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PERFORMANCE EVALUATION OF CONCRETE MIXTURE WITH HYBRID BLENDS OF METAKAOLIN AND GRANITE DUST

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ABSTRACT

This research investigates concrete mixture with blend of metakaolin and granite dust. The presence of microcracks is one of the major problems associated with cement concrete. Metakaolin proves to be useful in modifying the strength properties of concrete while granite dust improves concrete workability. This project helps to report the optimization of M20 grade concrete produced with metakaolin and granite dust. The chemical properties of the materials were conducted using X-ray Fluorescence (XRF). The setting time and consistency of the paste were determined. Cement replacements by MK and GD at different ratios were studied. The consistency of cement was 29% and increased with increasing Mk and GD content at equal quantities. At 5, 10, 15, and 20% cement replaced by Mk and GD, the values were 34, 35, 37, and 41%. The result of the slump test for the concrete with Mk and GD showed that at 0% (control), the result was 42 mm, 5% (Mk 2.5%, GD 2.5%) was 44 mm, 10% (Mk 5%, GD 5%) was 46 mm, 12.5% (5% Mk, 7.5% GD) was 49 mm, 17.5% (10% Mk, 7.5% GD) was 53 mm, and 20% (10% Mk, 10% GD) was 55 mm. Compressive, tensile and flexural strengths test were conducted on the concrete samples at 3, 28 and 56 days of curing. The strength properties were analysed and modelled using Design Expert 13 Software. Finally, the microstructural analysis will be carried out. The findings of this research will also contribute to the knowledge base regarding sustainable construction materials and provide valuable information for construction industries, architects, engineers, policymakers and building construction regulators.

KEYWORDS: ***Optimization, Metakaolin, Concrete, Central Composite Design, Strength, Granite Dust***

1.INTRODUCTION

Cement is a major component used for the production of concrete. Researchers in the construction industry are constantly trying to minimize the cost of construction materials by using available local materials. Replacing cement with percentages of pozzolanic materials have been reported to produce a concrete with good compressive strength by various researchers [1-5]. Currently, more efforts have been geared towards the use of local materials including agricultural wastes and industrial residues as construction materials [5]. They provide resistance to all sulphate attacks and alkali-silica reactions.

Concrete's main environmental impact is the emission of greenhouse gas from cement production and the mining of raw materials. The cement industry has one of the highest carbon footprints which makes mortar and concrete unsustainable in the future. The world is faced with global warming as a result of the depletion of the ozone layer. The production of cement in the industry is responsible for about 6% of all CO_2 emissions. This is because the production of one tonne of Portland cement emits approximately 0.9 tonnes of CO_2 into the atmosphere [6-8]. This gas is responsible for the depletion of the ozone layer that causes global warming. In this research metakaolin and granite dust as source of silica oxide, aluminium oxide and ferrite oxide were used to partially replace cement in concrete production.

The findings of this research contribute significantly to knowledge regarding sustainable construction materials and provide valuable information for the construction industry, architects, engineers, and policymakers. The results can be used to optimize the composition of cement blends and promote the utilization of waste materials as viable alternatives to traditional cement additives, thus reducing the environmental impact and enhancing the durability of concrete structures.

1.1 Kaolin and Metakaolin (Mk)

Kaolin is one of the industrial minerals that can be found in commercial quantities in Nigeria with a reserve of about (3) three billion metric tonnes of kaolin deposit scattered in difference parts of the country which includes Ogun, Edo, Plateau, Nassarawa, Katsina, Ekiti, Kogi, Abia, Kano, Niger, Bauchi, Sokoto, Kaduna, Oyo, Delta, and Borno states [9]. The market for kaolin is large, sustainable and expanding because of the numerous applications of its products. Good prospects exist in kaolin mining and prospecting in Nigeria [9]. Metakaolin, a product from incineration of kaolin at high temperature above 700^oC can react with some of the CH produced by cement hydration, thereby densifying the structure of the hydrated cement paste [6]. The rates of pozzolanic reaction and CH consumption in metakaolin systems have been shown to be higher than in silica fume systems, indicating a higher initial reactivity. This reaction with CH occurs early and rapidly, metakaolin incorporation may contribute to reduced initial and final set times. In addition, this refinement in the ITZ can result in increased strength in metakaolin concrete [10].

