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EVALUATING THE COMPRESSIVE STRENGTH AND MICROSTRUCTURAL PROPERTIES OF CONCRETE ADMIXED WITH CASSAVA PEEL ASH AND GRANITE DUST AS PARTIAL REPLACEMENTS FOR CEMENT

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ABSTRACT

The study investigated the compressive strength and microstructural properties of concrete admixed with cassava peel ash and granite dust as partial replacements for cement. Cassava peel and granite dust are produced on a daily basis, and the inadequate management of granite waste, along with a lack of sufficient landfills for cassava waste, poses a significant challenge. This research aims to transform these waste materials into valuable construction resources. The study examines how Cassava Peel Ash (CPA), Granite Dust (GD), and Curing Days (CD) affect the compressive strength (C.S) of grade 20 concrete. A Box-Behnken design was employed to assess the C.S, with CPA, GD, and CD ranging from 2 – 6%, 4 – 8%, and 3 – 56 days, respectively. The findings indicated that CPA, GD, and CD significantly influence compressive strength of the concrete. The results of the optimization indicate that the best combination of factors for achieving maximum Compressive Strength consists of 4% CPA, 7% GD, and a curing duration of 42 days, which predicts compressive strength value of 25.8 N/mm^2. A mathematical model was developed based on the relationships between the input factors and the resulting compressive strength. Furthermore, the microstructure of the concrete with additives was analyzed using a scanning electron microscope(SEM) at a magnification of X1500. This research highlights the effectiveness of employing Box-Behnken design to enhance concrete mix design and boost its compressive strength. According to the results of this research, the optimal mix of 2% Cassava Peel Ash, 4% Granite Dust, and a curing period of 42 days can effectively produce concrete grade 20 with enhanced compressive strength.

KEYWORDS: Optimization, Granite Dust, Cassava Peel Ash, Compressive Strength, Water Absorption, Microstructural Analysis

1.INTRODUCTION

The need for a housing system that is affordable for people in Nigeria is high. This study boosts the dire need to develop blended cement which will be readily available to provide low-cost housing for the continually growing population therefore; the use of locally available material such as cassava peel ash and granite dust would help in reducing the financial burden in building houses by low-income earners [1].

Cement, a major binder in concrete production, is an important material for the provision of physical infrastructure, shelter, and related amenities, which are typical indicators of underdevelopment and should be addressed by the supply of alternative, inexpensive, and accessible materials [2].

Granite dust, a non-biodegradable waste material is produced from granite stone industry. It is in form of fine powder during cutting and grinding process of granite. Granite industries produce a lot of waste materials in form of dust. The wastes from granite polishing factories are disposed to environment which cause health hazard. The open dumping of granite dust causes potential health hazard and contains some chemicals which cause pollution to the air, water, and soil. It is costly to clean up but the best approach for solving the generated granite dust issue would be recycling and reusing it most especially in concrete production. This granite dust can be utilized as partial replacement of cement in concrete.

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, [3], and have become a staple food for millions of people globally [3].

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 [2-4].

Conservation of natural resources, reduction in carbon dioxide emission, re-use of agricultural / industrial waste materials is some of the benefits of utilizing the results of this research. The use of these wastes materials as additional raw material in concrete production will provide a foreseeable solution to the challenges caused by production. It will also be a good alternative to developing cheap concrete for construction industry.

Adetoye *et al*. [5] investigated the compressive strength characteristics of concrete that contained wood ash and cassava peel ash. At a water-to-cement ratio of 0.5 and a mixed ratio of 1:2:4, cement was partially substituted with equal amounts of wood ash (W.A.) and cassava peel ash (C.P.A.) utilizing 0%, 5%, 10%, 15%, 20%, and 25% of mixed materials. At control (0%) concrete's mean compressive strength was 27.11 N/mm^2, 5% (24.44 N/mm^2), 10% (23.25 N/mm^2), 15% (23.36 N/mm^2), 20% (18.52 N/mm^2), and 25% (15.93 N/mm^2). The lowest mean strength at 28 days was achieved with a 25% replacement of cement. Concrete's strength decreases when more pozzolanic substances are added to replace cement.

