Journal of NAMP 71, (2025) 27-40

The Nigerian Association of Mathematical Physics

Journal homepage: https://nampjournals.org.ng

COST BENEFITS OF RECYCLED AGGREGATE CONCRETE DESIGNED USING SCHEFFE'S MODEL

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ARTICLE INFO

Article history:
Received xxxxx
Revised xxxxx
Accepted xxxxx
Available online xxxxx

Keywords:
Aggregate,
Cost,
Optimization,
Mix Ratio,
Scheffe's
Model.

ABSTRACT

This work investigated the cost benefits of Scheffe's optimized recycled aggregate concrete. It adopted the combination of analytical and experimental methods of scientific investigation. Analytically, Scheffe's optimization approach was used to formulate a theoretical model which was processed by computer using PYTHON language. A total of thirty mix ratios were used in this study. The first fifteen mix ratios were used to formulate the model while the remaining fifteen mix ratios were used to validate it. The formulated model was tested for adequacy at 5% level of significance using Fisher statistical test and was found to be adequate.

The overall cost of Scheffe's optimized recycle aggregate concrete considering all the mix proportions was ₦ 2,954,935.36k while that of natural aggregate concrete was ₦ 3,028,080.41k. Scheffe's optimized recycled aggregate concrete was more economical having the Overall and the Optimal cost benefits of 2.42% and 3.51% respectively.

1. INTRODUCTION

Concrete as a construction material consists of Portland cement, fine aggregates, coarse aggregates and water. Each of these components contributes to the strength their concrete possesses (Gambhir, 2004).

Concrete recycling gains importance because it protects natural resources and eliminates the need for disposal by using the readily available concrete as an aggregate source for new concrete. Thus, recycled aggregates, if used in making new concrete, will undoubtedly play a vital role in the conservation of our natural resources (Ravindrarajah, 1987 and Ray, 1991).

A process that seeks for a maximum or minimum value for a function of several variables while at the same time, satisfying a number of other imposed requirements is called an optimisation process (Majid, 1974).

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https://doi.org/10.60787/jnamp.vol71no.603

Awchat *et al*. (2021) investigated the Cost-Benefit Analysis of Using Recycled Coarse Aggregate in Plain and Fiber Reinforced Concrete. The paper concluded that 0.25% SF per metre cube in RAC provides an economically viable solution in terms of cost and benefits compared to NAC of a similar mixture.
Gowri *et al*. (2018) examined the Performance Assessment and Cost Effectiveness in Replacement of Aggregates with Construction and Demolition Waste in Concrete. The work showed that The RAC is capable of constructing Massive Structures according to the test results. The authors concluded that, the optimal mix was 47% cost-effective compared to the NAC.

Natt Makul (2020) analyzed the Cost-benefit of the production of ready-mixed high-performance concrete made with recycled concrete aggregate: The paper concluded that recycled concrete aggregate manufacturing set-ups can be used in the industrial-scale manufacture of recycled concrete and at low prices.

Dosho *et al*. (2015) studied the application of recycled aggregate concrete for structural concrete. Part 2 with the feasibility study on the cost effectiveness and environmental impact. The work was carried out under the concept of Life Cycle Assessment (LC A) for environmental management of construction utilizing recycled products. The study was divided into three main parts, (i) feasibility study on the reuse of recycled aggregate concrete, (ii) experimental study on the quality of recycled aggregate and (iii) concrete made with this material. The authors concluded that the findings of the feasibility study were used as a replacement model for thermal power stations.

Nworuh and Unaeze (1977) performed Optimization of price fluctuation calculations and gave price fluctuation factor for component materials for the next ten years as shown in Table 1.

Table 1 Materials price fluctuation factors for the first ten years

Number of years	Price fluctuation factor
Year 1	1.2326
Year 2	1.4638
Year 4	1.9300
Year 6	2.3939
Year 8	3.3260
Year 10	3.3260

Source: Nworah and Unaeze (1977)

Dosho (2007) examined the development of a sustainable concrete waste recycling system. The paper showed that recycled aggregate concrete using the aggregate replacing method can acquire sufficient quality as structural concrete and/or precast concrete products through material design based on the value of relative quality method. The author confirmed the possibility of recycling concrete waste produced from demolished buildings in a highly effective manner could reduce both recycling cost and environmental impact.

