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OPTIMIZATION OF CONCRETE CONTAINING SAWDUST ASH USING CENTRAL COMPOSITE DESIGN

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ABSTRACT

Concrete admixed with materials with pozzolanic properties helps to reduce micro cracks which is the major problem faced by conventional concrete. Incorporating sawdust ash in concrete helps to produce sustainable and cost effective concrete structures. This investigation focused on partial replacement of cement with sawdust ash in concrete. The physical and chemical properties of sawdust used were extensively explored and characterised. The performance of concrete mixtures was assessed in terms of workability, tensile strength, flexural strength, water absorption. The durability of admixed concrete in acidic and sulphate environment was also assessed. Optimization was carried out using central composite design to generate optimal value and model equations for the responses. The preliminary study showed that sawdust ash had enough silica content which can help in strength development of concrete at later ages. The consistency of cement was 29% and increased with increasing sawdust ash content. From the results of numerical optimization, the optimum tensile strength of 2.69N/mm^2, flexural strength of 7.69 N/mm^2 and water absorption of 1.33% were obtained at 10% SDA content and 56 days curing. It was evident that sawdust ash concrete absorbs more water compared to control specimens and also the strength of SDA concretes immersed in sulphate and acidic solutions have 50%$MgSO_4$, 90%HNO_3 23%Na_2SO_4 lower compressive strengths than the control cubes immersed in water only. The research recommends that research should be carried out to evaluate the effects of more supplementary locally available materials in binary and ternary mixture with SDA.

KEYWORDS: *Optimization, Sawdust Ash, Concrete, Central Composite Design, Flexural Strength*

1.INTRODUCTION

Concrete is one of the most commonly used materials for building construction in the world. In order to produce concrete that is more attractive and less cost implicative, attentions have turned to the use of pozzolanic materials for concrete production [1-3]. The alarming increase in cost of building materials for which cement is in the frontline also triggers the need to bring out alternative materials that can serve as binder in concrete. Increase in depletion of natural resources (such as limestone) has also triggered the need to search for alternative. Another problem associated with cement is the enormous amount of energy that its production requires exorbitant cost of cement, its production requires huge capital which is expensive to attain and maintain. Wood industries produce a lot of dirt and desecrate materials. The wastes from the wood industries are being disposed to surroundings which cause health vulnerability [3]. The main issue in the development of materials can only be achieved through the provision of alternative, cheap and affordable materials, Furthermore, the mineral admixtures have the capacity to enhance particle packing and reduce concrete's permeability. Most researchers minimized cost of construction materials by converting waste sawdust to useful construction material [3,4]. Many researchers have particularly found sawdust ash as suitable for use in producing blended cements with portland cement [5-7]. Saw dust ash is pozzolanic in nature, it reacts with the hydration product of cement $Ca(OH)_2$ to produce C-S-H which improve strength in concrete [8].

The results obtained from the investigation of the use of saw dust ash as an inhibitor for reinforcement corrosion in concrete showed that it is very effective and can be used to control corrosion. Addition of SDA to concrete can be effective in the control of corrosion.

2.METHODOLOGY

2.1 Concrete Production

The materials used were Portland cement, sawdust ash, superplasticizer, fine aggregates, coarse aggregates and water. A mix proportion of 1:1.92:2.88 was used with water cement ratio of 0.5. The concrete was designed based on minimum strength of 20N/mm^2 at 28days of curing in accordance with Design of Experiment (DOE) method. Central composite design (CCD) of response surface methodology was adopted in the design of experimental combinations. It was also used to show the relationship between the controllable input parameters and the obtained response surfaces. Sawdust ash replaced cement from 10% to 30% at increment of 10% at 3 days, 28 days and 56 days. The relative quantity of each ingredient used was determined based on the concrete mix design. Materials were mixed at different proportions. Proper mixing was done to ensure that the concrete mass becomes homogeneous, uniform in colour and consistency motorized concrete mixer was used in mixing the concrete. Concrete cube of 100mm were produced. Before casting of concretes, the surfaces of the moulds were oiled for easy removal of hardened concrete. Compaction was done to expel entrapped air. Curing by immersion in water was done till the testing days (3, 28 and 56 days).

