Five Component Concrete Mix Optimization of Aluminum Waste Using Scheffe's Theory

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ABSTRACT

The research investigated some mechanical properties of Aluminum Waste concrete to Harness its structural properties in the construction industry. Aluminum Waste which was obtained from Aluminum Extrusion Industry (ALEX) Inyishi in Ikeduru Local Government Area of Imo Sate, Nigeria was investigated. The work extended Scheffe's optimization techniques from fourth to fifth dimensions and obtained mathematical models for the optimization of the compressive and flexural strength of a five component concrete mix. A software for the Optimization of the mechanical properties of Aluminum Waste Concrete was developed. Seheffe's experimental design techniques was followed to produce concrete with different ingredient components which were used to cast cube and beam samples.

The cubes and beams have dimensions of 150mmx150mmx150mm and 100mmx100mmx500mm respectively. The samples were tested for 28 days hydration period. The developed software gave an optimum mix ratio of 1:1.1:1.75:1.15:0.7 (Cement, Fine Aggregate, Coarse Aggregate, Aluminum Waste, Water) which generated a compressive strength of 29.81N/mm^2, an increase of 14.35% in compressive strength over a standard mix. The result represented a saving of 16% by volume of concrete and a reduction of four thousand naira per cubic meter of concrete when compared with the standard mix. The software for the optimum mix ratio for flexural strength gave a value of 11.72N/mm^2. There was as increase in flexural strength of 9.46% of the standard mix. The research concludes that aluminum waste concrete is economical and produces high compressive and flexural strength and can be used in structural members such as beams and columns where high compressive strength concrete is needed.

KEYWORDS: compressive strength, flexural strength, scheffe's model, aluminum waste.

I. INTRODUCTION

Shelter is a serious problem in developing countries like Nigeria. As a result majority of the people in Nigeria especially those occupying the riverine areas are living in substandard house [1]. The major factor militating against the provision of affordable houses in Nigeria is high cost of ms.academicjournals.org/ building materials.

The materials commonly used in concrete construction industry include Water, Cement, Sand and Granite[2]. Water is always available in its natural state as Rainwater, River water, Fresh sea water and Borehole water. Sand is also available in its Natural state as River sand, Sea sand, Erosion sand and Desert dunes (sand from the desert). Cement and granite are not commonly available in their natural states. They are processed materials. In most cases the point of use is different from point of manufacture. According to [3], concrete is any product or mass made by the use of any cementing medium. Aggregates are defined as particles of rock which, when brought together in a bound or unbound conditions form part or whole of an engineering or building structure [4].

Concrete has been classified into two broad classes: Plan and reinforced [5].

Generally concrete is good in compression and poor in tension [6]. Modern research in concrete seeks to provide greater understanding of its constituent materials and possibilities of improving its desired qualities. For instance, cement has partially replaced with fuel ash [7]. The trend of cost of concrete products has led many researchers to go into the search for alternative and affordable materials for use in concrete. It is in the spirit of the search for alternative and affordable materials for concrete that this research work tried to see the applicability of aluminum waste in concrete production.

II. MATERIALS AND METHODS

Simplex design formulation: The relation between the actual components and pseudo components is according to [8].

Z = AX ______________________ (1)

Z and X are five element vectors where A is a five by five matrix. The value of matrix A will be obtained from the first five mix ratios. The mix ratios are:

Z_1[0.67:1:1.7:2:0.5],
Z_2[0.58:1:1.5:1.9:0.8],
Z_3[0.6:1:1.2:1.7:1],
Z_4[0.8:1:1:1.8:1.3],
Z_5[0.74:1:1.2:1.3:1.5],

The corresponding pseudo mix ratios are:

X_1[1:0:0:0:0], X_2[0:1:0:0:0],
X_3[0:0:1:0:0], X_4[0:0:0:1:0],
X_5[0:0:0:0:1]. Substitution of X_i and z into equation (1) gives the values of A as

$$A = \begin{Bmatrix} 0.67 & 0.58 & 0.6 & 0.8 & 0.74 \\ 1 & 1 & 1 & 1 & 1 \\ 1.7 & 1.5 & 1.2 & 1 & 1.2 \\ 2 & 1.9 & 1.7 & 1.8 & 1.3 \\ 0.5 & 0.8 & 1 & 1.3 & 1.5 \end{Bmatrix} \quad \text{-- (2)}$$

