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Original Research Article

Optimization of Flexural Strength of Sawdust Ash Blended Geopolymer Concrete

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Abstract

The usage of geopolymer concrete as a substitute for cement will enhance environmental sustainability by decreasing the release of greenhouse gases linked to the manufacture of cement. Geopolymer as a binder for making concrete consists of two (2) main components; (1) the alkaline liquid consisting of sodium or potassium silicate and sodium or potassium hydroxide and (2) source material of geological origin or by-products rich in silica and alumina. The combination proportions utilised in this investigation were formulated utilising Scheffe's (5,2) basic lattice mix design approach with the intent to create the trial mix and the control mix. A total of thirty (30) geopolymers concrete sample mixes were made in the laboratory, with fifteen samples for trial mixes and fifteen mixtures for control mixes. These mixtures were used to appraise the performance of the sawdust ash geopolymer concrete in term of its flexural strength property. The study used sawdust ash as the source material and investigation revealed that subjecting sawdust ash to pyrolysis without oxygen has a notable impact on the pozzolanic characteristics of the constituent. Consequently, this also affects the flexural qualities of the concrete. Furthermore, it has been shown that softwood sawdust exhibits superior pozzolanic properties when compared to hardwood sawdust. The study revealed that the optimum flexural strength of sawdust ash blended geopolymer concrete is 3.3002 MPa and the corresponding mix deign obtained. Computer programs were created using Matlab and used for the optimization and prediction of the flexural strength of sawdust ash based geopolymer concrete.

Keywords: Sawdust ash, geopolymer, pozzolanic property, Optimization, Prediction, optimum parameter.

INTRODUCTION

For a considerable amount of time, ordinary Portland cement has been utilised as a binder in the context of the production of ordinary Portland concrete (OPC). Rising infrastructure needs in many emerging nations, together with a growth in the summation of old, decaying concrete buildings in dire need of repair and rehabilitation, are driving up the anticipated demand for OPC. Having said that, (Mehta, 2001), revealed that the cement industry is responsible for almost seven percent (7%) of global greenhouse gas emissions and produces millions of tonnes of waste annually. Most recently, (Pearce, 2021), has it that the anthropogenic greenhouse gas emissions of cement industry accounts for 8% of world's greenhouse gases every year. In congruent with (Hardjito, *et al.*, 2005 and Madhava *et al*., 2013), the amount of carbon dioxide (CO_2) released into the environment during the manufacturing of one metric tonne of Portland cement is around one tonne.

The founder of the concept of geopolymer concrete, (Davidovits, 1991), has it that binders might be made by reacting silicon (Si) and aluminium (Al) in a geologically-derived source constituent or in by-product constituents like flue ashes and rice husk ash. He came up with the name "Geopolymer" to describe these binders as the chemical reaction involved is a polymerisation process. An alternative to traditional cement, geopolymer binder is made by combining pozzolanic precursors such as flue ashes, and in this case, sawdust ash, which are rich in silica and alumina, with an alkaline solution to activate the process (Luhar *et al*., 2019).

The cement business cannot be classified as a sustainable sector due to its reliance on raw constituents obtained via mining, which has adverse effects on land use patterns. Additionally, the products generated by this industry are not recyclable. By considering the principles of waste management, the by-products of a thermal power plant, i.e. flue ashes, and the by-products of the steel industry, i.e. slag, can be utilised as binders instead of cement. Additionally, the by-product of the wood industry, sawdust, can also be utilised as a binder. This substitution can lead to a substantial reduction in the energy required for cement production. Energy conservation and reduction of greenhouse gas emissions may be achieved by saving both raw constituents and energy resources, within a certain threshold. By utilising this approach, we may transform the waste by-product into a practical and valuable substance, i.e. Concrete that are geopolymers.

An experimental study on geo-polymer concrete owing to flue ashes was published, (Ivindra *et al*., 2018). Examining how the molarity of an alkaline activator solution (AAS) impacts the compressive resistance of concrete that are geopolymers was the primary goal of this research. An activator solution containing NaOH was utilised as the test variable. The NaOH solutions utilised had concentrations of 10 M, 12 M, and 14 M, and they were left to cure at room temperature. Each of the nine sections that make up the specimen is a concrete cylinder that is ten centimetres in diameter and twenty centimetres in height. At7,14, and 28 days after mixing, concrete undergoes compressive resistance testing. Tests on geo-polymer concrete showed that its compressive resistance improved when the concentration of sodium hydroxide (NaOH) solutions was raised. The ideal sodium hydroxide solution (NaOH) concentration for geo-polymer concrete's compressive resistance was 12 M. Their research showed that the compressive resistance of geo-polymer concretes is only about half as high as expected.

In their study on soil stabilisation, Jeremiah *et al*., (2021) reviewed the utilisation of geo-polymers made from various industrial wastes for stabilising weak clays. These geo-polymers comprise pulverised fuel ash (PFA), ground granulated blast furnace slag (GGBS), metakaolin (MK), glass powder (GP), palm oil fuel ash (POFA), silica fume (SF), rice husk ash (RHA), volcanic ash (VA) and marble powder (MP). By comparing the treated clays' 7-day UCS with the resistance requirement for stabilised constituents as described in BS EN 16907-4, the researchers were able to assess the performance of stabilised clays as subgrade and subbase constituents for road pavement construction. Researchers came to the conclusion that geo-polymers may be utilised to improve the engineering features of problematic clays, making them more suitable for real-world applications. The stabilised clays showed an upsurge in resistance when the precursor concentration, molarity of alkaline activator, and curing duration were upsurge.

The aim of this study is to determine the flexural strength of saw dust ash concrete that are geopolymers, while the objectives include determination of the pozzolanic properties of saw dust ash, formulate mathematical models for envisaging and optimizing the flexural resistance of saw dust ash concrete that are geopolymers and development of Matlab program for easy prediction and optimization of the flexural strength of saw dust ash geopolymer concrete.

MATERIALS AND METHODS

Materials

The constituents utilised in this study are discussed as follows:

1. Sawdust ash

The sawdust was collected from Rumuosi sawmills in Port Harcourt, Nigeria. The samples were taken from the waste of wood that was treated in the mills during the course of a single day. Sawdust from hardwood and sawdust from softwood were separated out of the samples that were collected throughout the process of collecting samples. “After being gathered in sac bags, the samples were then transformed into ash by the process of open burning in a metal container and utilising an incinerator. Oxide composition taste and X-ray diffraction analysis (XRD) were performed on the samples that were obtained with the intent to establish the pozzolanic property of the constituent and to identify the cementation characteristics.

2. Water

Clean tap water was utilised for this task. It was devoid of any impurity, had no colour, and had no smell. When the amount of impurities in the mixing water is too high, it may lead to efflorescence or corrosion of reinforcement, which in turn affects the setting time, resistance of the concrete, and volume stability (change in length).

3. Alkaline liquid

In this investigation, SiO_2 solutions and 8–14M NaOH were utilised to activate the sawdust ash alkaline. The sodium silicate and sodium hydroxide were sourced in Mile 3 market, here in Port Harcourt, Nigeria. The sodium hydroxide (NaOH) utilised in this research was dissolved in water at least six hours before mixing and came in pellet form with a purity level of 97-98 percent.