2.2 Workability of concrete

Workability is one of the physical parameter of concrete which affects the strength, durability and the appearance of the finished surface. The workability depends on the water cement ratio and the water absorption capacity of the aggregates. The test was carried out in accordance with British Standard [9]. The equipment or the slump test consists of a tamping rod and a truncated cone, 300 mm height and 100 mm diameter at the top and 200 mm diameter at the bottom. The base of 200 mm diameter is placed on a smooth surface with the smaller opening of 100 mm diameter at the top, and the container is filled with concrete in three layers. Each layer is tamped 25 times with a standard 16 mm diameter steel rod, rounded at the end, and the top surface is struck off by means of a screeding and rolling motion of the tamping rod. Immediately after filling, the cone is slowly lifted, and the unsupported concrete slumps down by its own weight. The decrease in the height of the centre of the slumped concrete is called slump, and is measured to the nearest 5mm.

2.3 Tests on Hardened Concrete

The tests conducted on hardened concrete includes:

1. Flexural Strength:

Flexural strength test was carried out on the hardened concrete beam of size 100mm x 100mm x 500mm and was conducted in accordance with British Standard [10].

$$F = PL/bd^2 \quad \ldots (1)$$

2. Split Tensile Strength:

Tensile strength is the maximum stress that a material can withstand while being stretched or pulled before breaking. In brittle materials the ultimate tensile strength is close to the yield point, whereas in ductile materials the ultimate tensile strength can be higher. The ultimate tensile strength is usually found by performing a tensile test according to BS specification [11]. The highest point of the stress–strain curve is the ultimate tensile strength and has units of stress. Split tensile strength is determined using equation 2.

$$SPT = \frac{2P}{\pi DL} \quad \ldots (2)$$

3. RESULTS AND DISCUSSIONS

3.1 Characterization of Materials

Test were conducted to check both the physical and chemical properties of cement and sawdust ash used for the experimental investigation.

Table 2: Oxide Composition of Portland cement.

S/N	Oxide composition	% oxide composition
1	CaO	63.70
2	SiO_2	19.90
3	AlO_3	5.60
4	FeO_3	2.90
5	SO_3	2.30
6	MgO	1.50
7	Na_2O	0.21
8	K_2O	0.71

Table 2 shows the composition of the Portland cement used for the study. It had 63.7% of calcium oxide, 19.9% of silica oxide and 5.6% of alumina oxide. The minor oxides are magnesium oxide, sodium oxide and potassium oxide with oxide compositions of 1.5%, 0.21% and 0.71% respectively. Table 3 shows the specific gravity properties of sawdust ash.

Table 3: Physical Properties of Sawdust ash

S/N	Property	Value
1	Specific Gravity	2.29
2	Loose bulk density	$31kg/m^3$
3	Loss of ignition	3.95%
4	Moisture content	2.3%
5	PH value	7.10

Table 4: Chemical Composition of SDA

S/N	Chemical composition	Percentage oxide composition
1	CaO	9.90
2	SiO_2	63.42
3	AlO_3	4.11
4	FeO_3	2.26
5	MgO	5.80
6	NaO	0.04
7	K_2O	11.67

Table 4 shows the results of physical properties of sawdust ash. It had specific gravity of 2.29 and moisture content of 2.3%. The respective percentage contents of the major oxides of SDA were SiO_2 as 63.4%, Al_2O_3 as 4.11, Fe_2O_3 as 2.26% and CaO as 9.9% whereas the percentage contents of the alkalis (Na_2O and K_2O) were 0.04% and 11.67 %. This shows that saw dust ash used had enough silica content which enhance better strength development of the concrete at a latter days.