This work examined the cost benefits of Scheffe's optimised recycled aggregate concrete compared to natural aggregate concrete. Mathematical model using (5, 2) factor space was developed which, with the aid of computer, predicted the cost of Scheffe's optimized recycled aggregate concrete. The statistical adequacy of the cost model was also tested.

2.0 MATERIALS AND METHOD

The materials used in this study are Ordinary Portland Cement, fine aggregate, recycled coarse aggregate (RCA) and water. Ordinary Portland cement with properties conforming to BS 12:1996 was used in this work. It is marketed at most cement shops in Nigeria. The water was clean, fresh, colourless, odourless, tasteless and free from organic matters in conformity with the requirements of BS EN 1008 (2002). Coarse aggregate, recycled coarse aggregate (RCA) and river sand (fine aggregate) were also used in this study. The RCA was sourced from demolished concrete culverts at Technical junction in Benin City and used as partial replacement of coarse aggregate after being thoroughly processed. While the fine aggregate was sourced from the Okhuahe river in Benin.

2.1 MODEL DEVELOPMENT

Scheffe's optimisation method is based on simplex lattice design in which the sum of all the components must be equal to unity:

$$X_1 + X_2 + X_3 + \cdots \dots \dots .. + X\text{q} = 1 \quad (1)$$

$$\Sigma X\text{i} = 1 \quad (2)$$

where q is the number of components of a mixture and i ranges from 1 to q.
Xi is the proportion of the ith component in the mixture.

2.2 DETERMINATION OF THE COEFFICIENTS IN (5,2) POLYNOMIAL

Assuming the response function for the pure component, i and that for the binary mixture of components i and j are y_i and y_{ij} respectively, then;

$$y_i = \sum \alpha_i X_i \quad (3)$$

and

$$y_{ij} = \sum \alpha_i X_i + \sum \alpha_{ij} X_i X_j \quad (4)$$

where 1≤i≤5, 1≤i≤j≤5

Substituting the values of X_1, X_2, X_3, $X_4$and X_5 at the ith point (i.e. any of the vertices of the lattice) into (3), gives the following general equation:

$$y_i = \alpha_i$$

(5a)

$$y_1 = \alpha_1 \quad (5b)$$

Substituting the values of X_1, X_2, X_3, $X_4$and X_5 at the point ij (that is at the midpoint of the borderline connecting points i and j) of the lattice into (4) yields:

$$yij = ½\, \alpha i + ½\, \alpha j + ¼\, \alpha ij \quad (5c)$$

For point 12, that is at the midpoint of the borderlines connecting points 1 and 2 of the lattice, the values of $X_1 = X_2 = ½$ while the values of X_3, X_4 and X_5 are equal to zero because $\sum X\text{i} = 1$. Substituting the values of X_1, X_2, X_3, X_4 and X_5 into (5c), gives (5d)

$$y_{12} = ½\, \alpha_1 + ½\, \alpha_2 + ¼\, \alpha_{12} \quad (5d)$$

From (5a),

$$\alpha i = yi \quad (6)$$

Similarly,

$$\alpha j = yj \quad (7)$$

Rearranging (5c) yields:

$$\alpha ij = 4yij - 2\alpha i - 2\alpha j \quad (8)$$

Substituting (7) and (8) into (9) gives:

$$\alpha_{ij} = 4y_{ij} - 2y_i - 2y_j \tag{9}$$

When (8), and (9) are substituted, (5) becomes:

$$y = y_1x_1 + y_2x_2 + y_3x_3 + y_4x_4 + y_5x_5 + (4y_{12} - 2y_1 - 2y_2)x_1x_2 + (4y_{13} - 2y_1 - 2y_3)x_1x_3 + (4y_{14} - 2y_1 - 2y_4)x_1x_4 + (4y_{15} - 2y_1 - 2y_5)x_1x_5 + (4y_{23} - 2y_2 - 2y_3)x_2x_3 + (4y_{24} - 2y_2 - 2y_4)x_2x_4 + (4y_{25} - 2y_2 - 2y_5)x_2x_5 + (4y_{34} - 2y_3 - 2y_4)x_3x_4 + (4y_{35} - 2y_3 - 2y_4)x_3x_5 + (4y_{45} - 2y_4 - 2y_5)x_4x_5$$

(10)

Let the coefficients of $y_1 = x_1 - 2x_1(x_2 + x_3 + x_4 + x_5)$ (11)