4. Fine aggregates

The riverbank Choba, sand dump provided the fine constituent utilised in this investigation. The clean, naturally occurring sand with rounded or sub-rounded particles is this fine aggregate, which is readily accessible in the area. The fine aggregate was sourced from a nearby provider and consistently utilised throughout all batches. Prior to being utilised for concreting, it underwent washing and sun drying. Ensuing this, a particle size distribution test was performed. In accordance with BS 1881-2(1970), the

fine aggregate's characteristics and grain size distribution were assessed.

5. Coarse aggregates

Bags of coarse granites were collected at Mile 3 Market and brought to the lab for this research. Before being utilised for concreting, it was sun-dried and cleaned to remove impurities. Ensuing this, a particle size distribution was performed. The research utilised coarse aggregates of crushed granite with nominal maximum sizes of 7mm, 10mm, and 20mm.

6. Super-plasticiser

Utilising naphthalene at continuous dose of 1.25 percent of the binder weight of superplasticizer was utilised in the concrete formulations. A desired slump was the primary goal of utilising this admixture type. In Port Harcourt, Rivers State, Nigeria, the admixture was bought from mile 3 market.

Methods

The methods employed in this study comprises:

i. Experimental method
ii. Mathematical model development

Experimental Method

Particle size distribution, oxide composition test, specific gravity, density of constituent materials and flexural strength of sawdust ash derived geoplymer concrete were the laboratory tests carried out in course of this work.

1. Sieve Analysis

The percentage of aggregate particles of various sizes was calculated utilising sieve analysis. A tower of interconnecting sieves with progressively smaller holes was utilised for the test. The sieve analysis was carried out in accordance with the standard BS 1881-2(1970).

Fine aggregate

- A consistent weight was achieved by drying the 1kg test sample at a temperature of 110 ± 5oC and then weighing it.
- Fifty-two grammes of fine aggregate that had been oven-dried was utilised for the sieve analysis. Since the tested sample's mass was higher than the required value specified in BS 1881-2(1970) (each part not lower than 150gm), the sand sample was divided into two halves. After the test was finished, the weight of particles retained on each sieve was combined again and these were taken as functions of the individual sieves.
- The next step was to use a mechanical shaker to strain the sample. The ensuing sieves were utilised: 2.36 mm, 1.18 mm, 600 µm, 300 µm, and 150 µm.
- The constituent on each sieve was weighed once sieving was finished, and the overall weight of the sample was computed as a percentage of the weight of each sieve's cumulative passage.
- To get the fineness modulus, we added up the percentage of aggregates that passed via each filter and then divided the total by 100.

Coarse aggregate

The sieve analysis of the coarse aggregate followed the same process as that of the fine aggregate. Here is the process:

- In congruent with BS 1881-2(1970), the sample was dried at a temperature of 110 ± 5oC until it reached a constant mass, and the value was recorded to the closest 0.1 percent of the total mass of the sample, or 0.1 gm.
- Coarse aggregate was sieved utilising several sizes of mesh, comprising 26.5mm, 19mm, 9.5mm, 4.75mm, 2.36mm, and 1.18mm. After around ten minutes of shaking, the sieves were set in the mechanical shaker.
- At last, the mass of the aggregate that was kept was documented.

2. Specific Gravity and Density of Constituent Materials

The specific gravity and density of constituent materials used in this work such as sawdust ash, fine aggregates, coarse aggregate were determined in the laboratory and tabulated.

3. Flexural strength

The flexural resistance is given in MPa, and was found in congruent with BS 1881-2(1970). Flexural resistance of two (2) samples per test run was done for each mix by loading them with a 100 mm x 100 mm concrete beam that had a span length of 500 mm. The tests were done at 28 days and the ensuing steps that made up the test are:

- To help with a level load, the specimen's surface was cleaned of any oil and grit.
- The specimen was put on top of the two bottom rollers, which were 300 mm apart. The top of the specimen was then touched by the loading roller.
- The load was put on the sample without any shocks, and it kept going up at a rate of 0.0167 MPa/sec. It was written down the highest force that was utilised, likewise the average width and average depth at the breakdown part.

The equation (1) was utilised to find the flexural strength.

$$f_{cf} = 1000 * PL/BD^2 \quad \ldots\ldots (1)$$

Where;

f_{cf} = modulus of rupture (MPa),
P = maximum applied force indicated by the testing machine (kN),
L = span length (mm),

B = average width of the specimen at the section of failure (mm),

D = average depth of specimen at the section of failure (mm),

Plate 1: Conduction of Flexural resistance test

Mathematical Model development

1. Trial and Control Mixes

(Scheffe, 1958) states that Equation 2 may be utilised to get the summation of experimental points.

$N = \frac{(q+m-1)}{(q-1)!m!}$ …….. (2)

Where;

q = summation of constituents;

m = maximum summation of interactions

For mixes with five and two constituents, the summation of experimental points is fifteen (15) when Equation (2) is utilised. The ensuing five ratios were utilised in the study: activator/SDA, water/binder, percent SDA in binder, NaOH conc. (M), and Na_2SiO_4/NaOH ratio. The simplex lattice design utilised in this investigation is shown in Figure 1.

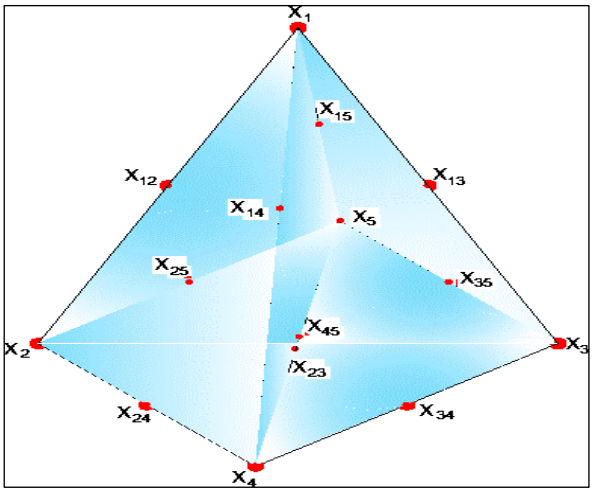

Figure 1: Scheffe's (5, 2) simplex lattice adopted in this study

Scheffe (1958) states that pseudo (theoretical) mix ratios are being utilised to depict mixture proportions. At each vertex, there is a pure substance, and the approach works on the assumption that the total of all pseudo mix ratios is 1. From a mathematical standpoint;

$\sum_{i=1}^{q} x_i = 1$ …….. (3)

With the intent to meet the requirements of Equation (4), the real mix ratios need to be transformed into pseudo mix ratios. Here is the correlation between the two sets of mix ratios:

$Z = [A]X$ …….. (4)

Where;

Z = column matrix of real constituent ratio.

X = column matrix of pseudo constituent ratio.

[A]= co-efficient matrix which is the transpose of the permutation matrix.