1.2 Granite Dust (G.D)

Granite is an igneous rock which is commonly used as a building material in the field of construction in various forms. Granite powder produced by the process of cutting and polishing of granite is exposed in environment producing health hazards. Granite dust is a non-biodegradable waste material that is produced from granite stone industry [11]. It is in form of fine powder. Granite industries produce a lot of waste materials in form of dust [12]. Danish *et al.* [11] revealed that granite fines exhibited the properties of fine aggregate such as size, fineness and filler capabilities. An investigation was conducted on replacement of sand with granite dust. The percentage replacement of granite fines to fine aggregate were 0%, 30%, 35%, 40%, for M20 mix proportions. Specimens were tested after 28 days of curing. The specimen casted with 40 % replacement of fine aggregate with granite fines gives higher strength when compared to control specimen.

Jerin *et al.* [13] revealed the possibility of using granite dust powder in concrete. Replacement of cement was done in different percentages at 5%, 10, 15%, and 20% by weight of cement. For each replacement compressive strength, splitting tensile strength and flexural strength were conducted after 28 days curing. From the test result 15% replacement of cement with granite dust powder is optimum. Since granite powder is free of cost it seems to be more economical.

2.0 Materials and methods

The materials used for the study are:

(i) Cement
(ii) Metakaolin
(iii) Granite Dust
(iv) Water
(v) Fine aggregates
(vi) Coarse aggregates
(vii) Superplasticizer

2.1 Experimental Design

Design-Expert software 13 was used to optimize the results of compressive and flexural strength of concrete. The software was used to analyse variance and generate a mathematical model. Response surface methodology (RSM) was adopted in the design of experimental combinations. It was used to quantify the relationship between the controllable input parameters and the obtained response surfaces. 20 Experimental runs were created by Design-Expert software 13 response surface methodology for an M20 grade concrete. The parameters used were GD from 5% to 15%, Mk 5% to 10% and curing age from 3 days to 56 days as shown in Table 1 and factors combinations in Table 2.

Table 1: Factor and Factor Levels of Mixture

Name	Units	Low	Middle	High
GD	%	6	8	10
Mk	%	5	7.5	10
Curing Age	days	3	28	56

Table 2: Experimental Runs

Run	Factor 1 A:GD %	Factor 2 B:Mk %	Factor 3 C:Curing days
Control	0	0	56
1	7.5	7.5	28
2	7.5	7.5	28
3	10	7.5	28
4	7.5	7.5	28
5	7.5	7.5	56
6	10	5	56
7	7.5	10	28
8	7.5	7.5	28
9	5	5	56
10	10	5	3
11	5	10	3
12	5	7.5	28
13	10	10	3
14	5	5	3
15	5	10	56
16	7.5	7.5	28
17	7.5	7.5	28
18	10	10	56
19	7.5	5	28
20	7.5	7.5	3

2.2 Test on hardened concrete

(1) Compressive strength

The compressive strength test was conducted at the structure laboratory, ATBU, Bauchi with a compression testing machine of 3000 kN capacity at a loading rate of 0.3kN/min. Concrete cubes were positioned so that the load is applied perpendicularly to the direction of pouring loaded. The load to failure of each cube was recorded, and the compressive strength was calculated. The compressive strength was calculated using equation. The test was carried out on cubic specimens of size (100 mm x 100 mm x 100 mm), in accordance to ASTM C109. The strength was recorded at 3, 7, 28 and 90 days respectively. The average reading of three cubes were recorded as the strength at the respective age.

$$Compressive\ strength = \frac{Load\ (N)}{Area\ (m^2)} \quad \ldots (1)$$

(2) Flexural Strength test.