From (1),

$$x_2 + x_3 + x_4 + x_5 = 1 - x_1$$

(12)

Substituting (12) into (11) gives the coefficient of y_1 as follows:

$$y_1 = x_1 - 2x_1(1 - x_1)$$

(13)

$$= x_1(2x_1 - 1)$$

(14)

Rearranging (10) and transferring all the coefficients of y_1 in like manner, gives the following mixture design model for optimization of a 5-component concrete.

$$y = x_1(2x_1 - 1)y_1 + x_2(2x_2 - 1)y_2 + x_3(2x_3 - 1)y_3 + x_4(2x_4 - 1)y_4 + x_5(2x_5 - 1)y_5 + 4x_1x_2y_{12} + 4x_1x_3y_{13} + 4x_1x_4y_{14} 4x_1x_5y_{15} + 4x_2x_3y_{23} + 4x_2x_4y_{24} + 4x_2x_5y_{25} + 4x_3x_4y_{34} + 4x_3x_5y_{35} + +4x_4x_5y_{45} \tag{15}$$

The terms y_i and y_{ij} are responses (representing the characteristics at the points i and ij. They are determined by carrying out laboratory test.

2.3 ACTUAL AND PSEUDO COMPONENTS (COMPONENTS TRANSFORMATION)

For component transformation we use the following equations:

$$X = BZ \tag{16}$$

$$S = AZ$$

(17)

where A = matrix whose elements are from the arbitrary mix proportions
B = the inverse of matrix A
S = matrix of actual components
X = matrix of pseudo components obtained from the lattice

2.4 THE STUDENT'S T-TEST

$$S_y = S\left(\sum \frac{\alpha_i}{n_i} + \sum \frac{\alpha_{ij}}{n_{ij}}\right) \tag{18}$$

for $1 \le i \le q$ and $1 \le i \le j \le q$ respectively,
thus S_{y^2}

$$S_y^2 = \frac{S^2 \mathcal{E}}{n} \tag{19}$$

Where

$$\mathcal{E} = \sum a_i + \sum a_{ij} \tag{20}$$

And Ɛ is the error for the predicted value of the response.
The unbiased estimate of the unknown variance is given by Cramer (1946) as

$$S_y^2 = [1/(n-1)] \ [\sum (y_i - y)^2] \tag{21}$$

y_i = the responses, y = the mean of responses for each control point
n = control points, n-1 = degree of freedom
The mean of the responses is given by:

$$y = \sum y/n \tag{22}$$

where 1≤i≤n
The t-test statistic equation is given by:

$$t = \Delta y\sqrt{n}/ \ (S_y\sqrt{l+\mathcal{E}} \tag{23}$$

where,

$$\Delta Y = y(\text{observed}) - y(\text{predicted}) \tag{24}$$

n = number of parallel or replicate observations at every point
ε = as defined by (20).
The t-statistics is compared with the tabulated value of $t_{\alpha/l}(v_e)$
Where
α = significant level (taken as 0.05)
l = number of control points
v_e = number of degrees of freedom
The null hypothesis is accepted if the value got from the table is greater than the calculated value(s).
Replication error, S_y

$$v_e = \sum(m_i - 1) \tag{25}$$

$$S_y^2 = \frac{1}{v_e} \sum S_y^2 \tag{26}$$

Replication error, $S_y = \sqrt{S_y^2}$ (27)

2.5 THE FISHER TEST

This statistical method was adopted to determine the differences between the experimental values observed and the predicted values calculated. The test statistics is given by

$$F = s_1^2 / s_2^2 \tag{28}$$

Where s_1^2 is the larger of the two variances

The variance is

$$S^2 = [1/(n-1)] \ [\sum (Y - y)^2] \tag{29}$$

And

$y = \sum Y/n$ for 1≤i≤n (30)

or the mean of the sample response Y
the upper limit of (29) is

$s_1^2 / s_2^2 \leq F_{1-\alpha} (v_1, v_2)$
(31)

and the lower limit is

$s_1^2 / s_2^2 \geq F_{1-\alpha} (v_2, v_1)$ (32)

Where S_1^2 is significant level taken as 0.05
v is the degree of freedom which is n-1
n is the number of observation data.