By flipping the permutation matrix over, we get Matrix A. The generated permutation matrix for NaOH concentration (M) was restricted to values between 8M and 15M, which meant that the mix's Na_2SiO_4/NaOH

ratio could only be between 1.5 and 3. Binder SDA content was restricted to 35 percent to 45 percent. While the activator/SDA ratio were from 2.3 to 3.1, the water/binder ratio could only be between 0 and 0.1. At the points where it was assumed that pure substances existed, the mix ratios are as follows: (8, 9.75, 11.5, 13.25, 15), (1.5, 1.875, 2.25, 2.625, 3), (35, 37.5, 40, 42.5, 45), (0, 0.025, 0.05, 0.075, 0.1) and (2.3, 2.485, 2.671, 2.856, 3.1) for these points, which is represented by the permutation matrix [P_0].

$$P_o = \begin{bmatrix} 8 & 1.5 & 35 & 0 & 2.3 \\ 9.75 & 1.875 & 37.5 & 0.025 & 2.485 \\ 11.5 & 2.25 & 40 & 0.005 & 2.671 \\ 13.25 & 2.625 & 42.5 & 0.075 & 2.856 \\ 15 & 3 & 45 & 0.1 & 3.1 \end{bmatrix}$$

Transpose of Po becomes

$$A = \begin{bmatrix} 8 & 9.75 & 11.5 & 13.25 & 15 \\ 1.5 & 1.875 & 2.25 & 2.625 & 3 \\ 35 & 37.5 & 40 & 42.5 & 45 \\ 0 & 0.025 & 0.05 & 0.075 & 0.1 \\ 2.3 & 2.485 & 2.671 & 2.856 & 3.1 \end{bmatrix}$$

Specifically, the ensuing are the pseudo mix proportions of the centre or interaction sites from Figure 1:

$$X = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0.5 & 0.5 & 0.5 & 0.5 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0.5 & 0 & 0 & 0 & 0.5 & 0.5 & 0.5 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0.5 & 0 & 0 & 0.5 & 0 & 0 & 0.5 & 0.5 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0.5 & 0 & 0 & 0.5 & 0 & 0.5 & 0 & 0.5 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0.5 & 0 & 0 & 0.5 & 0 & 0.5 & 0.5 \end{bmatrix}$$

The trail mix matrix, Z, becomes;

$$Z = \begin{bmatrix} 8 & 9.75 & 11.5 & 13.25 & 15 & 8.875 & 9.75 & 10.625 & 11.5 & 10.625 & 11.5 & 12.375 & 12.375 & 13.25 & 14.125 \\ 1.5 & 1.875 & 2.25 & 2.625 & 3 & 1.6875 & 1.875 & 2.0625 & 2.25 & 2.0625 & 2.25 & 4.4375 & 2.4375 & 2.625 & 2.8125 \\ 35 & 37.5 & 40 & 42.5 & 45 & 36.25 & 37.5 & 38.75 & 40 & 38.75 & 40 & 41.25 & 41.25 & 42.5 & 43.75 \\ 0 & 0.025 & 0.05 & 0.075 & 0.1 & 0.0125 & 0.025 & 0.0375 & 0.05 & 0.0375 & 0.05 & 0.0625 & 0.0625 & 0.075 & 0.0875 \\ 2.3 & 2.485 & 2.671 & 2.856 & 3.1 & 2.3925 & 2.4855 & 2.578 & 2.7 & 2.578 & 2.6705 & 2.7925 & 2.7635 & 2.8855 & 2.978 \end{bmatrix}$$

Tables 1 below represent the trial mix matrix of SDA concrete mixes respectively after proper application of Equation 5.

Table 1: Trial mix matrix points owing to Scheffe's (5, 2) factor space

N	Pseudo constituent					Actual constituent				
	X_1	X_2	X_3	X_4	X_5	Z_1 = NaOH conc. (M)	Z_2 = Na2SiO4/ NaOH	Z_3 = percent SDA in binder	Z_4 = water/binder	Z_5 = Activator/ SDA
1	1	0	0	0	0	8	1.5	35	0	2.3
2	0	1	0	0	0	9.75	1.875	37.5	0.025	2.485
3	0	0	1	0	0	11.5	2.25	40	0.05	2.671
4	0	0	0	1	0	13.25	2.625	42.5	0.075	2.856
5	0	0	0	0	1	15	3	45	0.1	3.1
6	½	½	0	0	0	8.875	1.6875	36.25	0.0125	2.3925
7	½	0	½	0	0	9.75	1.875	37.5	0.025	2.4855
8	½	0	0	½	0	10.625	2.0625	38.75	0.0375	2.578
9	½	0	0	0	½	11.5	2.25	40	0.05	2.7
10	0	½	½	0	0	10.625	2.0625	38.75	0.0375	2.578
11	0	½	0	½	0	11.5	2.25	40	0.05	2.6705
12	0	½	0	0	½	12.375	2.4375	41.25	0.0625	2.7925
13	0	0	½	½	0	12.375	2.4375	41.25	0.0625	2.7635
14	0	0	½	0	½	13.25	2.625	42.5	0.075	2.8855
15	0	0	0	½	½	14.125	2.8125	43.75	0.0875	2.978

Similarly, for the control mix matrix, the pseudo mix proportions adopted in line with Schefe's criteria is given as;

$$Xc = \begin{bmatrix} \frac{1}{3} & \frac{1}{3} & \frac{1}{3} & \frac{1}{3} & \frac{1}{4} & \frac{1}{4} & \frac{1}{4} & 0 & \frac{3}{10} & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & \frac{3}{20} & \frac{1}{5} & \frac{1}{4} \\ \frac{1}{3} & \frac{1}{3} & 0 & \frac{1}{3} & \frac{1}{4} & \frac{1}{4} & \frac{1}{4} & \frac{1}{4} & \frac{1}{10} & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & \frac{1}{4} & \frac{1}{5} & \frac{1}{5} \\ \frac{1}{3} & 0 & \frac{1}{3} & 0 & \frac{1}{4} & \frac{1}{4} & 0 & \frac{1}{4} & \frac{1}{5} & \frac{1}{10} & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & \frac{3}{20} & \frac{1}{5} \\ 0 & \frac{1}{3} & \frac{1}{3} & 0 & \frac{1}{4} & 0 & \frac{1}{4} & \frac{1}{4} & \frac{1}{5} & \frac{3}{10} & \frac{3}{10} & \frac{1}{5} & \frac{1}{5} & \frac{1}{4} & \frac{1}{5} \\ 0 & 0 & 0 & \frac{1}{3} & 0 & \frac{1}{4} & \frac{1}{4} & \frac{1}{4} & \frac{1}{5} & \frac{1}{5} & \frac{1}{10} & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & \frac{3}{20} \end{bmatrix}$$

Multiplying the pseudo mix proportions for control, Xc by A, the control mix matrix, Zc, becomes;

$$Zc = \begin{bmatrix} 9.75 & 10.33 & 10.92 & 10.92 & 10.63 & 11.06 & 11.50 & 12.38 & 11.33 & 11.68 & 11.33 & 11.50 & 11.59 & 11.59 & 11.15 \\ 1.88 & 2.00 & 2.13 & 2.13 & 2.06 & 2.16 & 2.25 & 2.44 & 2.21 & 2.29 & 2.21 & 2.25 & 2.27 & 2.27 & 2.18 \\ 37.50 & 38.33 & 39.17 & 39.17 & 38.75 & 39.38 & 40.00 & 41.25 & 39.75 & 40.25 & 39.75 & 40.00 & 40.13 & 40.13 & 39.50 \\ 0.03 & 0.03 & 0.04 & 0.04 & 0.04 & 0.04 & 0.05 & 0.06 & 0.05 & 0.05 & 0.05 & 0.05 & 0.05 & 0.05 & 0.05 \\ 2.49 & 2.55 & 2.61 & 2.63 & 2.58 & 2.64 & 2.69 & 2.78 & 2.66 & 2.70 & 2.66 & 2.68 & 2.69 & 2.69 & 2.64 \end{bmatrix}$$

The control mix design matrix and the trial mix design for concrete that are geopolymers adopted in this study is given in table 2 and table 3 respectively.