The flexural strength of concrete was determined by casting beam of size 100 mm x100 mm x 500mm. The beams were tested by placing them uniformly. Specimens were taken out from curing tank at age of 7, 28, 59 and 90 days of moist curing and tested after surface water dipped down from specimens. This test was performed on compression Testing Machine on beam attachment. The load (P) is applied gradually i.e. 0.1KN/sec. Beams were tested for two-point loading. At 1/3rd from support from both ends.

$$F = 2PL/(BD) \quad \ldots (2)$$

Where

F = Flexural strength (MPa),

P = Failure load (N),
L = Effective span of the beam (mm),
B = Breadth of the beam (mm),
D = Depth of the beam (mm).

3.0 RESULTS AND DISCUSSION

3.1 Properties of Binders

The oxide composition of binder (Cement) is presented in Table 3 and the oxide compositions of metakaolin and granite dust are shown in Table 4.

Table 3: Oxide Composition of Cement

Oxide composition %	Cement
SiO_2	22.5
Al_2O_3	6.2
Fe_2O_3	4.1
CaO	61.8
MgO	1.4
SO_3	2.88
K_2O	0.72
Na_2O	0.13
LOI	3.2

The respective 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 61.8% 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 0.72 %. The loss of ignition as 2.4. This shows that the cement used for this research work conforms to the Nigeria Industrial Standard.

Table 4: Oxide Composition of Mk and GD

Oxide composition %	Mk	GD
SiO_2	52.3	72.8
Al_2O_3	34.1	16.5
Fe_2O_3	3.5	3.29
CaO	0.44	2.3
MgO	0.07	0.05
SO_3	0.32	0.2
K_2O	0.48	0.10
Na_2O	0.12	0.09
LOI	7.5	4.20

The chemical test results for oxide composition of metakaolin and granite dust are presented in Table 4. The respective percentage contents of the major oxides of Mk are SiO_2 as 52.3%, Al_2O_3 as 34.1, Fe_2O_3 as 3.5% and CaO as 0.44% whereas the percentage contents of GD are SiO_2 as 72.8%, Al_2O_3 as 16.5, Fe_2O_3 as 3.29% and the alkalis Na_2O as 0.09%. This shows that metakaolin and granite dust have 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%. This demonstrated that the Mk and GD are in the same category with the Class F fly ash with high pozzolanic characteristics [14].

3.2 Particle Size Distribution on Aggregates

Particle size gradation tests were conducted on both fine and coarse aggregates and the result is shown in Figure 1 and Figure 2.

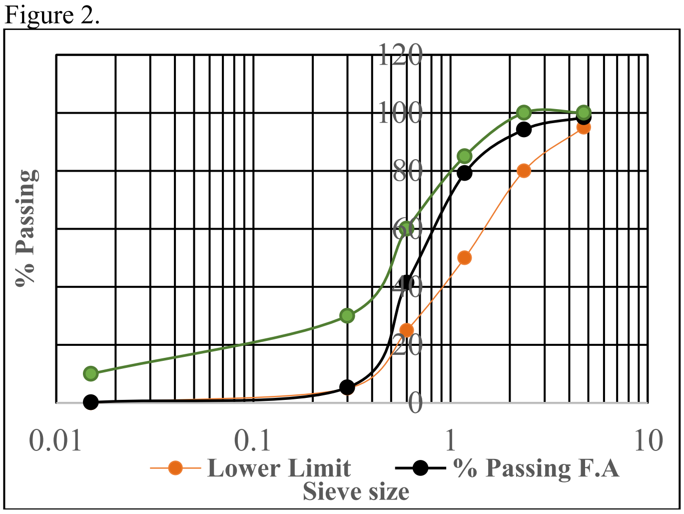

Figure 1: Particle Size Distribution of Fine Aggregates.