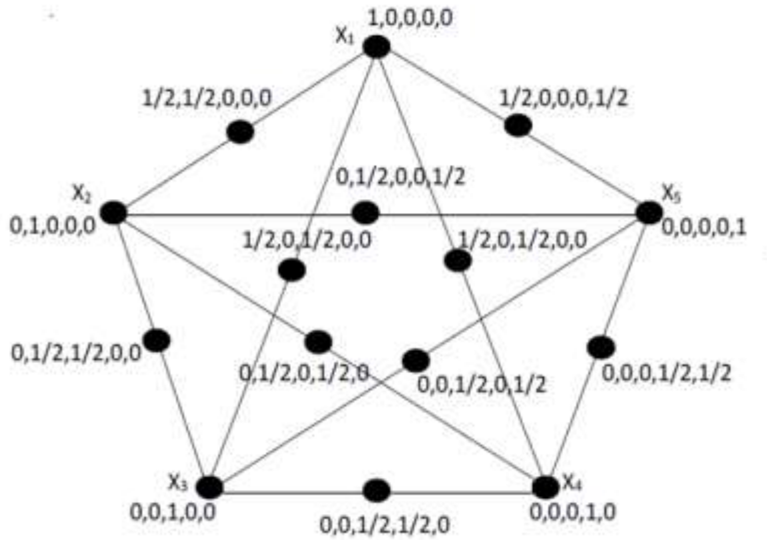

Figure 1: A factor space for a 5 – component material used in this study

Table 2 Design Matrix for Trial Points Based on Scheffe's (5, 2) Factor Space

Expt Points	Water (S_1)	Cement (S_2)	Sand (S_3)	Granite (S_4)	RCA (S_5)	Responds	X_1	X_2	X_3	X_4	X_5
1	0.500	1.000	1.310	3.350	0.180	Y_1	1	0	0	0	0
2	0.550	1.000	1.460	3.620	0.400	Y_2	0	1	0	0	0
3	0.600	1.000	1.620	3.720	0.660	Y_3	0	0	1	0	0
4	0.650	1.000	1,78	3.860	0.960	y_4	0	0	0	1	0
5	0.450	1.000	1.150	2.330	0.780	Y_5	0	0	0	0	1
6	0.525	1.000	1.385	3.485	0.290	Y12	0.5	0.5	0	0	0
7	0.550	1.000	1.465	3.535	0.420	Y13	0.5	0	0.5	0	0
8	0.575	1.000	1.545	3.605	0.570	Y14	0.5	0	0	0.5	0
9	0.475	1.000	1.230	2.840	0.480	Y15	0.5	0	0	0	0.5
10	0.575	1.000	1.540	3.670	0.530	Y23	0	0.5	0.5	0	0
11	0.600	1.000	1.620	3.740	0.680	Y24	0	0.5	0	0.5	0
12	0.500	1.000	1.305	2.975	0.590	Y25	0	0.5	0	0	0.5
13	0.625	1.000	1.700	3.790	0.810	Y34	0	0	0.5	0.5	0
14	0.525	1.000	1.385	3.025	0.700	Y35	0	0	0.5	0	0.5
15	0.550	1.000	1.465	3.095	0.870	Y45	0	0	0	0.5	0.5

Table 3 Design Matrix for Control Points Based on Scheffe's (5, 2) Factor Space

Expt Points	Water (S_1)	Cement (S_2)	Sand (S_3)	Granite (S_4)	RCA (S_5)	Responds	X_1	X_2	X_3	X_4	X_5
1	0.5495	0.9990	1.4619	3.5598	0.4129	YC_1	0.3333	0.3333	0.3333	0	0
2	0.5828	0.9990	1.5684	3.6379	0.5994	YC_2	0.3333	0	0.3333	0.3333	0
3	0.6328	0.9990	1.4119	3.1768	0.6394	YC_3	0.3333	0	0	0.3333	0.3333
4	0.5750	1	1.5425	3.6375	0.5500	yC_4	0.25	0.25	0.25	0.25	0
5	0.5500	1	1.4650	3.3150	0.6450	YC_5	0.25	0	0.25	0.25	0.25
6	0.5250	1	1.3850	3.2550	0.5050	YC12	0.25	0.25	0.25	0	0.25
7	0.5375	1	1.4250	3.5100	0.3550	YC13	0.5	0.25	0.25	0	0
8	0.5000	1	1.3075	2.9325	0.6000	YC14	0.25	0	0.25	0	0.5
9	0.5600	1	1.4960	3.5800	0.4760	YC15	0.4	0.2	0.2	0.2	0
10	0.5500	1	1.4640	3.3760	0.5960	YC23	0.2	0.2	0.2	0.2	0.2
11	0.5450	1	1.4490	3.3490	0.5740	YC24	0.3	0.1	0.2	0.2	0.2
12	0.5650	1	1.5110	3.4270	0.6740	YC25	0.1	0.2	0.2	0.3	0.2
13	0.5200	1	1.3700	3.2280	0.4830	YC34	0.35	0.15	0.25	0	0.25
14	0.5450	1	1.4485	3.3575	0.5270	YC35	0.25	0.2	0.15	0.2	0.2
15	0.5175	1	1.3635	3.1595	0.5270	YC45	0.45	0.05	0	0.2	0.3