3.2 Paste Characteristics

Table 5: Consistency and Setting time result

Mix (%SDA)	S.P Conplast Dosage (ml)	Consistency (%)	Initial (min)	Final (min)
Control	5.7	29	438	572
ST-10	5.7	31	133	252
ST-20	5.7	34	121	234
ST-30	5.7	36	115	218
ST-40	5.7	37	103	202

Table 5 shows the initial and final setting time of saw dust ash/cement paste. The setting time of the cement paste was higher than the values of blended cement with SDA. The initial and final setting time of cement paste was 438 mins and 572 mins respectively. The percentage replacement of cement with SDA causes a decrease in both initial and final setting time of paste. The consistency of cement was 29% and increased with increasing SDA content. At 10, 20, 30, and 40% cement replaced with SDA, the values were 31, 34, 36, and 37%. The results stated that cement consistency is less than that of cement with SDA. The higher the replacement level, the higher the consistency value. The findings of this study are also in accordance with Ayuba [12] which reported that addition of SDA in cement increased consistency.

3.3 Slump test result

Table 6: Slump Test Result

(%SDA)	Conplast (mL)	Slump (mm)
SL-00	5.7	130
SL-10	5.7	120
SL-20	5.7	115
SL-30	5.7	110
SL-40	5.7	100

The results of the slump test carried out on the fresh concrete with varying percentage of SDA as cement replacement are presented in Table 6. The result shows that the slump decrease with increase in the amount of SDA. This indicates that more water is required to maintain consistency as SDA content increases. This implies that SDA concrete absorbs more water than Portland limestone cement in concrete. Onyechere [13] recorded similar result.

3.4 Flexural Strength

Table 7: Flexural Strength Response

Run	Factor 1 A:SDA %	Factor 2 B:Curing Age Days	Flexural strength N/mm^2
Control	0	56	8.19
1	10	3	6.72
2	20	28	7.03
3	10	56	7.67
4	20	28	7.03
5	20	3	6.46
6	20	28	7.03
7	20	28	7.03
8	20	56	7.46
9	30	56	5.79
10	30	3	4.90
11	20	28	7.03
12	10	28	7.36
13	30	28	5.61

Table 8: ANOVA for Flexural Strength

Source	Sum of Squares	Df	Mean Square	F-value	P-value
Model	7.80	5	1.56	561.75	< 0.0001
A-SDA	4.95	1	4.95	1783.25	< 0.0001
B-C.A	1.35	1	1.35	487.59	< 0.0001
A²	1.04	1	1.04	373.30	< 0.0001
B²	0.08	1	0.079	28.53	0.0011
Residual	0.019	7	0.003		
Lack of Fit	0.019	3	0.007		
Pure Error	0.000	4	0.000		
Cor Total	7.82	12			

The early strength results of flexural strength showed concrete with low strength development as shown in table 7. At latter ages (28 and 56) days, SDA addition increased the strength of concrete possibly due to pozzolanic reaction as more calcium hydroxide is being removed from the system and accelerates the Portland Cement (OPC) hydration. The control shows higher flexural strength compared to concrete made with sawdust ash. This result is in agreement with previous findings [14] and [15].

The analysis of variance of the quadratic model in Table 8 shows F-value of 561.75 which implies the model is significant. The 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 R^2 is 0.9975 and the Predicted R^2 of 0.9797 is in reasonable agreement with the Adjusted R^2 of 0.9957; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio of 77.3 indicates an adequate signal. This model can be used to navigate the design space. The model equation for the flexural strength is given below.

$$\text{Flexural Strength} = 5.67 + 0.156 * SDA + 0.0334 * CA + -6.01e - 05 * SDA\,(CA) + -0.0061 * (SDA)^2 + -0.0002 * (CA)^2 \quad \ldots (3)$$