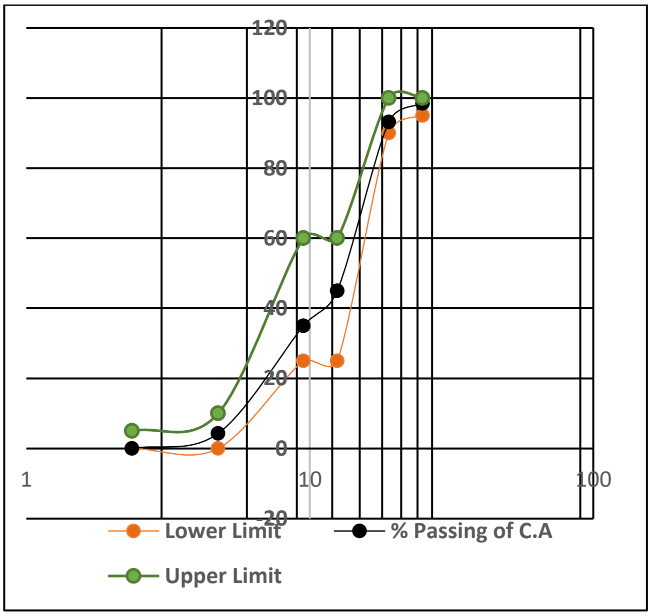

Figure 2: Particle Size Distribution of Coarse Aggregates.

Based on the plot shown above, the aggregates can be classified into two types of sizes - coarse and fine aggregates

- which have similar proportions. It was also found that there was no presence of silt or dust in the material, indicating that it was clean and suitable for use in concrete mixtures.

3.3 Consistency and Setting Time of Paste

The results of consistency, initial and final setting time of paste admixed with Mk and GD are shown in Figures 3 and 4 respectively.