The first five mixture ratios are located at the vertices of the four dimensional factor space. Ten other pseudo mix ratios located at mid points of the lines joining the vertices of the factor space are:

Z_{12}[½ : ½ :0:0:0], X_{13}[½ :0: ½ :0:0],
Z_{14}[½ :0:0: ½ :0], X_{15}[½ :0:0:0: ½],
Z_{23}[0: ½ : ½ :0:0], X_{24}[0: ½ :0: ½ :0],
Z_{25}[0:0: ½ :0: ½], X_{34}[0:0: ½ : ½ :0],
Z_{35}[0:0: ½ :0: ½], X_{45}[0:0:0 ½ : ½].

Substituting these values into equation (1) will give the corresponding actual mix ratios, Z as;

Z_{12}[0.625:1:1.6:1.95:0.65],
Z_{13}[0.635:1 :1.45:1.85:0.75],
Z_{14}[0.735:1:1.35:1.90:0.90],
Z_{15}[0.705:1:1.45:1.65:1.],
Z_{23}[0.59:1:1.35:1.80:0.9],
Z_{24}[0.69:1:1.25:1.85:1.05],
Z_{25}[0.66:1:1.35:1.60:1.15],
Z_{34}[0.70:1:1.10:1.75:1.15],
Z_{35}[0.67:1:1.20:1.50:1.25],
Z_{45}[0.77:1:1.10:1.55:1.40].

No pseudo component according to [9] should be more than one or less than zero. The summation of all the pseudo components in a mix ratio must be equal to one [10,11].

That is

$0 \le xi \le 1$ _______________ (3)

$\sum Xi = 1$ ______________________ (4)

The general equation for regression is given as:

Y = bo + ∑bixi + ∑bijxixj + ∑biixixjxk +………………… + ∑bij, i2…………… inxi, xi2……….xin + e
________ (5)

Where i≤i1 ≤i2 ≤…………≤ in ≤q respectively [12].

Expanding equation (5) up to second order Polynomial for five component mixture, we obtain:

$$\mathbf{Y} = b_o+b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_{11}x_1^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{15}x_1x_5 + b_{22}x_2^2 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{25}x_2x_5 + b_{33}x_3^2 + b_{34}x_3x_4 + b_{35}x_3x_5 + b_{44}x_4^2 + b_{45}x_4x_5 + b_{55}x_5^2 + e \quad \_\_\_\_\_\_\_\_ (6)$$

But $\sum x_i = 1$

That is $X_1 + X_2 + X_3 + X_4 + X_5 = 1$ ________ (7)

Multiplying equations (7) by bo will give

$box_1 + box_2 + box_3 + box_4 + box_5 = bo$ ____________ (8)

Multiplying equation (7) by x_1 will give

$X_1^2 + x_1x_2 + x_1x_3 + x_1x_4 + x_1x_5 = X_1$ ______ (9)

Similarly multiplying equation (7) by x_2, x_3, x_4 and x_5 will respectively give:

$X_1x_2 + x_2^2 + x_2x_3 + x_2x_4 + x_2x_5 = X_3$ _____________ (10)

$X_1x_3 + x_2x_3 + x_3^2 + x_3x_4 + x_3x_5 = X_3$ ______________ (11)

$X_1x_4 + x_2x_4 + x_3x_4 + x_4^2 + x_4x_5 = X_4$ ______________ (12)

$X_1x_5 + x_2x_5 + x_3x_5 + x_4x_5 + x_5^2 = X_5$ ________ (13)

Rearranging equations (9) to (13) in terms

of xi^2 will give respectively

$X_1^2 = x_1 - x_1x_2 – x_1x_3 – x_1x_4 – x_1x_5$ ________ (14)