Table 2: Control mix matrix owing to Scheffe's (5, 2) factor space

N	Pseudo constituent					Actual constituent				
	X_1	X_2	X_3	X_4	X_5	Z_1 = NaOH conc. (M)	Z_2 = Na2SiO4/ NaOH	Z_3 = percent SDA in binder	Z_4 = water/binder	Z_5 = Activator/ SDA
1	1/3	1/3	1/3	0	0	9.75	1.88	37.50	0.03	2.49
2	1/3	1/3	0	1/3	0	10.33	2.00	38.33	0.03	2.55
3	1/3	0	1/3	1/3	0	10.92	2.13	39.17	0.04	2.61
4	1/3	1/3	0	0	1/3	10.92	2.13	39.17	0.04	2.63
5	¼	¼	¼	¼	0	10.63	2.06	38.75	0.04	2.58
6	¼	¼	¼	0	¼	11.06	2.16	39.38	0.04	2.64
7	¼	¼	0	¼	¼	11.50	2.25	40.00	0.05	2.69
8	0	¼	¼	¼	¼	12.38	2.44	41.25	0.06	2.78
9	3/10	1/10	1/5	1/5	1/5	11.33	2.21	39.75	0.05	2.66
10	1/5	1/5	1/10	3/10	1/5	11.68	2.29	40.25	0.05	2.70
11	1/5	1/5	1/5	3/10	1/10	11.33	2.21	39.75	0.05	2.66
12	1/5	1/5	1/5	1/5	1/5	11.50	2.25	40.00	0.05	2.68
13	3/20	¼	1/5	1/5	1/5	11.59	2.27	40.13	0.05	2.69
14	1/5	1/5	3/20	¼	1/5	11.59	2.27	40.13	0.05	2.69
15	¼	1/5	1/5	1/5	3/20	11.15	2.18	39.50	0.05	2.64

Table 3: Trial mix design of Sawdust ash geopolymer and OPC concrete

GEO-POLYMER CONCRETE MIX DESIGN												
S/NO	Mix ID	Conc. Of NaOH (M)	SS/SH	Activator/SDA	Super-Plasticiser (percent of Binder)	Binder (Kg)	percent of SDA in Binder	SDA (Kg)	Cement (Kg)	SAND (Kg)	Aggregates (Kg)	Water/ Binders
1	OPC								2.1	4.1	8.2	0.4
2	GPC1	8	1.5	2.3	0.05	2.1	35	0.74		4.1	8.2	0
3	GPC2	9.75	1.875	2.485	0.05	2.1	37.5	0.79		4.1	8.2	0.025
4	GPC3	11.5	2.25	2.671	0.05	2.1	40	0.84		4.1	8.2	0.05
5	GPC4	13.25	2.625	2.856	0.05	2.1	42.5	0.89		4.1	8.2	0.075
6	GPC5	15	3	3.10	0.05	2.1	45	0.95		4.1	8.2	0.1
7	GPC6	8.875	1.6875	2.39	0.05	2.1	36.25	0.76		4.1	8.2	0.0125

8	GPC7	9.75	1.875	2.49	0.05	2.1	37.5	0.79		4.1	8.2	0.025
9	GPC8	10.625	2.0625	2.58	0.05	2.1	38.75	0.81		4.1	8.2	0.0375
10	GPC9	11.5	2.25	2.70	0.05	2.1	40	0.84		4.1	8.2	0.05
11	GPC10	10.625	2.0625	2.58	0.05	2.1	38.75	0.81		4.1	8.2	0.0375
12	GPC11	11.5	2.25	2.67	0.05	2.1	40	0.84		4.1	8.2	0.05
13	GPC12	12.375	2.4375	2.79	0.05	2.1	41.25	0.87		4.1	8.2	0.0625
14	GPC13	12.375	2.4375	2.76	0.05	2.1	41.25	0.87		4.1	8.2	0.0625
15	GPC14	13.25	2.625	2.89	0.05	2.1	42.5	0.89		4.1	8.2	0.075
16	GPC15	14.125	2.8125	2.98	0.05	2.1	43.75	0.92		4.1	8.2	0.0875

2. Optimization Model Development

It has been earlier established that mixture proportions are being represented in pseudo (theoretical) mix ratios, from Scheffe's (5,2) simple lattice. It was equally established that pure substance exist at the vertices points and the method rely on the condition that the summation of all pseudo mix ratios at any point must be equal to 1. This explains the constraint in the optimization process as represented in Equation 3.

The (q, m) polynomial have a general form represented by Equation 5 (Scheffe, 1958);

$$Y = b_o + \Sigma b_i x_i + \Sigma b_{ij} x_i x_j + \Sigma b_{ijk} x_i x_j x_k + \cdots + \Sigma b_{i1,i2..im} x_{i1} x_{i2} x_{im} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where;

$1 \leq i \leq q$, $1 \leq i \leq j \leq q$, $1 \leq i \leq j \leq k \leq q$

b_o is a constant coefficient

For (5, 2) polynomial problem as adopted in this study, Equation (5) becomes;

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_{12}X_{12}X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{15}X_1X_5 + b_{25}X_2X_5 + b_{24}X_2X_4 + b_{23}X_2X_3 + b_{34}X_3X_4 + b_{35}X_3X_5 + b_{45}X_4X_5 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{44}X_4^2 + b_{55}X_5^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

For a ternary mixture, Equation (7) is obtained from Equation (3).

$$X_1 + X_2 + X_3 + X_4 + X_5 = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Multiplying through by constant, b_0, yields Equation (8).

$$b_0X_1 + b_0X_2 + b_0X_3 + b_0X_4 + b_0X_5 = b_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Again, multiplying Equation (8) by X_1, X_2, X_3, X_4 and X_5 in succession and rearranging, Equation (9) is produced.

$$\left.\begin{aligned} X_1^2 &= X_1 - X_1X_2 - X_1X_3 - X_1X_4 - X_1X_5 \\ X_2^2 &= X_2 - X_1X_2 - X_2X_3 - X_2X_4 - X_2X_5 \\ X_3^2 &= X_3 - X_1X_3 - X_2X_3 - X_3X_4 - X_3X_5 \\ X_4^2 &= X_4 - X_1X_4 - X_2X_4 - X_3X_4 - X_4X_5 \\ X_5^2 &= X_5 - X_1X_5 - X_2X_5 - X_3X_5 - X_4X_5 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Substituting Equations (8) and (9) into Equation (6), Equation (10) was obtained after necessary transformation.