Ahmed and Uche [6] studied the effect of using cassava peel ash (CPA) and egg shell powder (ESP) as partial replacement of cement in concrete production. CPA and ESP were mixed in a proportion of 10:90, 20:80, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80 and 10:90, respectively for the partial replacement of 0, 5, 10, 20, 30 and 40%, respectively by weight of cement. The results showed that CPA was predominantly of silicon oxide (56.73%) and a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 66.75%; and the result of the investigations showed that ESP was predominantly of calcium oxide (52.75%). The addition of CPA and ESP in concrete production showed slight increase in compressive strength with increase in CPA/ESP additive up to 10% and decrease in compressive strength with further increase in CPA and ESP content.

2. METHODOLOGY

2.1 Concrete mix design

The concrete mix of M20 grade was designed based on the principles of existing American Concrete Institute Method of Mix Design [7]. Detail of the quantities of the concrete materials based on the mix ratio of cement: fine aggregate: coarse aggregate: water /cement ratio: superplasticizer. 1: 2.81: 2.30: 0.52: 0.02 are shown in Table 1

Table 1: Concrete Mix Design

S/N	Material	Normal Concrete
1	Cement (kg/m^3)	355
2	Water (litre/m^3)	185
3	Fine aggregate (kg/m^3)	800
4	Coarse aggregate (kg/m^3)	1016
5	Water / cement ratio	0.52
6	Superplasticizer (%)	7.1

2.2 Experimental design by BBD

The tests were carried out using a Box-Behnken Design (BBD) with three components at three levels. The CPA, GD and curing age were chosen as the input factors (independent variables) for the optimization. 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 and the obtained response surfaces. It was used to optimise the results of compressive strength, tensile strength and water absorption and also to generate a mathematical model. The factor level of mixture is presented in Table 2.

Table 2: Factor and Factor Levels of Mixture

Name	Units	Low	High
CPA	(%)	2	6
GD	(%)	4	8
C.A	days	3	56

The response is Compressive Strength

2.3 Test on Compressive Strength

The compressive strength test was conducted at the structure laboratory, Abubakar Tafawa Balewa University, Bauchi with a compression testing machine of 3000 kN capacity at a loading rate of 5 N/s. Concrete cubes were positioned so that the load is applied perpendicularly to the direction of pouring. The load to failure of each cube was recorded, and the compressive strength is calculated using equation (1). The test was carried out on cubic specimens of size (100 mm x 100 mm x 100 mm). The strength was recorded at 3, 28 and 56 days respectively. The average reading of three cubes were recorded as the strength at the respective age. The strength is given as in equation (1).

$$Compressive\ strength = \frac{Crushing\ Load}{Cross-sectional\ Area\ of\ Cube} N/mm^2 \quad \ldots (1)$$

2.4 Microstructural analysis

The mixture used for microstructural analysis comprised of the control and optimal percentage of CPA/GD concrete specimens. It was conducted at the Department of Chemical Engineering, Ahmadu Bello University, Zaria in accordance with ASTM [8]. Energy-dispersive X-ray spectroscopic (EDX) analysis were conducted for concrete specimens in order to determine the chemical characteristics of the minerals formed in the cracked specimens. EDX analysis confirm the deposition of calcium compounds in the concrete specimens. SEM provides high resolution images of microstructure to visualize the shape, size concrete matrix.

3.RESULTS AND DISCUSSION

3.1 Properties of CPA and GD

The results of physical properties of CPA and GD are presented in Table 3.

Table 3: Physical Properties of CPA and GD

Property	CPA	GD
Specific gravity	2.42	2.64
Colour	Grey	Off-white
Shape Texture	Irregular	Irregular

CPA and GD have average specific gravity of 2.42 and 2.64 respectively. This implies that admixtures have more surface area than cement with specific gravity of 3.14 according to BS EN 196-3. The colour of CPA and cement were grey while GD has off-white colour.