$X_2^2 = x_2 - x_1x_2 – x_2x_3 – x_2x_4 – x_2x_5$ _______________ (15)

$X_3^2 = x_3 – x_1x_3 – x_1x_3 – x_2x_3 – x_3x_4 – x_3x_5$ ___________(16)

$X_4^2 = x_4 – x_1x_4 – x_1x_4 – x_2x_4 – x_3x_4 – x_4x_5$ ___________(17)

$X_5^2 = x_5 – x_1x_5 – x_2x_5 – x_2x_5 – x_3x_5 – x_4x_5$ _________ (18)

Substituting equation (8) into equations (14-18) and equation (6) and re-arranging and replacing with a constant α will yield.

$$\begin{aligned} Y &= \alpha_1x_1 + \alpha_2x_2 + \alpha_3x_3 + \alpha_4x_4 + \alpha_5x_5 \\ &+ \alpha_{12}x_1x_2 + \alpha_{13}x_1x_3 + \alpha_{14}x_1x_4 + \alpha_{15}x_1x_5 \\ &+ \alpha_{23}x_2x_3 + \alpha_{24}x_2x_4 + \alpha_{25}x_2x_5 + \alpha_{34}x_3x_4 + \alpha_{35}x_3x_5 \\ &+ \alpha_{45}x_4x_5 + e \quad \_\_\_\_\_\_\_\_ (19) \end{aligned}$$

Equation (19) can be re-written as $Y = y + e$ _____________ (20)

Where e = Standard error or standard deviation and

$$Y = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 + \alpha_{12} X_1 X_2 + \alpha_{13} X_1 X_3 + \alpha_{14} X_1 X_4 + \alpha_{15} X_1 X_5 + \alpha_{23} X_2 X_3 + \alpha_{24} X_2 X_4 + \alpha_{25} X_2 X_5 + \alpha_{34} X_3 X_4 + \alpha_{35} X_3 X_5 + \alpha_{45} X_4 X_5 \qquad (21)$$

Equation (21) is the Scheffe's (5,2) Lattice Polynomial equation. These responses are constant and are determined by carrying out Laboratory practicals. A total of fifteen (15) such practical tests were carried out to correspond to the fifteen coefficients of equation (21).
To validate the model extra fifteen mix ratios (control) were determined and used in the Students T-test.

Table 1: Pseudo and Actual Mix Ratios for the Control Test

Points	Ratio of Materials									
	Water	Cement	Sand	Coarse aggregate	Aluminum waste	Water	Cement	Sand	Coarse aggregate	Aluminum waste
	X_1	X_2	X_3	X_4	X_5	Z_1	Z_2	Z_3	Z_4	Z_5
C_1	0.25	0.25	0.25	0.25	0	0.6625	1	1.35	1.85	0.90
C_2	0.25	0.25	0.25	0	0.25	0.6475	1	1.40	1.725	0.95
C_3	0.25	0.25	0	0.25	0.25	0.6975	1	1.35	1.75	1.025
C_4	0.25	0	0.25	0.25	0.25	0.7025	1	1.275	1.70	1.075
C_5	0	0.25	0.25	0.25	0.25	0.68	1	1.225	1.675	1.15
C_6	0.2	0.2	0.2	0.2	0.2	0.678	1	1.32	1.74	1.02
C_7	0.3	0.3	0.3	0.1	0	0.635	1	1.42	1.86	0.82
C_8	0.3	0.3	0.3	0	0.1	0.629	1	1.44	1.81	0.84
C_9	0.3	0.3	0	0.3	0.1	0.689	1	1.38	1.84	0.93
C_{10}	0.3	0	0.3	0.3	0.1	0.695	1	1.29	1.78	0.99
C_{11}	0	0.3	0.3	0.3	0.1	0.668	1.	1.23	1.75	1.08
C_{12}	0.1	0.3	0.3	0.3	0	0.661	1	1.28	1.82	0.98
C_{13}	0.3	0.1	0.3	0.3	0	0.679	1	.132	1.84	0.92
C_{14}	0.3	0.3	0.1	0.3	0	0.675	1	1.38	1.88	0.88
C_{15}	0.1	0.2	0.3	0.4	0	0.683	1	1.23	1.81	1.03