Legend:

S_1 = Actual proportion of water

S_2 = Actual proportion of cement

S_3 = Actual proportion of sand

S_4 = Actual proportion of Granite

S_5 = Actual proportion of R CA

X_1 = Pseudo proportion of water

X_2 = Pseudo proportion of cement

X_3 = Pseudo proportion of sand

X_4= Pseudo proportion of Granite

X_5 = Pseudo proportion of RCA

3.0 RESULTS AND DISCUSSION

3.1 COST MODEL

The cost per kg of the component materials was obtained based on their most current market prices as shown in Table 4. This costing is applicable most especially in the south west area of Nigeria.

Table 4: Cost per kg of the Component Materials

S/N	Component	Cost (Naira)/kg
1	Water	4
2	Cement	230
3	Sand	6.5
4	Granite	12.5
5	RCA	0

The unit cost of concrete component materials in Naira per Kg are:

Water = 4; cement = 230; RCA= 0; sand = 6.5 and granite = 12.5.

The unit cost of RCA was assumed to be zero because it is regarded as waste obtained from demolition sites or construction sites. These values were used to obtain the overall cost of producing one cubic metre ($1m^3$) of Sheffe's optimized recycled aggregate concrete in Naira for the various mix ratios in Tables 2 and 3, the results are presented in Tables 5 and 6. The various costs for the first 15 mix ratios were used to formulate the model while the various costs for the remaining 15 mix ratios were used to validate the model. Similarly, the cost of producing one cubic metre ($1m^3$) of natural aggregate concrete in Naira for the various mix ratios in Tables 2 and 3 was also obtained and the results are presented in Tables 8 and 9. The cost comparison of Scheffe's optimized recycled aggregate concrete and natural aggregate concrete is presented in Table 10.

Table 5 Quantity of Materials in kg per m^3 of Scheffe's Optimized Recycled Aggregate Concrete

S/no	Concrete Mixes	Water	Cement	Sand	Granite	RCA
1	0.5:1:1.31:3.35:0.18	189.274	378.549	495.899	1268.139	68.139
2	0.55:1:1.46:3.62:0.4	187.767	341.394	498.435	1235.846	136.558
3	0.6:1:1.62:3.72:0.66	189.474	315.789	511.579	1174.737	208.421
4	0.65:1:1.78:3.86:0.96	189.091	290.909	517.818	1122.909	279.273
5	0.45:1:1.15:2.33:0.78	189.142	420.315	483.363	979.335	327.846
6	0.525:1:1.385:3.485:0.290	188.482	359.013	497.233	1251.159	104.114
7	0.550:1:1.465:3.535:0.420	189.383	344.333	504.448	1217.217	144.620
8	0.575:1:1.545:3.605:0.570	189.171	328.992	508.293	1186.018	187.526
9	0.475:1:1.230:2.840:0.480	189.212	398.340	489.959	1131.286	191.203
10	0.575:1:1.540:3.670:0.530	188.653	328.093	505.263	1204.101	173.889
11	0.600:1:1.620:3.740:0.680	188.482	314.136	508.901	1174.869	213.613
12	0.5:1:1.305:2.975:0.590	188.383	376.766	491.680	1120.879	222.292
13	0.625:1:1.700:3.790:0.810	189.274	302.839	514.826	1147.760	245.300
14	0.525:1:1.385:3.025:0.700	189.902	361.718	500.980	1094.197	253.203
15	0.55:1:1.465:3.095:0.870	189.112	343.840	503.725	1064.183	299.140
Control						
16	0.5495:0.9990:1.4619:3.5598:0.4129	188.8560	343.3432	502.4359	1223.4566	141.9083
17	0.5828:0.9990:1.5684:3.6379:0.5994	189.3360	324.5482	509.5310	1181.8558	194.7289
18	0.6328:0.9990:1.4119:3.1768:0.6394	221.3910	349.5095	493.9664	1111.4331	223.7001
19	0.5750:1:1.5425:3.6375:0.5500	188.9117	329	506.7762	1195.0719	180.6982
20	0.5500:1:1.4650:3.3150:0.6450	189.2473	344	504.0860	1140.6452	221.9355
21	0.5250:1:1.3850:3.2550:0.5050	188.9055	360	498.3508	1171.2144	181.7091
22	0.5375:1:1.4250:3.5100:0.3550	188.9418	352	500.9154	1233.8338	124.7895
23	0.5000:1:1.3075:2.9325:0.6000	189.2744	379	494.9527	1110.0946	227.1293
24	0.5600:1:1.4960:3.5800:0.4760	188.9764	337	504.8369	1208.0990	160.6299
25	0.55:1:1.4640:3.3760:0.5960	188.9493	344	502.9488	1159.8053	204.7524
26	0.5450:1:1.4490:3.3490:0.5740	189.0993	347	502.7613	1162.0067	199.1615
27	0.5650:1:1.5110:3.4270:0.6740	188.9369	334	505.2808	1145.9941	225.3867
28	0.5200:1:1.3700:3.2280:0.4830	189.0623	364	498.1063	1173.6404	175.6098
29	0.5450:1:1.4485:3.3575:0.5270	190.1716	349	505.4376	1171.5615	183.8907
30	0.5175:1:1.3635:3.1595:0.5270	189.1131	365	498.2718	1154.5946	192.5847