The X-ray fluorescence test results for oxide composition of CPA and GD are presented in Table 4.

Table 4: Chemical Properties of CPA and GD

Oxide Composition	Percentage by wt. (%)	
	CPA	GD
SiO_2	48.3	72.1
Al_2O_3	4.52	14.5
Fe_2O_3	3.91	2.30
CaO	24.2	1.79
MgO	2.32	0.15
SO_3	0.32	0.22
Na_2O	3.25	2.88
K_2O	16.1	0.12
P_2O_5	1.83	0.05
LOI	5.41	2.90

The respective percentage contents of the major oxides of CPA are SiO_2 as 48.3%, Al_2O_3 as 4.5, Fe_2O_3 as 3.9% and CaO as 24.2% whereas the percentage contents of the minor oxides were: MgO as 2.3% SO_3 as 0.3% and the alkalis (Na_2O and K_2O) as 3.25% and 16.1 %. The loss of ignition as 5.4. This shows that CPA and granite dust used for this research work have enough silica content which enhance better strength development of the concrete at a later age. The respective percentage contents of the major oxides of GD were SiO_2 as 72.1%, Al_2O_3 as 14.5%, Fe_2O_3 as 2.3%, MgO as 0.15% SO_3 as 0.22 and the alkalis Na_2O as 2.88%. The sum of SiO_2 +Al_2O_3 + Fe_2O_3 exceeds 70%. This demonstrated that the CPA and GD are in the same category with the Class F fly ash [9] with high pozzolanic characteristics.

3.2 Consistency and Setting Time of Paste

The results of consistency, initial and final setting time of paste admixed with CPA and GD are shown in Figure 1.

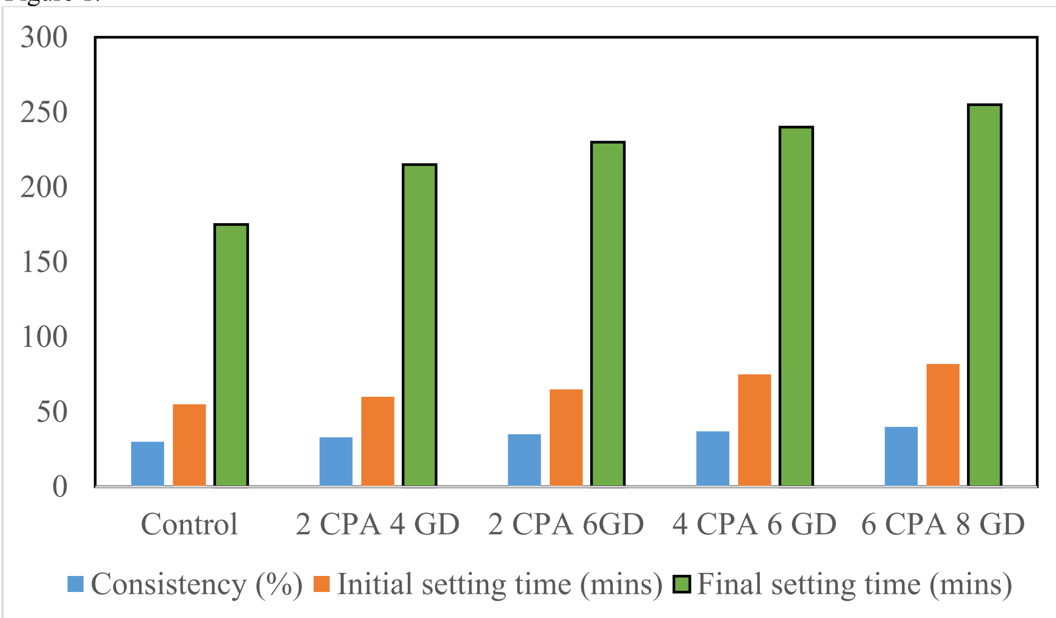

Figure 1: Consistency and Setting-time of Paste

The consistency value of the cement is lower than the values of blended cement with CPA/GD. This may be attributed to the fineness of admixture. The consistency of cement is 30% and increased with increasing CPA/GD content. At 5, 10, 15, and 20% cement replacement, the values were 33, 35, 37, and 40%. The results stated that cement consistency is less than that of cement with CPA/GD. At higher replacement level, the initial setting time increased which shows that the admixtures retards setting time of cement.