COMPRESSIVE AND FLEXURAL STRENGTH TEST: THE MATERIAL USED INCLUDES:

- Granite which is free from deleterious material with a maximum size of 20mm.
- The cement used is Dangote cement which is a brand of Ordinary Portland cement and conform to [13].
- The water used is clean water from borehole.
- River sand used in this research work is free from deleterious material with a specific gravity of 2.62.
- Aluminum waste was obtained from the Aluminum Extrusion industry (ALEX) Inyishi in Ikeduru local Government of Imo State, Nigeria. The waste was sieved with 150µm sieve size in order to obtain a finely divided material.

The materials were batched by weight. Mixing was done manually using spade and hand trowel. 150mm x 150mm x 150mm concrete cube moulds were used for compressive strength test while 100mm x 100mm x 100mm x 500mm beam moulds were used for flexural strength. The concrete cubes and beams were cured for 28 days at room temperature. At the end of the hydration period the cubes and beams were crushed and the compressive and flexural strengths were determined according to the requirement of [14].

RESULTS AND DISCUSSION

The results of the compressive and flexural strength obtained by the optimization approach applied in the work are presented in table 2 and table 4.

The results of the experimental test and Simplex (Scheffe) Model are Presented in table 3 and 5 respectively. The proposed regression models for compressive and flexural strength were tested for adequacy using the Students' T-test. This is shown is table 7 for compressive strength and table 9 for flexural strength. Table 6 presents the results obtained from test carried out to experimentally check the outcome of the regression models. The experimental results agreed favorably with the software derived. The compressive strength gave 29.81 N/mm^2 and the flexural strength 11.72N/mm$^{2.}$

Table 6 showed that aluminum waste is not weak in flexure and will therefore be adequate in structural members where the concrete may be required to resist some measure of flexural stress such as in rigid pavements. The results of table 6 also showed that the use of the proposed optimized aluminum waste produced a saving of 16% in mass of concrete. The economic benefit analysis of the work showed that four thousand naira is saved per cubic meter of concrete when aluminum waste is used instead of a standard component 1:2:4 concrete mix.

Table 2: Compressive Strength Test Result

Points	Replicate 1 (N/mm^2)	Replicate 2 (N/mm^2)	Replicate 3 (N/mm^2)	Average Compressive strength (N/mm^2)
1	27.20	30.22	30.80	29.41
2	17.78	19.56	21.64	19.66
3	18.49	21.29	26.00	21.93
4	21.64	18.58	22.76	20.99
5	26.04	21.07	13.56	20.22
12	13.29	9.51	20.35	14.38
13	18.40	22.04	19.16	19.87
14	23.20	27.04	26.27	25.50
15	24.62	23.02	22.22	23.29
23	21.87	22.27	25.78	23.31
24	14.67	20.04	26.76	20.49
25	15.33	27.47	22.36	21.72
34	31.16	23.11	35.16	29.81
35	21.73	28.36	27.29	25.79
45	18.53	15.20	12.49	15.41
C_1	31.38	18.02	23.38	24.26
C_2	16.27	17.82	27.69	20.59
C_3	17.18	20.80	23.82	20.60
C_4	23.56	19.47	21.96	21.66
C_5	23.78	22.25	18.70	21.58
C_6	14.31	17.51	22.67	18.16
C_7	22.80	23.91	20.84	22.52
C_8	29.20	17.87	20.22	22.43
C_9	25.16	12.93	13.69	17.26
C_{10}	24.27	26.22	28..13	26.21
C_{11}	20.58	18.40	17.73	18.90
C_{12}	22.93	18.70	19.78	20.47
C_{13}	21.02	20.04	30.22	23.76
C_{14}	21.78	8.98	20.27	17.01
C_{15}	18.27	24.49	12.71	18.49

Table 3: Result of experimental test and simplex (Scheffe) model.