Table 6 Cost of Materials in kg per m^3 of Scheffe's Optimized Recycled Aggregate Concrete

S/N	Concrete Mixes	Water	Cement	Sand	Granite	RCA	Total Cost

1	0.5:1:1.31:3.35:0.18	757.098	87066.246	3223.344	15851.735	0.000	106,898.423
2	0.55:1:1.46:3.62:0.4	751.067	78520.626	3239.829	15448.080	0.000	97,959.602
3	0.6:1:1.62:3.72:0.66	757.895	72631.579	3325.263	14684.211	0.000	91,398.947
4	0.65:1:1.78:3.86:0.96	756.364	66909.091	3365.818	14036.364	0.000	85,067.636
5	0.45:1:1.15:2.33:0.78	756.567	96672.504	3141.856	12241.681	0.000	112,812.609
6	0.525:1:1.385:3.485:0.290	753.927	82572.924	3232.012	15639.491	0.000	102,198.355
7	0.550:1:1.465:3.535:0.420	757.532	79196.557	3278.910	15215.208	0.000	98,448.207
8	0.575:1:1.545:3.605:0.570	756.683	75668.266	3303.907	14825.223	0.000	94,554.078
9	0.475:1:1.230:2.840:0.480	756.846	91618.257	3184.730	14141.079	0.000	109,700.913
10	0.575:1:1.540:3.670:0.530	754.614	75461.381	3284.211	15051.265	0.000	94,551.470
11	0.600:1:1.620:3.740:0.680	753.927	72251.309	3307.853	14685.864	0.000	90,998.953
12	0.5:1:1.305:2.975:0.590	753.532	86656.201	3195.918	14010.989	0.000	104,616.641
13	0.625:1:1.700:3.790:0.810	757.098	69652.997	3346.372	14347.003	0.000	88,103.470
14	0.525:1:1.385:3.025:0.700	759.608	83195.177	3256.368	13677.468	0.000	100,888.621
15	0.55:1:1.465:3.095:0.870	756.447	79083.095	3274.212	13302.292	0.000	96,416.046