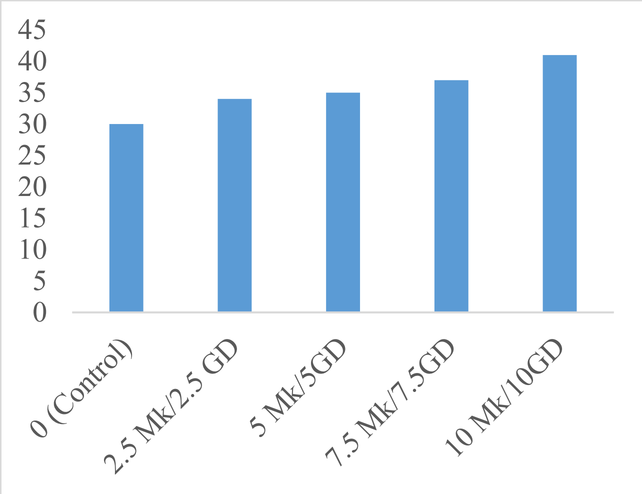

Figure 3: Consistency for Cement / Mk/GD Paste

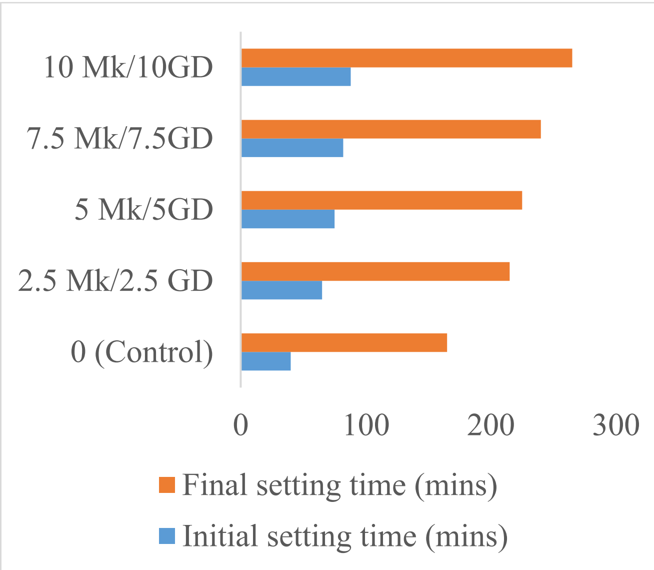

Figure 4: Setting-time for Cement / Mk/GD Paste

The consistency value of the cement paste is lower than the values of blended cement with Mk and GD. This may be attributed to the fineness of Mk and GD. The consistency of cement was 30% and increased with increasing Mk and GD content. At 5, 10, 15, and 20% cement replaced by Mk and GD, the values were 34, 35, 37, and 41%. The results stated that cement consistency is less than that of cement with Mk and GD. At higher replacement level, the initial setting time increased which shows that Mk and GD retards setting time of cement. These admixtures act as retarding agent for a concrete. The results were in accordance with the result from the study conducted by Egwuonwu *et al.* [15].

3.4 Test Results on Aggregates

The tests conducted on aggregates are aggregate gradation, specific gravity, bulk density, water absorption, fineness modulus aggregates crushing value and aggregate impact value. The result of the tests conducted on the physical properties of fine and coarse aggregates are shown in Table 5 and 6.

Table 5: Physical Properties of Fine Aggregates

Property	Fine Aggregate
Specific gravity	2.66
Loose bulk density (kg/m^3)	1422
Water absorption (%)	1.6
Fineness modulus	2.8

Table 6: Physical Properties of Coarse Aggregates

Property	Coarse Aggregate
Specific gravity	2.69
Loose bulk density (kg/m^3)	1232
Water absorption (%)	0.7
Aggregate crushing value (%)	25.0
Aggregate impact value (%)	28.5

The result shows that specific gravity of fine aggregates was 2.66 while coarse aggregate was 2.69. The aggregate crushing value of 25% and Aggregate Impact value of 28.5 are within the specified limits.

3.5 Performance of Mk and GD in Concrete

3.5.1 Slump test result

Workability of concrete was tested by slump test. The result of the slump test is presented in the Table 7.

Table 7: Result of Slump Test

Percentage Replacement of Cement	Slump Height (mm)
Control (0%)	42
Mk 2.5%, GD 2.5%	44
Mk 5%, GD 5%	46
Mk 5%, GD 7.5%	49
Mk 10%, GD 7.5%	53
Mk 10%, GD 10%	55

The result of the slump test for the admixes concrete containing Mk and GD showed that at 0% (control), the result was 42 mm, 5% (Mk 2.5%, GD 2.5%) was 44 mm, 10% (Mk 5%, GD 5%) was 46 mm, 12.5% (5% Mk, 7.5% GD) was 49 mm, 17.5% (10% Mk, 7.5% GD) was 53 mm, and 20% (10% Mk, 10% GD) was 55 mm. All replacements showed that concretes made with Mk and GD were workable. The higher the replacement of cement with Mk and GD, the higher the

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slump value. This shows that the Mk and GD absorb more water. The slump result indicates a true slump which shows that the concrete is workable. 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 Mk and GD and the narrower particle size distributions of the cement blends.

3.5.2 Compressive strength properties

The result of the compressive strength test conducted on admixed concrete at 3 days, 28 days and 56 days are presented in Table 8.

Table 8: Compressive Strength Result

Run	Response 1 Compressive strength N/mm^2
Control	24.7
1	23.1
2	23.1
3	23.8
4	23.1
5	25.3
6	24.0
7	24.5
8	23.1
9	22.4
10	9.1
11	11.0
12	22.2
13	9.4
14	7.9
15	25.5
16	23.1
17	23.1
18	25.1
19	21.6
20	10.2

The compressive strength of concrete containing metakaolin and granite dust show good performance than the control mix. The best result of 25.3 N/mm^2 was achieved at 5% of GD and 10% of Mk at 56 days of curing. The amount of high reactivity Mk and GD is able to react with calcium hydroxide. Concrete strength was enhanced in approximate proportion to the degree of addition of MK and GD. Compared to the findings from other studies, it appears that the results of this study adhere with some of the studies conducted by various researchers. From the result, it was clear that there is no advantage in using Metakaolin beyond 10%. The result is in agreement with the results gotten from the research by various researcher [15]. They reported the highest compressive strength when metakaolin replaced cement in their research. For all mixtures, Metakaolin increased compressive strength appreciably.