S/No	Experimental compressive test result (N/mm^2)	Scheffe's model compressive strength test result (N/mm^2)
1	29.41	29.41
2	19.66	19.66
3	21.93	21.93
4	20.99	20.99
5	20.22	20.22
6	14.38	14.38
7	19.87	19.87
8	25.50	25.50
9	23.29	23.29
10	23.31	23.31
11	20.49	20.49
12	21.72	21.72
13	29.81	29.81
14	25.79	25.79
15	15.41	15.41
16	24.26	21.841
17	20.59	20.688
18	20.60	18.913
19	21.66	23.349
20	21.58	23.783
21	18.16	21.666
22	22.52	19.618
23	22.43	19.08
24	17.26	18.959
25	26.21	24.506
26	18.90	24.923
27	20.47	23.807
28	23.76	23.794
29	17.01	20.33
30	18.49	25.052

Table 4: Flexural strength test result

Points	Replicate 1 (N/mm^2)	Replicate 2 (N/mm^2)	Replicate 3 (N/mm^2)	Average Compressive strength (N/mm^2)
1	5.80	6.05	7.60	6.48
2	7.45	9.85	9.30	8.87
3	8.95	9.90	10.60	9.82
4	5.65	6.95	6.60	6.40
5	10.45	12.90	11.80	11.72
12	6.60	7.60	7.90	7.37
13	7.00	9.00	8.50	8.17
14	5.90	6.20	9.00	7.03
15	7.75	8.10	11.00	8.95
23	8.70	9.60	10.50	9.60
24	7.00	8.00	10.00	8.33
25	9.50	12.00	10.10	10.53
34	7.45	9.55	8.90	8.63
35	9.95	12.50	10.90	11.12
45	8.74	10.45	8.65	9.28
C_1	8.48	8.00	8.25	8.24
C_2	8.20	10.55	8.75	9.17
C_3	9.00	7.90	7.00	7.97
C_4	9.50	9.98	7.50	8.99
C_5	15.63	14.55	8.10	12.76
C_6	8.96	13.35	8.90	10.40
C_7	10.00	8.70	9.00	9.23
C_8	9.30	9.20	9.30	9.27
C_9	11.00	7.90	8.50	9.13
C_{10}	9.11	14.00	6.95	10.02
C_{11}	8.95	9.68	6.70	8.44
C_{12}	8.45	11.04	6.25	8.58
C_{13}	11.70	8.15	7.60	9.15
C_{14}	12.95	10.68	9.85	11.16
C_{15}	14.00	10.00	8.10	10.70

Table 5: Result of Experimental Test and Simplex (Scheffe) Model

S/No	Experimental flexural strength test result (N/mm^2)	Scheffe's model flexural strength test result (N/mm^2)
1	6.48	6.48
2	8.87	8.87
3	9.82	9.82
4	6.40	6.40
5	11.72	11.72
6	7.37	7.37
7	8.17	8.17
8	7.03	7.03
9	8.95	8.95
10	9.60	9.60
11	8.33	8.33
12	10.53	10.53
13	8.63	8.63
14	11.12	11.12
15	9.28	9.28
16	11.47	8.336
17	9.17	9.324
18	7.97	8.689
19	8.99	8.993
20	12.76	9.771
21	11.38	9.047
22	9.23	8.397
23	9.27	8.764
24	9.13	8.086
25	11.32	8.439
26	8.44	9.325
27	8.58	8.741
28	9.15	8.181
29	11.16	7.955
30	10.70	8.534

Table 6: Mass and strength of standard and optimization mixes compared

Item	Cement (kg)	Fine aggregate (kg)	Aluminum waste (kg)	Coarse aggregate (kg)	Water (kg)	Compressive strength (N/mm^2)	Flexural Strength (N/mm^2)
Standard mix	**1**	**2.00**	**0.00**	**4.00**	**0.55**	**26.07**	**9.46**
optimized mix	**1**	**1.1**	**1.15**	**1.75**	**0.70**	**29.81**	**11.72**
Saving	**0**	**0.9**		**2.25**	**0.15**	**3.74**	

ECONOMIC BENEFITS

From table 6, saving in concrete mass per design mass.