Table 9: Showing Actual and Predicted Values for Flexural Strength

Run Order	Actual Value	Predicted Value
1	6.45	6.43
2	7.03	7.05
3	7.46	7.38
4	4.90	4.93
5	7.03	7.05
6	7.36	7.34
7	7.67	7.69
8	6.72	6.71
9	7.03	7.05
10	7.03	7.05
11	5.61	5.53
12	5.79	5.84
13	7.03	7.05

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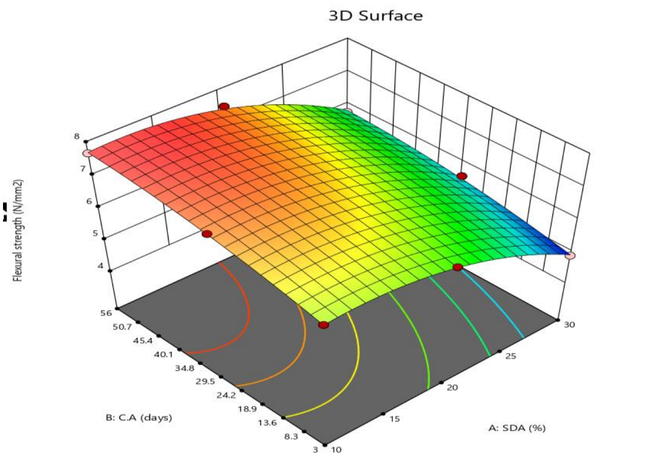

Figure 1: 3D Surface for Flexural Strength, Saw Dust Ash and Curing Age.

Figure 1 shows the 3D response surface graph of interactions between SDA and CA and the influence on flexural strength of concrete. The 3-D surface elucidates the correlation between the dependent variables (responses) and the independent variables (factors). The graph shows that increase in SDA causes decrease in flexural strength while increase in C.A causes increase in flexural strength. They are all in agreement with [14] and [15].

3.5 Split Tensile Strength Result

Table 10: Split Tensile Strength Result

Run	Factor 1 A:SDA %	Factor 2 B:Curing days	Response 2 Tensile strength N/mm^2
Control	0	56	2.77
1	10	3	1.74
2	20	28	2.11
3	10	56	2.62
4	20	28	2.11
5	20	3	1.59
6	20	28	2.11
7	20	28	2.11
8	20	56	2.55
9	30	56	2.48
10	30	3	1.53
11	20	28	2.11
12	10	28	2.17
13	30	28	2.10

Table 11: ANOVA for Tensile strength

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1.33	5	0.2665	415.53	< 0.0001
A-SDA	0.0291	1	0.0291	45.40	0.0003
B-C.A	1.30	1	1.30	2022.49	< 0.0001
B^2	0.0126	1	0.0126	19.60	0.0031
Residual	0.0045	7	0.0006		
Lack of Fit	0.0045	3	0.0015		
Pure Error	0.0000	4	0.0000		
Cor Total	1.34	12			

Table 10 shows the split tensile strength properties of sawdust ash admixed concrete and the control specimen without SDA. All percentage replacements show lower tensile strength properties compared to control specimen.

The ANOVA in table 11 shows that Model F-value of 415.53 indicates the model is significant. The P-values less than 0.05 indicate model terms are significant. In this case A, B, B^2 are significant model terms. The R^2 is 0.9966, the Predicted R^2 of 0.9658 is in reasonable agreement with the Adjusted R^2 of 0.9942; 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 62.150 indicates an adequate signal meaning the model can be used to navigate the design space. The model equation of Tensile strength is given in equation 4.

$$\text{Tensile strength} = 1.807 - 0.018 * SDA + 0.022 * C.A + 6.223e-05 * SDA(C.A) + 0.00024 * (SDA)^2 - 9.64681e-05 * (C.A)^2. \quad \ldots(4)$$