The analysis of variance for compressive strength is shown in Table 9.

Table 9: ANOVA for Quadratic Model of Compressive Strength

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	758.87	9	84.32	529.25	< 0.0001
A-GD	0.5864	1	0.5864	3.68	0.0840
B-Mk	11.05	1	11.05	69.33	< 0.0001
C-Curing	558.01	1	558.01	3502.	< 0.0001
AC	2.88	1	2.88	18.08	0.0017
BC	0.0712	1	0.0712	1.85	0.5191
C^2	101.03	1	101.03	0.4466	< 0.0001
Residual	1.59	10	0.1593	634.12	
Lack of	1.59	5	0.3186		
Fit	0.0000	5	0.0000		
Pure Error	760.46	19			
Cor Total					

The Model F-value of 529.25 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.05 indicate model terms are significant. In this case B, C, AB, C^2 are significant model terms. Values greater than 0.1 indicate the model terms are not significant. The fit statistics for compressive strength is shown in Table 10. The model equation for the compressive strength is shown in equation 3.

$$Compressive\ strength = -7.11 + 1.67 * A + 1.92 * B + 0.76 * C - 0.096 * AB + 0.0029 * AC + 0.0014 * BC - 0.063 * A^2 - 0.06 * B^2 - 0.009 * C^2 \quad ... \quad (3)$$

Table 10:Fit Statistics for Quadratic Model of Compressive Strength

Parameters	Values
Std. Dev.	0.3991
Mean	20.03
C.V. %	1.99
R^2	0.9979
Adjusted R^2	0.9960
Predicted R^2	0.9834
Adeq Precision	63.2737

The Predicted R^2 of 0.9834 is in reasonable agreement with the Adjusted R^2 of 0.9960; 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 63.274 indicates an adequate signal. The adjusted R^2 indicates that the model can explain response value change of 99.6 %.

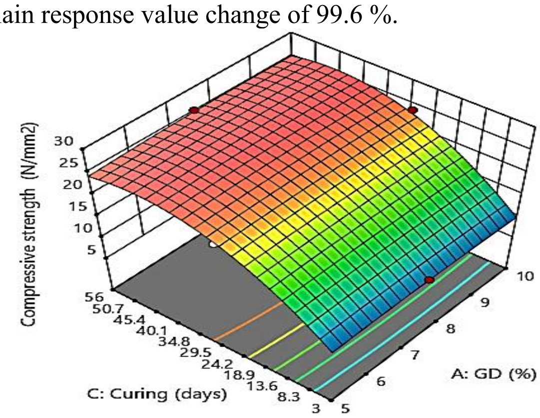

Figure 5: 3D Response Graph of GD, Curing and Compressive Strength.

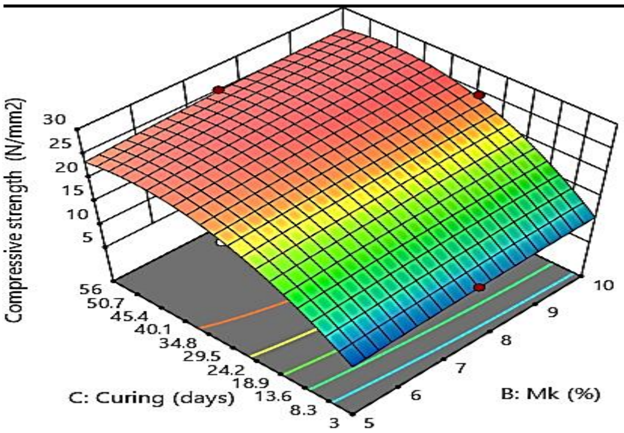

Figure 6: 3D Response Graph of Mk, Curing and Compressive Strength.

