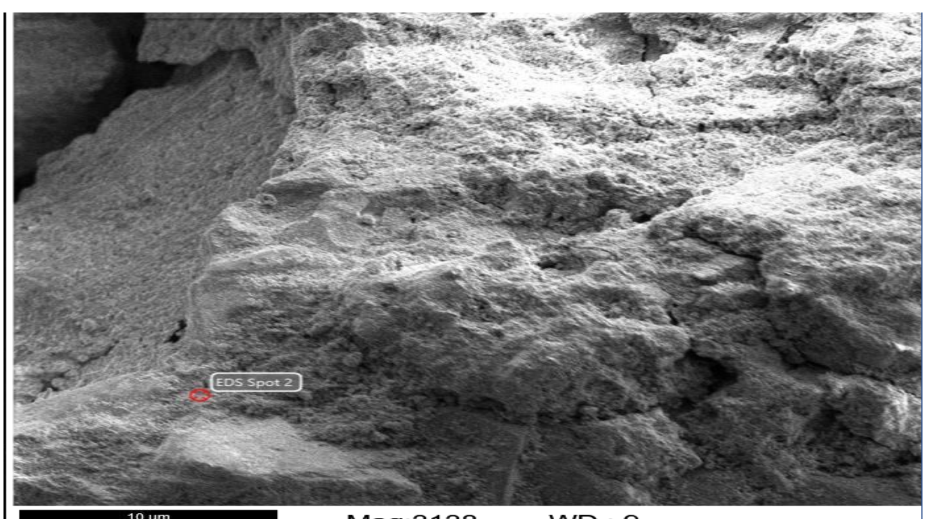

Plate II: SEM Image of Pore Structure of 5% CPA Concrete

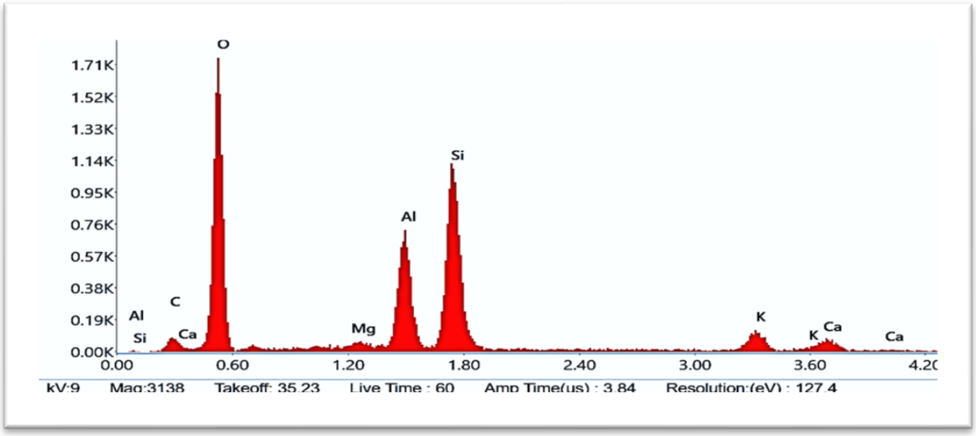

Figure 9: EDX Spectrum of CPA at 56 Days of Curing.

Table 12: Quant Result - Analysis Uncertainty for Admixed Concrete

Element	Weight %	MDL	Atomic %
C K	6.23	1.35	10.66
O K	42.66	0.3	54.77
Mg K	0.44	0.27	0.37
Al K	12.37	0.3	9.41
Si K	23.09	0.33	16.88
K K	8.42	1.13	4.42
Ca K	6.79	1.2	3.48

The image in Plate I appears to be loosely packed and thus porous, on the other hand, the SEM images of Plate II containing 5.4% CPA have few calcium hydroxide Ca $(OH)_2$ platelets and the pores are smaller and appear denser compared to the control. The pozzolanic effect involving the consumption of calcium hydroxide $Ca(OH)_2$ to produce the secondary C-S-H gel is seen in Plate II. Moreover, the secondary pozzolanic reactions are known to lead to reduced pore crosslinking.

The high content of calcium (Ca) and Silica (SiO_2) was seen in the EDX spectrum as presented in Figure 8 while the high content of silica oxide as shown in EDX spectrum in Figure 9. This is attributed to the effect of pozzolanic reaction. Thus, it could be concluded that the improvement in the strengths properties of admixed concrete with CPA was as a result of densification and pore refinement.

5.CONCLUSIONS

Performance evaluation of concrete containing CPA ash was studied, analysed and optimized using central composite design of design expert 13 software. Based on the findings, the following conclusions were made:

i.The slump test result for the concrete with CPA replacement was 51 mm at 0% (control), 54 mm at 5%, 57 mm at 10%, 64 mm at 15%, and 68 mm at 20%. Admixed concretes produced with CPA were workable and had a true slump at all replacements.

ii.The density of the CPA-Concrete is within the range of 2.4 to 2.54 kg/m3 and higher than the control density 2.42 kg/m3. The highest compressive strength was recorded as 26.4 N/mm2 with 5% CPA at 56 days, this is higher than the control strength of 22.5 N/mm2. The highest flexural strength was recorded at 3.4 N/mm2 with 5% CPA at 56 days of curing, it is higher than the control flexural strength of 3.1 N/mm2.

iii.The numerical optimization function of Design-Expert software version 13 indicates that the optimal values of the factors as 5.4% CPA at 50 days of curing with combined desirability of 1

iv.There are less calcium hydroxide Ca (OH)2 platelets and the pores are smaller and denser in the SEM pictures of Plate II containing 5.4% CPA than in the control, which appears to be loosely packed and porous. Plate II illustrates the pozzolanic action, which includes the consumption of calcium hydroxide Ca(OH)2 to create the secondary C-S-H gel.

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