3.3 Compressive Strength Result of Admixed Concrete

The results of all the compressive strength on admixed concrete containing cassava peel ash and granite dust is presented in Table 5.

Table 5: Test Results for the Responses

Run	Factor 1 A: Cassava peel ash %	Factor 2 B: Granite dust %	Factor 3 C: Curing age days	Response 1 Compressive strength (N/mm^2)
Control	0	0	56	24.8
1	2	4	28	22.8
2	4	6	28	25.5
3	6	8	28	22.0
4	4	4	56	25.0
5	6	4	28	18.0
6	4	8	3	9.40
7	6	6	56	26.0
8	4	8	56	28.0
9	4	4	3	9.50
10	2	8	28	26.1
11	4	6	28	25.5
12	4	6	28	25.5
13	2	6	56	28.0
14	6	6	3	8.50
15	2	6	3	9.00

The compressive strength of the CPA-GD Concrete is within the range of 8.5 to 9.5 N/mm^2 after 3 days of curing, 18 – 26.1 N/mm^2 after 28 days of curing and 24 – 28 N/mm^2 after 56 days of curing. The admixed concrete results are higher than the control result of 24.8 N/mm^2. The highest compressive and tensile strengths were recorded as 28 N/mm^2 and 3.1 N/mm^2 and were achieved using 2% CPA and 6% GD at 56 days of curing by water immersion. This is higher than the control strength of 24.8 N/mm^2. These results are in agreement with the results achieved by researchers [10-12].

The ANOVA is presented in Table 6.

Table 6: ANOVA for Compressive Strength

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	792.15	6	132.02	93.08	< 0.0001
A-Cassava peel ash	16.25	1	16.25	11.45	0.0096
B-Granite dust	13.00	1	13.00	9.17	0.0164
C-Curing age	623.05	1	623.05	439.25	< 0.0001
A^2	10.51	1	10.51	7.41	0.0261
B^2	9.31	1	9.31	6.56	0.0336
C^2	152.77	1	152.77	107.70	< 0.0001
Residual	11.35	8	1.42		
Lack of Fit	11.35	6	1.89		
Pure Error	0.0000	2	0.0000		
Cor Total	803.50	14			

The Model F-value of 93.08 implies the model is significant. P-values less than 0.05 indicate model terms are significant. In this case A, B, C, A^2, B^2, C^2 are significant model terms. The Fit statistics for C.S is presented in Table 7.

Table 7: Fit Statistics Table

Parameters	Values
Std. Dev.	1.19
Mean	20.59
C.V. %	5.79
R^2	0.9859
Adjusted R^2	0.9753
Predicted R^2	0.9435
Adeq Precision	25.19

The Predicted R^2 of 0.9435 is in reasonable agreement with the Adjusted R^2 of 0.9753; 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 25.19 indicates an adequate signal. The 3-D response surface graph of factors interaction on compressive strength is shown in Figure 2. The model equation is shown in Equation 2.

$$Compressive\ strength = -13.8189 + 2.6625 * A + 5.4 * B + 0.876\, C - 0.422 * A^2 - 0.4\, B^2 - 0.009 * C^2 \quad \ldots (2)$$