Figure 5 shows the influence of granite dust and curing on compressive strength of admixed concrete. The higher the curing age, the higher the compressive strength while slight improvement was witnessed as the granite dust increased from 5 to 10%. Figure 6 shows the influence of Mk and CA on compressive strength of concrete. Metakaolin significantly improved the compressive strength of concrete within the limits and the higher the curing age, the higher the compressive strength.

3.5.3 Flexural strength properties

The flexural strength property of concrete produced was determined after curing at 3, 28 and 56 days. The result of the test is shown in Table 11 and ANOVA in Table 12.

Table 11: Flexural Strength Result

Run	Response 2 Flexural strength (N/mm^2)
Control	4.5
1	3.3
2	3.3
3	4.2
4	3.3
5	5.1
6	3.8
7	4
8	3.3
9	5.4
10	2.3
11	2.5
12	3.2
13	2.3
14	2
15	5.2
16	3.3
17	3.3
18	4.3
19	3.3
20	1.8

Table 12: Analysis of Variance for Flexural Strength

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	17.05	3	5.68	32.04	< 0.0001
A-GD	0.1960	1	0.1960	1.10	0.3088
B-Mk	0.2250	1	0.2250	1.27	0.2767
C-Curing	16.63	1	16.63	93.75	< 0.0001
Residual	2.84	16	0.1774		
Lack of Fit	2.84	11	0.2580		
Pure Error	0.0000	5	0.0000		
Cor Total	19.89	19			

The Model F-value of 32.04 implies the model is significant. P-values less than 0.05 indicate model terms are significant. In this case C is a significant model term. Values greater than 0.1 indicate the model terms are not significant. The model equation for the flexural strength is shown in equation 7, the fit statistics is shown in Table 13.

$$F.S = 2 - 0.056 * A + 0.06 * B + 0.05 * C \quad ... (4)$$

Table 13: Fit Statistics for Quadratic Model of Flexural Strength

Parameters	Values
Std. Dev.	0.4212
Mean	3.46
C.V. %	12.17
R^2	0.8573
Adjusted R^2	0.8305
Predicted R^2	0.7363
Adeq Precision	16.761

The Predicted R^2 of 0.7363 is in reasonable agreement with the Adjusted R^2 of 0.8305; 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 16.761 indicates an adequate signal. This model can be used to navigate the design space.

3.5.4 Tensile strength properties

The tensile strength property of concrete produced was determined after curing at 3, 28 and 56 days. The result of the test is shown in Table 14 and ANOVA in Table 15.

Table 14: Tensile Strength Result

Run	Response 3 Tensile strength N/mm^2
Control	2.4
1	2.1
2	2.1
3	2.7
4	2.1
5	2.9
6	2.2
7	2.2
8	2.1
9	3.0
10	1.8
11	1.9
12	2.1
13	1.8
14	1.2
15	3.0
16	2.1
17	2.1
18	2.7
19	2.1
20	1.2

The result of the early strength of concrete showed lower strength development. The 3 days' tensile strength ranged from 1.2 to 1.8 N/mm^2. At latter ages (28, and 56) days, Mk and GD addition increased the strength of admixed concrete possibly due to an improved transition zone. At latter ages, more calcium hydroxide is being removed from the system and accelerates the Portland cement hydration. This is pozzolanic reaction. Mk and GD slows down early age strength gain but boosts later age strength. This is because the pozzolanic reaction starts later than the hydration of the cement, and continues even after the cement may have stopped hydrating.