$$Y = (b_0 + b_1 + b_{11})X_1 + (b_0 + b_2 + b_{22})X_2 + (b_0 + b_3 + b_{33})X_3 + (b_0 + b_4 + b_{44})X_4 + (b_0 + b_5 + b_{55})X_5 + (b_{12} - b_{11} - b_{22})X_1X_2 + (b_{13} - b_{11} - b_{33})X_1X_3 + (b_{14} - b_{11} - b_{44})X_1X_4 + (b_{15} - b_{11} - b_{55})X_1X_5 + (b_{23} - b_{22} - b_{33})X_2X_3 + (b_{24} - b_{22} - b_{44})X_2X_4 + (b_{25} - b_{22} - b_{55})X_2X_5 + (b_{34} - b_{33} - b_{44})X_3X_4 + (b_{35} - b_{33} - b_{55})X_3X_5 + (b_{45} - b_{44} - b_{55})X_4X_5 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

Denoting;

$\beta_i = b_0 + b_i + b_{ii}$ and

$\beta_{ij} = b_{ij} - b_{ii} - b_{jj}$

With five variables, the simplified second-degree polynomial may be seen in Equation (11).

$$Y = \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{14}X_1X_4 + \beta_{15}X_1X_5 + \beta_{23}X_2X_3 + \beta_{24}X_2X_4 + \beta_{25}X_2X_5 + \beta_{34}X_3X_4 + \beta_{35}X_3X_5 + \beta_{45}X_4X_5 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

Equation (11) uses fifteen (15) coefficients instead of the many coefficients in Equation (6). Therefore, Equation (12) shows the reduced second-degree polynomial in q-variables.

$$Y = \sum_{1 \leq i \leq q} \beta_i X_i + \sum_{i \leq j \leq q} \beta_{ij} X_i X_j \quad \ldots\ldots\ldots\ldots\ldots \quad (12)$$

Where;

Y = Expected response

β_i, β_{ij} = Co-efficient of the quadratic polynomial

X_i, X_j = Pseudo proportion of factors considered

Equation (13) is obtained by substituting the coordinates of the vertices from Figure 1 into Equation (9).

$$\left.\begin{array}{l} Y_1 = \beta_1 \\ Y_2 = \beta_2 \\ Y_3 = \beta_3 \\ Y_4 = \beta_4 \\ Y_5 = \beta_5 \end{array}\right\} \quad \ldots\ldots (13)$$

For interaction point X_{12} of Figure 1;

$$Y_{12} = {}^1/_2 X_1 + {}^1/_2 X_2 + {}^1/_4 X_1 X_2 = {}^1/_2 \beta_1 + {}^1/_2 \beta_2 + {}^1/_4 \beta_{12} \quad \ldots\ldots (14)$$

In congruent with Equation (7), β_i is equal to Y_i, where i ranges from 1 to n. By plugging the values into Equation (8), the ensuing upshot was obtained:

$$Y_{12} = ({}^1/_2)Y_1 + ({}^1/_2)Y_2 + ({}^1/_4)\beta_{12} \quad \ldots\ldots (15)$$

Simplifying Equation (15), yielded:

$$B_{12} = 4Y_{12} - 2Y_1 - 2Y_2 \quad \ldots\ldots (16)$$

Equations (17) to (20) were derived in a similar manner. Therefore:

$$B_{13} = 4Y_{13} - 2Y_1 - 2Y_3 \quad \ldots\ldots (17)$$
$$B_{14} = 4Y_{14} - 2Y_1 - 2Y_4 \quad \ldots\ldots (18)$$
$$B_{15} = 4Y_{15} - 2Y_1 - 2Y_5 \quad \ldots\ldots (19)$$
$$B_{23} = 4Y_{23} - 2Y_2 - 2Y_3 \quad \ldots\ldots (20)$$

By generalising equations (16) to (20), equation (21) was derived.

$$\left.\begin{array}{l} \beta_i = Y_i \\ \beta_{ij} = 4Y_{ij} - 2Y_i - 2Y_j \end{array}\right\} \quad \ldots\ldots (21)$$

The numbers mentioned above are utilised as the co-efficient for the second-degree polynomial with coordinates (5, 2) in Equation (9).

3. Optimization models validation

For validation and appropriateness check, models generated utilising Equation (11) were put via the Fisher test (F-test). The F-statistic is the variance ratio of the experimental value to the expected or model response value. With the intent to validate the models, the ensuing hypotheses were accepted:

Null Hypothesis: H_0 = there exist no substantial difference between the experimental and calculated responses.

Alternate Hypothesis: H_1= there is a substantial difference between the experimental and calculated responses.

The F-test may be expressed mathematically as Equation (22).

$$F = \frac{S_1^2}{S_2^2} \quad \ldots\ldots (22)$$

Where;

S_1^2 = Larger of both variances

S_2^2 = Smaller of both variance

S2 is calculated utilising the ensuing equation:

$$S^2 = \frac{1}{n-1}\left[\sum (Y - \bar{Y})^2\right] \quad \ldots\ldots (23)$$

Where:

$\bar{Y}$= Average mean of response, Y

Y = Mean of response

For the models to be considered sufficient, the F-values computed utilising Equation (22) must be smaller than the values reported in the F-distribution table.

RESULTS AND DISCUSSION

The results of the tests on constituent materials, fifteen (15) trial run of geopolymer concrete trial mixtures and fifteen (15) control mixes for flexural strength are presented and discussed in this section.

Table 4: Oxide composition text

Chemical properties Parameter	**Hardwood sawdust ash**		**Softwood sawdust ash**	
Chemical properties Parameter	**Sample 1 (with oxygen)**	**Sample 2 (without oxygen)**	**Sample 3 (with oxygen)**	**Sample 4 (without oxygen)**
CaO (%)	6.13	4.18	5.46	5.11
SiO2 (%)	69.84	71.02	66.79	72.57
Al2O3 (%)	3.78	4.32	4.81	5.16
Fe2O3 (%)	1.94	1.82	2.27	2.36
MgO (%)	3.20	3.47	4.10	4.43
Na_2O (%)	0.28	0.19	0.11	0.15
K2O (%)	2.95	3.11	2.88	3.28
Loss of Ignition	2.92	3.11	3.56	3.44

Table 5a: Specific Gravity of Sawdust ash

Bottle/Test Number		**1**	**2**
Weight of Bottle only(g)	M_1	28.0	26.5
Weight of Bottle and dry sample(g)	M_2	36.0	35.0
Weight of Bottle, sample and water(g)	M_3	82.0	80.0
Weight of Bottle and water(g)	M_4	78.0	78.0
$G_s = M_2 - M_1/(M_4 - M_1) - (M_3 - M_2)$		2.0	1.308
AVERAGE(Gs)		**1.654**	

Table 5b: Specific Gravity of Fine aggregate

Bottle/Test Number		**1**	**2**
Weight of Bottle only(g)	M_1	28.0	26.5
Weight of Bottle and dry sample(g)	M_2	64	64.5
Weight of Bottle, sample and water(g)	M_3	102	100
Weight of Bottle and water(g)	M_4	78.0	78.0
$G_s = M_2 - M_1/(M_4 - M_1) - (M_3 - M_2)$		3.0	2.375
AVERAGE(Gs)		**2.6875**	