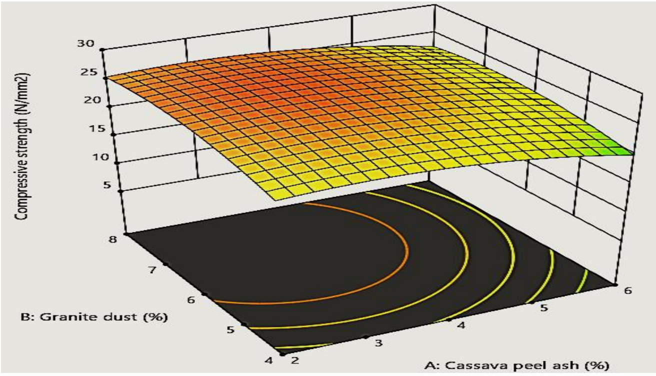

Figure 2: 3D Graph of CPA, GD and Compressive Strength of Concrete

In Figure 2, the higher the percentage increase in GD from 2 to 5% and curing days, the higher the compressive strength. In Figure 7, as the curing age increases, there is a significant increase in the compressive strength on concrete.

3.4 Optimization of concrete

The automatic optimization function of Design-Expert software version 13 indicates that the optimal values of the factors as 4% CPA and 7% GD at 42 days of curing with combined desirability of 0.894 as presented in Figure 3.

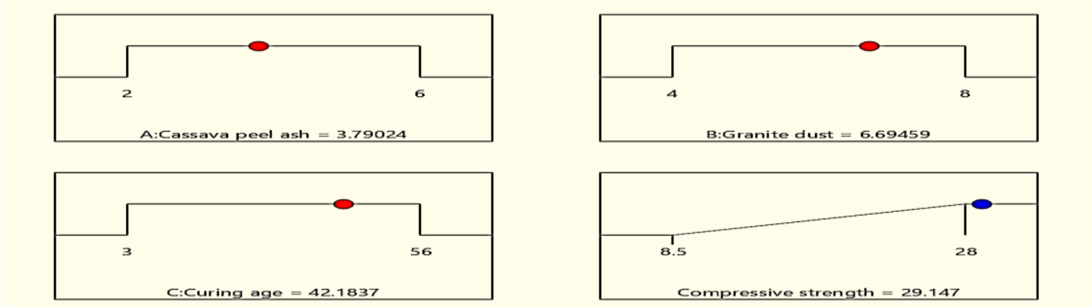

Figure 3: Ramp Plot Showing the Optimal Values for CPA, GD, C.A and C.S

3.5 Analysis of Concrete Microstructure

The nature of the hydrated binder and the binder-aggregate interfacial zones were investigated using energy-dispersive X-ray (EDX) analysis and scanning electron microscopy (SEM). Concrete was subjected to SEM and EDX examination 56 days after curing; the findings are shown in Figures 4 and 5, Tables 8 and 9, and Plate I and II.

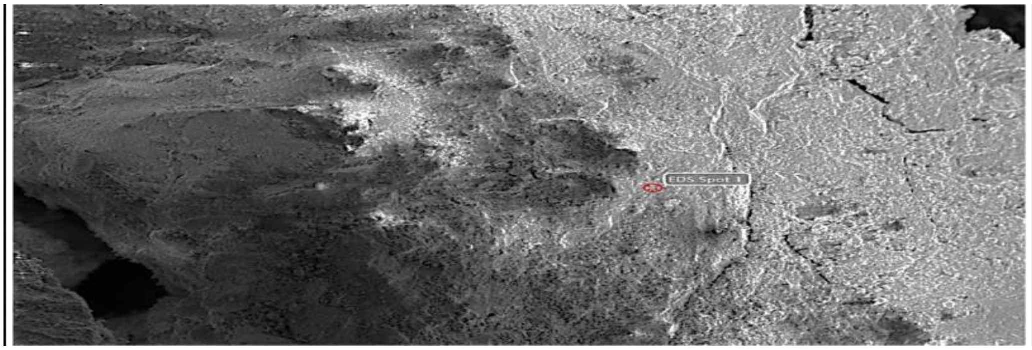

Plate I: SEM Image of Pore Structure of Concrete (Control) at 56 days

Table 8: Quant Result - Analysis Uncertainty for Control

Element	Weight %	MDL	Atomic %
C K	9.52	1.24	15.58
O K	51.38	0.34	63.08
Na K	1.00	0.26	0.85
Mg K	0.65	0.21	0.53
Al K	1.00	0.3	0.73
Si K	6.38	0.23	4.46
K K	3.31	0.54	1.66
Ca K	3.19	1.61	13.12