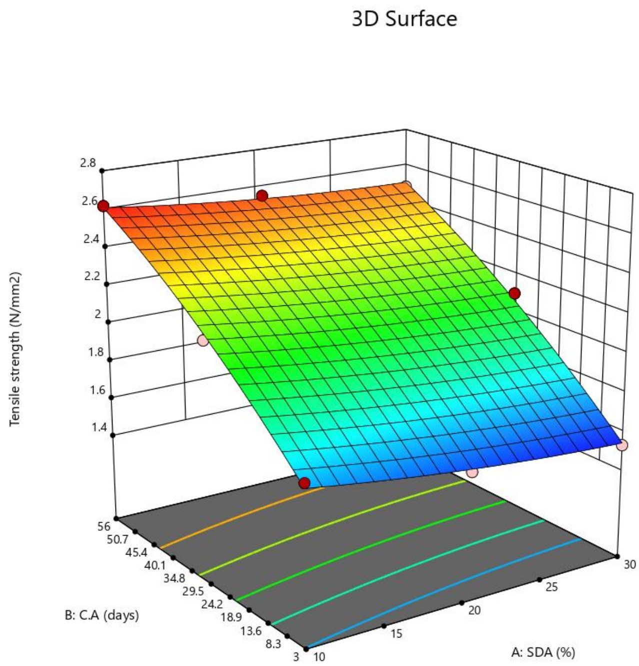

Figure 2: 3D Surface for Tensile Strength, Saw Dust Ash and Curing Age

Figure 2 shows 3D response surface graph of interactions between SDA and CA and the influence on tensile strength of M20 concrete. The 3-D surface elucidates the correlation between the dependent variables (responses) and the independent variables (factors). The graph shows that increase in SDA causes a decrease in tensile strength and increase in curing age causes increase in tensile strength.

3.6 Water Absorption

Table 12: Water Absorption Response

Run	Factor 1	Factor 2	Response 3
	A:SDA %	B:Curing Age Days	Water absorption %
Control	0	56	1.38
1	10	3	1.01
2	20	28	1.46
3	10	56	1.31
4	20	28	1.46
5	20	3	1.21
6	20	28	1.46
7	20	28	1.46
8	20	56	1.60
9	30	56	1.92
10	30	3	1.37
11	20	28	1.46
12	10	28	1.35
13	30	28	1.72

Table 13: ANOVA for Water Absorption

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.5953	5	0.1191	98.87	< 0.0001
A-SDA	0.3023	1	0.3023	251.07	< 0.0001
B-Curing	0.2563	1	0.2563	212.82	< 0.0001
Age	0.0162	1	0.0162	13.42	0.0080
AB	0.0299	1	0.0299	24.83	0.0016
B^2	0.0084	7	0.0012		
Residual	0.0084	3	0.0028		
Lack of Fit	0.0000	4	0.0000		
Pure Error					
Cor Total	0.6037	12			

Analysis of variance is shown in table 13. The Model F-value of 98.87 implies the model is significant. P-values less than 0.05 indicate model terms are significant. In this case A, B, AB, B^2 are significant model terms. The R^2 is 0.9860. The Predicted R^2 of 0.8831 is in reasonable agreement with the Adjusted R^2 of 0.9761; 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 36.582 indicates an adequate signal. This model can be used to navigate the design space. The model for water absorption is given in equation 5.

$$\text{Water Absorption} = 0.966 + 0.0003 * SDA + 0.012 * C.A + 0.00024 * SDA\,(C.A) + 0.0004 * (SDA)^2 + -0.000148731 * (C.A)^2 \quad \ldots (5)$$

Table 14: Actual and Predicted Value for Water Absorption

Run Order	Actual Value	Predicted Value
1	1.01	1.05
2	1.46	1.47
3	1.31	1.33
4	1.46	1.47
5	1.21	1.17
6	1.46	1.47
7	1.46	1.47
8	1.60	1.58
9	1.92	1.91
10	1.37	1.37
11	1.46	1.47
12	1.35	1.29
13	1.72	1.73