Table 5c: Density of Sawdust ash

Volume of Mould		$2.2 * 10^{-4} m^3$	
TEST		**1**	**2**
Wt. of Specimen + Mould	gms	678.0	776.0
Wt. of Mould only	gms	444.0	444.0
Wt. of Specimen	gms	234.0	332.0
Density of Specimen	g/m^3	1.045	1.482
Average Density	g/m^3	1.2635	
Bulk Density	Kg/m^3	1.2635	
Unit Weight	KN/m^3	**12.609**	

Table 5d: Density of Fine aggregate

Volume of Mould		$2.2 * 10^{-4} m^3$	
TEST		**1**	**2**
Wt. of Specimen + Mould	gms	864.0	872.0
Wt. of Mould only	gms	444.0	444.0
Wt. of Specimen	gms	420.0	428.0
Density of Specimen	g/m^3	1.875	1.910
Average Density	g/m^3	1.8925	
Bulk Density	kg/m^3	1.8925	
Unit Weight	KN/m^3	**18.560**	

Table 4 presents the results of the oxide composition test carried out on the softwood and hardwood sawdust ash. From the results, softwood sawdust ash which when through pyrolysis presents better pozzolanic property and thus used for the laboratory investigation. XRD test carried out on the sawdust ash sample also supported our choice of softwood sawdust ash. Table 5a – 5d presents the specific gravity and density of sawdust ash and fine aggregate. The results shows that they are adequate for the test.

Table 6 is the presentation of the flexural strength results obtained from laboratory experiments using the trial mix design in Table 3. In the laboratory experiment, geopolymer binder fully replaced cement in the test. Fine and coarse aggregate were kept constant all through the test run. Other factors that were kept constant includes rest period and curing temperature. The samples were cured in the oven at 90°c for three days and was also allowed to age to 28 days before crushing.

Table 6: Flexural Resistance of Sawdust ash geopolymer concrete Experimental Result for Trial mixes at 28 days curing age

N	Pseudo constituent					Actual constituent					Response	
	X_1	X_2	X_3	X_4	X_5	Z_1 = NaOH conc. (M)	Z_2 = Na2SiO4/ NaOH	Z_3 = percent SDA in binder	Z_4 = water/binder	Z_5 = Activator/ SDA	Symbol	Flexural Strength (N/mm^2)
1	1	0	0	0	0	8	1.5	35	0	2.3	F_1	3.263
2	0	1	0	0	0	9.75	1.875	37.5	0.025	2.485	F_2	2.664
3	0	0	1	0	0	11.5	2.25	40	0.05	2.671	F_3	3.263
4	0	0	0	1	0	13.25	2.625	42.5	0.075	2.856	F_4	2.664
5	0	0	0	0	1	15	3	45	0.1	3.1	F_5	2.963
6	½	½	0	0	0	8.875	1.6875	36.25	0.0125	2.3925	F_{12}	2.963
7	½	0	½	0	0	9.75	1.875	37.5	0.025	2.4855	F_{13}	2.664
8	½	0	0	½	0	10.625	2.0625	38.75	0.0375	2.578	F_{14}	2.963
9	½	0	0	0	½	11.5	2.25	40	0.05	2.7	F_{15}	3.263
10	0	½	½	0	0	10.625	2.0625	38.75	0.0375	2.578	F_{23}	2.963
11	0	½	0	½	0	11.5	2.25	40	0.05	2.6705	F_{24}	3.263
12	0	½	0	0	½	12.375	2.4375	41.25	0.0625	2.7925	F_{25}	3.263
13	0	0	½	½	0	12.375	2.4375	41.25	0.0625	2.7635	F_{34}	3.263
14	0	0	½	0	½	13.25	2.625	42.5	0.075	2.8855	F_{35}	2.664
15	0	0	0	½	½	14.125	2.8125	43.75	0.0875	2.978	F_{45}	1.884

Modeling the Flexural Strength of sawdust ash Geopolymer Concrete

The geopolymer concrete Flexural test response result for model development (Trial mix) is given in Table 6. This table and Equation 11, was used in the development of the model coefficients of the Scheffe's (5, 2) optimization models for the flexural strength of sawdust ash geopolymer concrete

The optimization model for Schefe's (5,2) for the flexural resistance of sawdust ash blended geopolymer concrete is developed as thus;

$\beta_1 = F_1 = 3.263$
$\beta_2 = F_2 = 2.664$
$\beta_3 = F_3 = 3.263$
$\beta_4 = F_4 = 2.664$
$\beta_5 = F_5 = 2.963$

$$\beta_{12} = 4F_{12} - 2F - 2F_2 = 4(2.963) - 2(3.263) - 2(2.664) = -0.002$$
$$\beta_{13} = 4F_{13} - 2F_1 - 2F_3 = 4(2.664) - 2(3.263) - 2(3.263) = -2.396$$
$$\beta_{14} = 4F_{14} - 2F_1 - 2F_4 = 4(2.963) - 2(3.263) - 2(2.664) = -0.002$$
$$\beta_{15} = 4F_{15} - 2F_1 - 2F_5 = 4(3.263) - 2(3.263) - 2(2.963) = 0.600$$
$$\beta_{23} = 4F_{23} - 2F_2 - 2Y = 4(2.963) - 2(2.664) - 2(3.263) = -0.002$$
$$\beta_{24} = 4F_{24} - 2F_2 - 2F_4 = 4(3.263) - 2(2.664) - 2(2.664) = 2.396$$
$$\beta_{25} = 4F_{25} - 2F_2 - 2F_5 = 4(3.263) - 2(2.664) - 2(2.963) = 1.798$$
$$\beta_{34} = 4F_{34} - 2F_3 - 2F_4 = 4(3.263) - 2(3.263) - 2(2.664) = 1.198$$
$$\beta_{35} = 4F_{35} - 2F_3 - 2F_5 = 4(2.664) - 2(3.263) - 2(2.963) = -1.798$$
$$\beta_{45} = 4F_{45} - 2F_4 - 2F_5 = 4(1.884) - 2(2.664) - 2(2.963) = -3.718$$

Equation (3.20) allows one to substitute the aforementioned co-efficient values for forecasting the flexural resistance of sawdust ash concrete that are geopolymers by means of optimisation model.

$$F = 3.263x_1 + 2.664x_2 + 3.263x_3 + 2.664x_4 + 2.963x_5 - 0.002x_1x_2 - 2.396x_1x_3 - 0.002x_1x_4 + 0.600x_1x_5 - 0.002x_2x_3 + 2.396x_2x_4 + 1.798x_2x_5 + 1.198x_3x_4 - 1.798x_3x_5 - 3.718x_4x_5 \quad \text{..... (24)}$$

Equation (24) expresses the (5, 2) optimisation model for estimating the flexural resistance of sawdust ash blended geopolymer concrete. This model can thus be utilised in predicting the flexural resistance of sawdust

ash concrete for any desired value within the range of values of the flexural strength in the trial mix.