Table 15: ANOVA for Tensile Strength Model

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	3.64	3	1.21	17.71	< 0.0001
A-GD	4.441E-16	1	4.441E-16	6.474E-15	1.0000
B-Mk	0.1690	1	0.1690	2.46	0.1361
C-Curing	3.48	1	3.48	50.66	< 0.0001
Residual	1.10	16	0.0686		
Lack of Fit	1.10	11	0.0998		
Pure Error	0.0000	5	0.0000		
Cor Total	4.74	19			

The Model F-value of 17.71 implies the model is significant. The P-values less than 0.05 indicate model terms are significant. In this case C is the only significant model term. The values greater than 0.1 indicate the model terms are not significant. The fit statistics is presented in Table 16.

Table 16: Fit Statistics for Tensile Strength Model

Parameters	Values
Std. Dev.	0.2619
Mean	2.17
C.V. %	12.07
R^2	0.7685
Adjusted R^2	0.7251
Predicted R^2	0.5570
Adeq Precision	12.2778

The Predicted R^2 of 0.5570 is in reasonable agreement with the Adjusted R^2 of 0.7251; i.e. the difference is less than 0.2. The ratio of 12.278 indicates an adequate signal. This model can be used to navigate the design space. The model equation for the tensile strength is shown in equation 4.

$$T.S = 1.14 + 5.5e - 17 * A + 0.05 * B + 0.02 * C \quad ...(4)$$

3.5.5 Optimization of concrete

The goals set for responses in numerical optimization are presented in Table 17

Table 17: Goals for Numerical Optimization.

Name	Goal	Lower Limit	Upper Limit
A: GD	is in range	5	10
B: Mk	is in range	5	10
C: Curing age	is in range	3	56
Compressive strength	maximize	7.5	25.5
Flexural strength	maximize	1.8	5.4
Tensile strength	maximize	1.2	3.0

The automatic optimization function of Design-Expert software version 13 indicates that the optimal values of the factors as 5% GD and 10% Mk at 56 days of curing gives compressive strength of 25.6N/mm^2, Flexural strength 5.07 N/mm^2 and Splitting tensile strength of 2.9N/mm^2 with combined desirability of 0.952.

4.0 Conclusion

Optimization of Self-Compacting Concrete Containing Metakaolin and Granite Dust using Central Composite Design was studied and based on the findings, the following conclusions were made:

1.The X-ray fluorescence test results for oxide composition of Metakaolin and GD showed that both used for this research work had enough silica and alumina content which enhanced better strength development of concrete at a later age.

2.The consistency of cement was 29% and increased with increasing Mk and GD content at equal quantities. At 5, 10, 15, and 20% cement replaced by Mk and GD, the values were 34, 35, 37, and 41%. The result of the slump test for the concrete Mk and GD replacement of the cement showed that at 0% (control), the result was 42 mm, 5% (Mk 2.5%, GD 2.5%) was 44 mm, 10% (Mk 5%, GD 5%) was 46 mm, 12.5% (5% Mk, 7.5% GD) was 49 mm, 17.5% (10% Mk, 7.5% GD) was 53 mm, and 20% (10% Mk, 10% GD) was 55 mm. All replacements showed that concretes made with Mk and GD were workable.

3.The compressive, flexural and tensile strengths of concrete containing metakaolin and granite dust at 5% of GD and 10% of Mk at 56 days of curing show good performance than the control mix. The result of the early strength of concrete showed lower strength development while at latter ages (28, and 56 days), Mk and GD addition increased the strength of admixed concrete possibly due to an improved transition zone.

4.Optimization of strengths of the resulting concrete by central composite design shows the optimal result was 5% GD and 10% Mk at 56 days with maximum compressive strength of 25.6 N/mm2, flexural strength of 5 N/mm2 and tensile strength of 2.9 N/mm2.

5.0 Recommendations

This research has indicated the limits in which OPC can be replaced with GD and Mk to beneficially produce workable and good concrete without detrimentally affecting the strength of concrete. This study also recommends the use of Mk at 10% and 5% GD as cement replacement in M20 grade concrete.

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