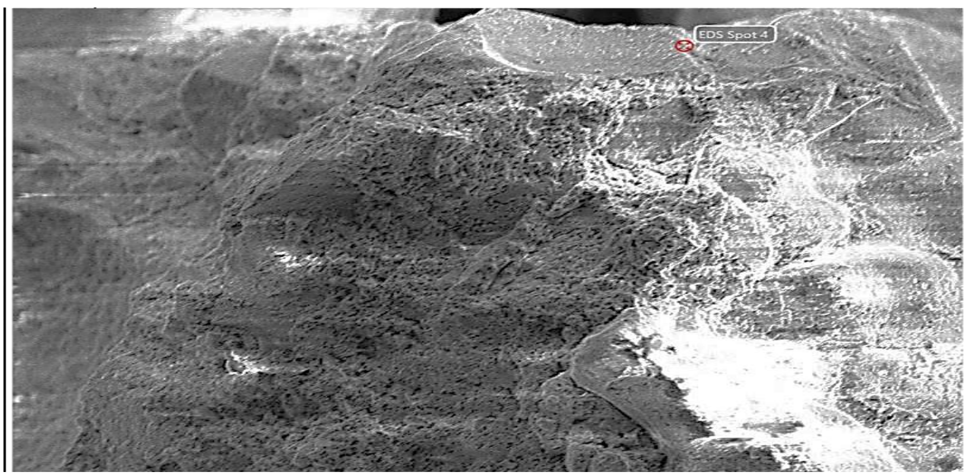

Plate II: SEM Image of Pore Structure of 4% *CPA and 7% GD* Concrete

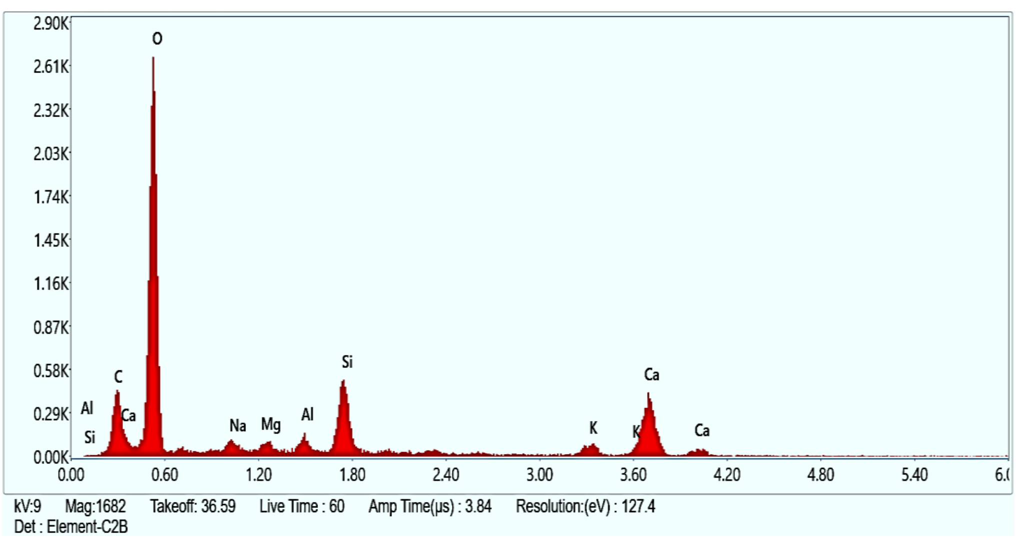

Figure 4: EDX Spectrum of Control at 28 Days of Curing

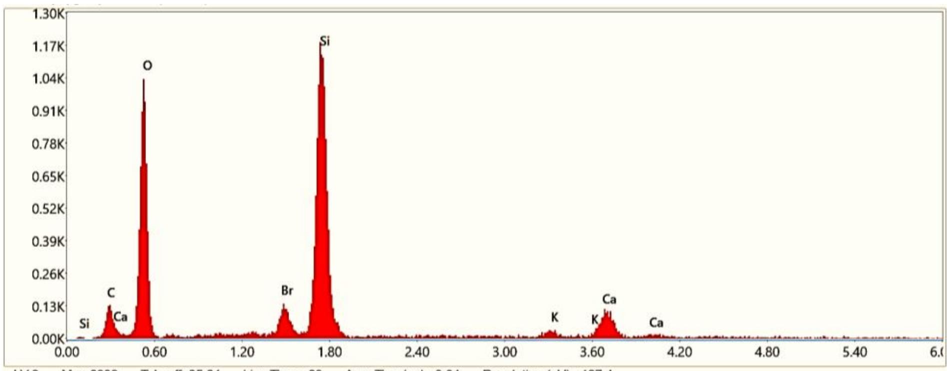

Figure 5: EDX Spectrum of 4% CPA and 7% GD at 56 Days of Curing

Table 9: Quant Result - Analysis Uncertainty for Admixed Concrete

Element	Weight %	MDL	Atomic %
C K	13.70	1.61	23.33
O K	35.21	0.36	45.00
Si K	30.94	0.28	22.52
K K	1.61	1.14	0.84
Ca K	14.00	1.36	7.14
Br L	4.54	0.92	1.16

The SEM pictures of Plate II, which contains 4% CPA and 7% GD, show less calcium hydroxide Ca $(OH)_2$ platelets and smaller, denser-looking pores than the control image in Plate I which seems to be loosely packed and porous. Plate II illustrates the pozzolanic action, which creates the secondary C-S-H gel by consuming calcium hydroxide $(Ca(OH)_2)$. Furthermore, it is known that the subsequent pozzolanic reactions result in less pore in concrete microstructure.

The EDX spectrum in Figure 4 revealed a high concentration of calcium (Ca) and silica (SiO_2), whereas Figure 5 displayed a high concentration of silica oxide. The pozzolanic reaction is responsible for this. Therefore, it could be said that densification and pore refinement were the reasons for the improvement in the strength qualities of the concrete that was admixed with 4% CPA and 7% GD.

4.CONCLUSIONS