With the use of matlab code, developed for this research work, the modified pseudo coefficients, x_1 to x_5 below, was obtained. These values can also be obtained using excel solver.

X_1	X_2	X_3	X_4	X_5	$\sum x$
0.75	0	0	0	0.25	1

Substituting the optimal pseudo coefficients into equation 24, the optimum flexural strength for the sawdust ash based geopolymer concrete becomes;

$F_{op} = 3.3002$

Applying the modified pseudo co-efficient, the optimized mix design for sawdust ash blended geopolymer concrete is given in Table 7 below;

Table 7: Flexural Strength Optimum mix design for sawdust ash based geopolymer concrete

Pseudo constituent					**Actual constituent**					**Optimum Flexural resistance (N/mm^2)**
X_1	X_2	X_3	X_4	X_5	Z_1 = NaOH conc. (M)	Z_2 = Na2SiO4/ NaOH	Z_3 = percent SDA in binder	Z_4 = water/ binder	Z_5 = Activator/ SDA	
0.75	0	0	0	0.25	9.7500	1.8750	37.5	0.0250	2.5000	3.3002

Validation and verification of optimization model

Adequacy tests utilising the F-statistics and verification tests utilising R^2 statistics were conducted on optimisation models constructed in the preceding section. This part of study made utilisation of the flexural resistance laboratory response values for the control mix design matrix in Table 2. Table 8 below offers the response flexural resistance of the control mix experimental results. The average Flexural resistance values in Table 8 is compared with the predicted values in Table 9. The predicted values are calculated by substituting the pseudo matrix for control in Table 2 in the optimization model already developed (Equation 24). Figure 2 is the graphical representation (R^2 statistics) of the predicted values and the control mix values compared in Table 9 and thus used to determine the R^2 value. And finally, Table 10 represents F-statistics validation and used to calculate the variances of the experimental value and predicted value.

Table 8: Control mix Flexural Resistance Experimental Results at 28 days curing age

N	**Pseudo constituent**					**Actual constituent**					**Response symbol**	**Flex. Resistance (N/mm^2)**		**Average Flexural resistance (N/mm^2)**
	X_1	X_2	X_3	X_4	X_5	Z_1 = NaOH conc. (M)	Z_2 = Na2SiO4/ NaOH	Z_3 = percent SDA in binder	Z_4 = water/binder	Z_5 = Activator/ SDA		Sample 1	Sample 2	
1	1/3	1/3	1/3	0	0	9.75	1.88	37.50	0.03	2.49	Y_1	2.848	3.021	2.934
2	1/3	1/3	0	1/3	0	10.33	2.00	38.33	0.03	2.55	Y_2	3.263	3.104	3.183
3	1/3	0	1/3	1/3	0	10.92	2.13	39.17	0.04	2.61	Y_3	3.021	3.021	3.021
4	1/3	1/3	0	0	1/3	10.92	2.13	39.17	0.04	2.63	Y_4	3.184	3.340	3.262
5	¼	¼	¼	¼	0	10.63	2.06	38.75	0.04	2.58	Y_5	3.021	3.184	3.102
6	¼	¼	¼	0	¼	11.06	2.16	39.38	0.04	2.64	Y_{12}	2.848	3.104	2.976
7	¼	¼	0	¼	¼	11.50	2.25	40.00	0.05	2.69	Y_{13}	3.184	3.021	3.102
8	0	¼	¼	¼	¼	12.38	2.44	41.25	0.06	2.78	Y_{14}	2.848	3.062	2.955
9	3/10	1/10	1/5	1/5	1/5	11.33	2.21	39.75	0.05	2.66	Y_{15}	2.848	3.062	2.955
10	1/5	1/5	1/10	3/10	1/5	11.68	2.29	40.25	0.05	2.70	Y_{23}	2.936	3.104	3.020
11	1/5	1/5	1/5	3/10	1/10	11.33	2.21	39.75	0.05	2.66	Y_{24}	3.021	3.104	3.062
12	1/5	1/5	1/5	1/5	1/5	11.50	2.25	40.00	0.05	2.68	Y_{25}	3.062	2.848	2.955
13	3/20	¼	1/5	1/5	1/5	11.59	2.27	40.13	0.05	2.69	Y_{34}	3.104	3.021	3.062
14	1/5	1/5	3/20	¼	1/5	11.59	2.27	40.13	0.05	2.69	Y_{35}	3.021	3.021	3.021
15	¼	1/5	1/5	1/5	3/20	11.15	2.18	39.50	0.05	2.64	Y_{45}	2.936	3.104	3.020

Table 9: Comparison of Predicted Flexural resistance values with the Experimental values

N	Pseudo constituent					Actual constituent					Response symbol	Flexural Resistance (N/mm^2)	
	X_1	X_2	X_3	X_4	X_5	Z_1 = NaOH conc. (M)	Z_2 = Na2SiO4/ NaOH	Z_3 = percent SDA in binder	Z_4 = water/binder	Z_5 = Activator/ SDA		Experiment Result	Predicted value
1	1/3	1/3	1/3	0	0	9.75	1.88	37.50	0.03	2.49	Y_1	2.934	2.797
2	1/3	1/3	0	1/3	0	10.33	2.00	38.33	0.03	2.55	Y_2	3.183	3.130
3	1/3	0	1/3	1/3	0	10.92	2.13	39.17	0.04	2.61	Y_3	3.021	2.930
4	1/3	1/3	0	0	1/3	10.92	2.13	39.17	0.04	2.63	Y_4	3.262	3.230
5	¼	¼	¼	¼	0	10.63	2.06	38.75	0.04	2.58	Y_5	3.102	3.038
6	¼	¼	¼	0	¼	11.06	2.16	39.38	0.04	2.64	Y_{12}	2.976	2.926
7	¼	¼	0	¼	¼	11.50	2.25	40.00	0.05	2.69	Y_{13}	3.102	2.955
8	0	¼	¼	¼	¼	12.38	2.44	41.25	0.06	2.78	Y_{14}	2.955	2.881
9	3/10	1/10	1/5	1/5	1/5	11.33	2.21	39.75	0.05	2.66	Y_{15}	2.955	2.827
10	1/5	1/5	1/10	3/10	1/5	11.68	2.29	40.25	0.05	2.70	Y_{23}	3.020	2.872
11	1/5	1/5	1/5	3/10	1/10	11.33	2.21	39.75	0.05	2.66	Y_{24}	3.062	2.954
12	1/5	1/5	1/5	1/5	1/5	11.50	2.25	40.00	0.05	2.68	Y_{25}	2.955	2.886
13	3/20	¼	1/5	1/5	1/5	11.59	2.27	40.13	0.05	2.69	Y_{34}	3.062	2.916
14	1/5	1/5	3/20	¼	1/5	11.59	2.27	40.13	0.05	2.69	Y_{35}	3.021	2.882
15	¼	1/5	1/5	1/5	3/20	11.15	2.18	39.50	0.05	2.64	Y_{45}	3.020	2.913

Where; X_1, Z_1= pseudo and actual constituent of NaOH concentration; X2, Z2 = pseudo and actual constituent of Na2SiO4/NaOH ratio; X3, Z3 = pseudo and Actual constituent of percent of SDA in binder; X4, Z4 = pseudo and actual constituent of water/binder ratio; X5, Z5 = pseudo and actual constituent of Activator/SDA Ratio