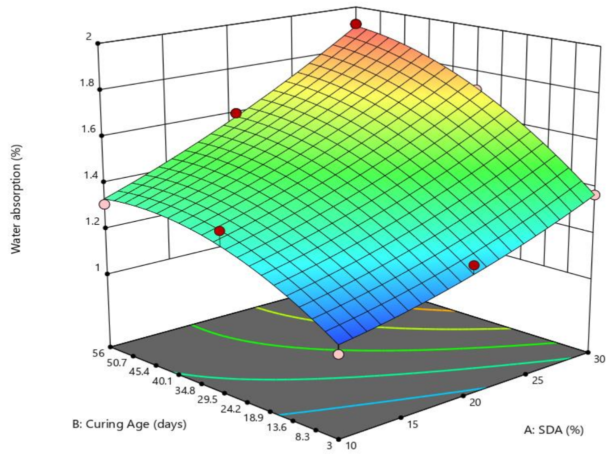

Figure 3: 3D Surface Graph for SDA, C.A and Water Absorption.

Figure 3 shows 3D response surface graph of interactions between sawdust ash and curing age and the influence on water absorption. The 3-D surface elucidates the correlation between the dependent variables (responses) and the independent variables (factors). The graph shows that increase in SDA causes an increase in rate of water absorption. The result is in agreement with [16]

3.7 Numerical Optimization of SDA-Concrete Mixtures.

Many researchers have used numerical optimization by response surface methodology for the optimization of admixed concrete to generate optima values and modelling of concrete engineering properties [17], [18], [19] and [20]. The goals set for each response are presented in Table 15

Table 15: Goals Used for Numerical Optimization of SDA-Concrete.

Name	Goal	Lower Limit	Upper Limit
A: SDA	is in range	10	30
B: Curing age	is in range	3	56
Flexural strength	maximize	4.9	7.67
Tensile strength	maximize	1.53	2.62
Water Absorption	minimize	1.01	1.92

The automatic optimization function of Design-Expert software version 13 indicates that the optimal values of the factors for highest concrete strength for SDA Concrete are presented in figure 4.

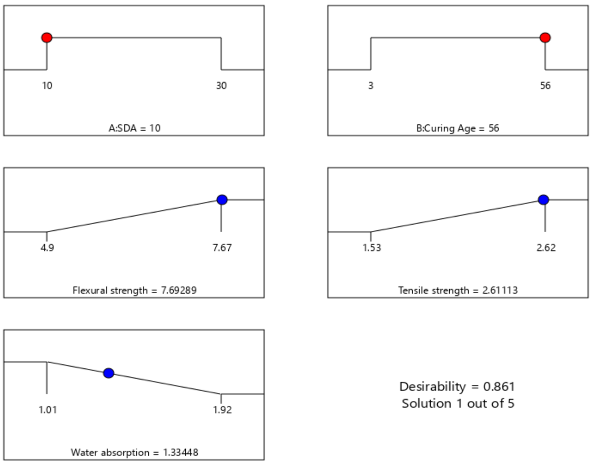

Figure 4: Ramp plot showing the optimal values for responses

4.CONCLUSION

This investigation focused on the use of sawdust ash in the production of concrete. Optimization of concrete containing sawdust ash by CCD was studied and based on the findings, the following conclusions were made:

The consistency of cement was 29% and increased with increasing SDA content. At 10, 20, 30, and 40% cement replaced with SDA, the values were 31, 34, 36, and 37%. The results stated that cement consistency is less than that of cement with SDA.

The numerical optimization function of Design-Expert software version 13 indicated the optimal value of 10% SDA in replacement of cement and cured for 56 days. After validation, 10% SDA generated tensile strength value of 2.62N/mm^2, flexural strength of 6.79 N/mm^2, and water absorption of 1.31 %. The strength properties were increased up to 12% compared to the control. It was also evident that SDA concrete absorbs more water compared to the control specimen.

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