Performance evaluation of concrete containing CPA and GD 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 properties of the binder paste and the workability of admixed concrete were found to be affected by the mixture of CPA and GD. Cement's 30% consistency rose as the amount of CPA/GD in it increased. Values were 33, 35, 37, and 40% for 5, 10, 15, and 20% cement substitution. The concrete with CPA/GD replacement's slump test result demonstrated that admixed concretes with CPA/GD were workable with real slump. The slump value increases with the amount of cement substituted with CPA/GD.

ii.The CPA-GD Concrete's compressive strength is greater than the control result of 24.8 N/mm^2 and falls between 8.5 and 10 N/mm^2 after 3 days of curing, 18 and 26.1 N/mm^2 after 28 days of curing, and 24 and 28 N/mm^2 after 56 days of curing.

iii.The SEM pictures of the admixed concrete containing 4% CPA and 7% GD show fewer calcium hydroxide $Ca(OH)_2$ platelets and smaller, denser pores than the control sample, which seems to be loosely packed and porous. The control's EDX spectrum showed a high concentration of calcium (Ca) and silica (SiO_2), but the admixed concrete spectrum showed a high concentration of silica oxide. Therefore, it could be said that densification and pore refinement were the reasons for the improvement in the strength qualities of the concrete that was admixed with CPA and GD.

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