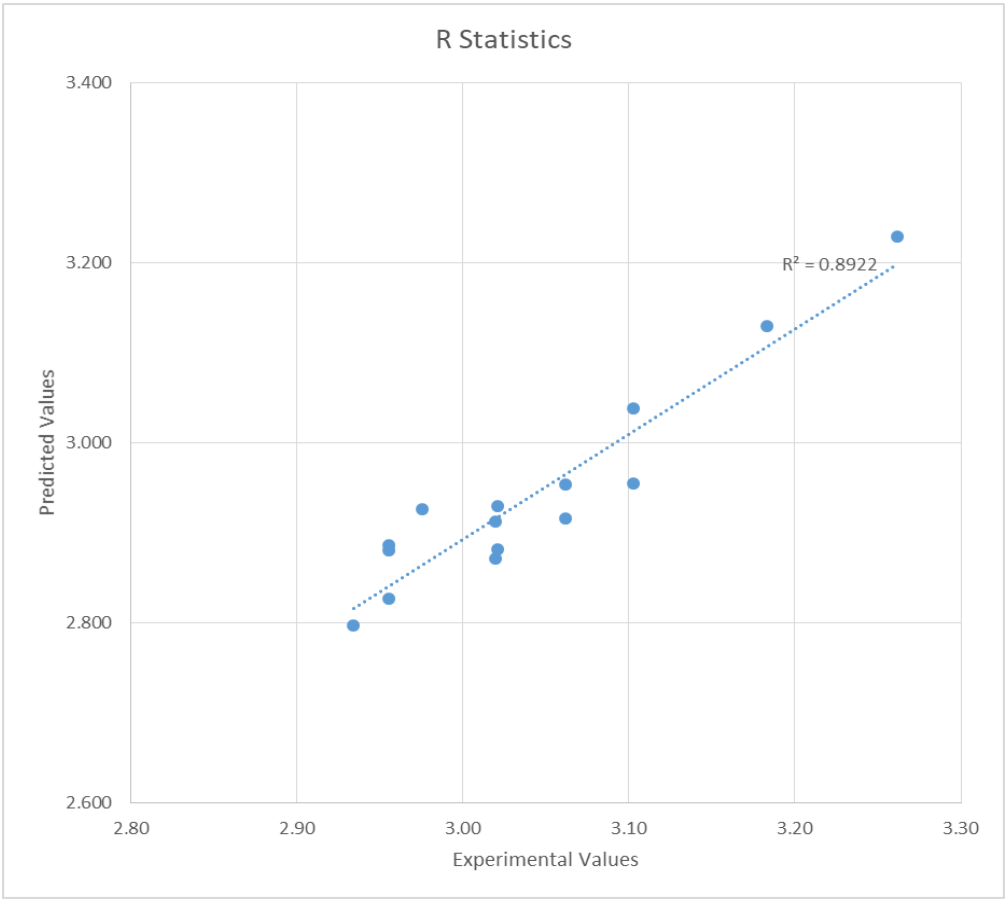

Figure 2: R^2 Statistics of sawdust ash blended geopolymer concrete Flexural resistance model

Table 10: F-Statistics for Validation of Sawdust Ash concrete that are geopolymers Flexural Resistance Optimization Model

Experiment Value = Y_e	Pred. value = Y_m	Y_e-$\hat{Y}_e$	Y^m-$\hat{Y}^m$	$(Y_e$-$\hat{Y}_e)^2$	$(Y^m$-$\hat{Y}^m)^2$
2.9344	2.7971	-0.1076	-0.1454	0.0116	0.0211
3.1832	3.1297	0.1412	0.1872	0.0199	0.0351
3.0208	2.9302	-0.0212	-0.0123	0.0005	0.0002
3.2619	3.2295	0.2199	0.2870	0.0483	0.0824
3.1025	3.0383	0.0605	0.0958	0.0037	0.0092
2.9758	2.9260	-0.0662	-0.0165	0.0044	0.0003
3.1025	2.9555	0.0605	0.0130	0.0037	0.0002
2.9552	2.8806	-0.0868	-0.0619	0.0075	0.0038
2.9552	2.8266	-0.0868	-0.1159	0.0075	0.0134
3.0196	2.8720	-0.0224	-0.0705	0.0005	0.0050
3.0621	2.9536	0.0201	0.0111	0.0004	0.0001
2.9552	2.8865	-0.0868	-0.0560	0.0075	0.0031
3.0621	2.9164	0.0201	-0.0261	0.0004	0.0007
3.0208	2.8822	-0.0212	-0.0603	0.0005	0.0036
3.0196	2.9132	-0.0224	-0.0293	0.0005	0.0009
$\hat{Y}_e$ = 3.0420	$\hat{Y}^m$ =2.9425			∑= 0.1169	∑= 0.1790

With the aid of Table 10 and Equation (23) the following was deduced:

$S_e^2 = {}^{0.1169}/_{14} = 0.0083$

$S_m^2 = {}^{0.1790}/_{14} = 0.0128$

The F-value which is the ratio of the two squared variances was computed using Equation (22) as;

$F = {}^{0.0128}/_{0.0083} = 1.5319$

Because F-cal (1.5319) is less than F-tab (2.4986), the null hypothesis is accepted and the model is considered adequate.

Furthermore, the R^2 statistics displayed in Figure 4.5 below revealed an R^2 value of 89.22%. This indicates that over 89% of the data set is explained by the optimization model.

CONCLUSIONS

Based on the experimental work reported in this study, the following conclusions were drawn:

1. Sawdust ash show to be a better pozzolanic material when it undergoes pyrolysis in the absence of oxygen than when it was burnt in the presence of oxygen.
2. Softwood sawdust are better pozzolanic material compared to hardwood sawdust.
3. The mathematical formulation that predicts the flexural resistance of the sawdust ash derived concrete that are geopolymers is $F = 3.263x_1 + 2.664x_2 + 3.263x_3 + 2.664x_4 + 2.963x_5 - 0.002x_1x_2 - 2.396x_1x_3 - 0.002x_1x_4 + 0.600x_1x_5 - 0.002x_2x_3 + 2.396x_2x_4 + 1.798x_2x_5 + 1.198x_3x_4 - 1.798x_3x_5 - 3.718x_4x_5$.
4. The fresh sawdust ash-based geopolymer concrete is easily handled up to 120 minutes without any sign of setting and without any degradation in the flexural strength.
5. As the H_2O-to-Na_2O molar ratio increases, the flexural strength of sawdust ash-based geopolymer concrete decreases.
6. As the ratio of water-to-geopolymer solids by mass increases, the flexural strength of sawdust ash-based geopolymer concrete decreases.
7. The effect of the Na2O-to-Si2O molar ratio on the flexural strength of sawdust ash-based geopolymer concrete is not significant.
8. The flexural strength of heat-cured sawdust ash-based geopolymer concrete does not depend on age.
9. Prolonged mixing time of up to sixteen minutes increases the flexural strength of sawdust ash-based geopolymer concrete.
10. The average density of sawdust ash-based geopolymer concrete is similar to OPC concrete.

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