= 0.9 + 2.25 + 0.15 = 3.3kg.

Mass of concrete in $1m^3$ concrete= 2400kg [15]

Hence mass of concrete saved in $1m^3$

= 3.3 x mass of concrete in $1m^3$/design unit mass

$= 3.3 \times \frac{2400}{20.5} = 386.34kg$

But density of concrete $= \frac{mass}{Volume} = 2400$

Hence volume of concrete saved

$= \frac{Mass}{Density} = \frac{386.35}{2400} = 0.16m^3$

Cost of $1m^3$ of concrete = #25,000

:. Cost of concrete saved per m^3

= #25000 x 0.16 = #4,000

:. Percentage volume of concrete saved per m^3

$= \frac{0.16m^3}{1m^3} \times \frac{100}{1} = 16\%$

Table 7: T-statistics for the Control Parts of Compressive Strength

Points	**Method of Mixing/Test ye**	**ym**	**Difference d_1 = ye – ym**
C_1	24.26	24.841	+2.419
C_2	20.59	20.688	-0.098
C_3	20.60	18.913	+1.687
C_4	21.66	23.349	-1.689
C_5	21.58	23.783	-2.203
C_6	18.16	21.666	-3.506
C_7	22.52	19.618	+2.902
C_8	22.43	19.08	+3.35
C_9	17.26	18.959	-1.699
C_{10}	26.21	24.506	+1.704
TOTAL			**2.867**

Average difference $d = \frac{\sum d_1}{n} = \frac{2.867}{10}$

$= 0.2867$

Variance, $\sum d^2 = \frac{\sum(d-d)^2}{n-1} = \frac{53.0318}{9}$

$= 5.892$

Standard deviation, Sd = 2.427

t-statistics, t = $\frac{d}{Sd/\sqrt{10}} = \frac{0.2867}{2.427/\sqrt{10}}$

= 0.37

For the case of two tailed test and for 5% level of significant and 9 degrees of freedom, we obtain $t_{0.975}$, 9 = 2.26.

Because the calculated t-value is less than that obtained from the table (i.e 2.26), we conclude that there is no significant difference in the two methods.

That is to say we accept null hypothesis.

Table 8: t- Statistics for the Control Points of Flexural strength

Points	Method of Mixing/Test ye	ym	Difference d_1 = ye – ym
C_1	8.24	8.336	-0.096
C_2	9.17	9.324	-0.154
C_3	7.97	8.689	-0.719
C_4	8.99	8.993	-0.003
C_5	8.20	8.771	-0.571
C_6	10.40	9.047	1.353
C_7	9.23	8.397	0.833
C_8	9.27	8.764	0.506
C_9	9.13	8.086	1.044
C_{10}	10.02	8.439	1.581
		TOTAL	**3.774**

ye = Experimental laboratory result

ym = model result.

Average difference, d = $\frac{\sum d_1}{n} = \frac{3.776}{10}$ = 0.3774

Variance, $Sd^2 = \frac{\sum (d_1-d)^2}{n-1} = \frac{5.8218}{9}$ = 0.6460

Standard deviation, Sd = 0.8043

t-statistics, t = $\frac{d}{sd/\sqrt{10}} = \frac{0.3774\ \ S}{2.8043/\sqrt{10}}$

= 1.484

For the case of two tailed test and for 5% level significant and the degree of freedom of 9, we obtain $t_{0.975}$, 9 = 2.26. Because the calculated t, value is less than that obtained from the table (i.e 1.484 < 2.26), we concluded that the result is not significant at 5% level.

Therefore, we accept null hypothesis.

CONCLUSION

The research concludes that aluminum waste can be used in construction as an additive in concrete but should not exceed 16%. Aluminum waste can also be used as a fifth component in concrete production.

Aluminum waste has the advantage of high compressive strength material and cost saving over its standard counterpart.

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