Control

16	0.5495:0.9990:1.4619:3.5598:0.4129	755.4238	78968.9393	3265.8332	15293.2079	0.0000	98,283.404
17	0.5828:0.9990:1.5684:3.6379:0.5994	757.3442	74646.0914	3311.9513	14773.1980	0.0000	93,488.585
18	0.6328:0.9990:1.4119:3.1768:0.6394	885.5639	80387.1777	3210.7815	13892.9139	0.0000	98,376.437
19	0.5750:1:1.5425:3.6375:0.5500	755.6468	75565	3294.0452	14938.3984	0.0000	94552.772
20	0.5500:1:1.4650:3.3150:0.6450	756.9892	79140	3276.5591	14258.0645	0.0000	97,431.398
21	0.5250:1:1.3850:3.2550:0.5050	755.6222	82759	3239.2804	14640.1799	0.0000	101,393.703
22	0.5375:1:1.4250:3.5100:0.3550	755.7671	80850	3255.9502	15422.9220	0.0000	100,284.145
23	0.5000:1:1.3075:2.9325:0.6000	757.0978	87066	3217.1924	13876.1830	0.0000	104,916.719
24	0.5600:1:1.4960:3.5800:0.4760	755.9055	77615	3281.4398	15101.2373	0.0000	96,753.881
25	0.55:1:1.4640:3.3760:0.5960	755.7973	79015	3269.1669	14497.5666	0.0000	97,537.704
26	0.5450:1:1.4490:3.3490:0.5740	756.3973	79803	3267.9485	14525.0831	0.0000	98,352.812
27	0.5650:1:1.5110:3.4270:0.6740	755.7475	76912	3284.3249	14324.9268	0.0000	95,277.358
28	0.5200:1:1.3700:3.2280:0.4830	756.2491	83624	3237.6913	14670.5045	0.0000	102,288.138
29	0.5450:1:1.4485:3.3575:0.5270	760.6862	80256	3285.3446	14644.5188	0.0000	98,946.438
30	0.5175:1:1.3635:3.1595:0.5270	756.4522	84050	3238.7667	14432.4324	0.0000	102,477.899

3.3 Final Prediction Models for Cost of Scheffe's Optimized Recycled Aggregate Concrete

$\acute{\alpha}_1 = 106898.423$, $\acute{\alpha}_2 = 97959.602$, $\acute{\alpha}_3 = 91398.947$, $\acute{\alpha}_4 = 85067.636$, $\acute{\alpha}_5 = 112812.609$

$\acute{\alpha}_{12} = 4(102,198.355) - 2\,(106898.423) - 2(97959.602) = -922.631$

$\acute{\alpha}_{13} = 4(98,448.207) - 2\,(106898.423) - 2(91398.947,) = -2801.914$

$\acute{\alpha}_{14} = 4(94,554.078) - 2\,(106898.423) - 2(85067.636) = -5715.806$

$\acute{\alpha}_{15} = 4(109,700.913) - 2\,(106898.423) - 2(112812.609) = -618.413$

$\acute{\alpha}23 = 4(94,551.470) - 2\,(97959.602) - 2(91398.947,) = -511.220$

$\acute{\alpha}24 = 4(90,998.953) - 2\,(97959.602) - 2(85067.636) = -2058.665$

$\acute{\alpha}25 = 4(104,616.641) - 2\,(97959.602) - 2(112812.609) = -3077.860$

$\acute{\alpha}34 = 4(88,103.470) - 2\,(91398.947,) - 2(85067.636) = -519.287$

$\acute{\alpha}_{35} = 4(100,888.621) - 2\,(91398.947) - 2(112812.609) = -4868.630$

$\acute{\alpha}_{45} = 4(96,416.046) - 2\,(85067.636) - 2(112812.609) = -10096.308$

$$Y_{cost} = 106898.423X_1+97959.602X_2+91398.947X_3+85067.636X_4+112812.609X_5-922.631X_1X_2-2801.914X_1X_3-5715.806X_1X_4-618.413X_1X_5-511.220X_2X_3-2058.665X_2X_4-3077.860X_2X_5-519.287X_3X_4-4868.630X_3X_5-10096.308X_4X_5 \quad (33)$$

Equation (33) is the model for the prediction of the cost of Scheffe's optimized recycled aggregate concrete.

The fluctuations in the market prices of the component materials for the first ten years can be taken care of by using the values shown in Table 1 of the literature review Nworuh and Unaeze (1977).

3.4 Test of Adequacy of Scheffe's Prediction Models

Table 7: F-Statistics Test Computations for the Cost of Scheffe's Optimized Recycled Aggregate Concrete.

Responds Symbol	$Y_{(observed)}$	$Y_{(predicted)}$	Y_{0bs} - Y_{0bs}	Ypre - Ypre	$(Y_{0bs}-Y_{0bs})^2$	$(YpreYpre)^2$
C_1	98283.404	98183.872	-404.689	-595.824	163773.063	355006.398
C_2	93448.585	93358.443	-5239.508	-5421.253	27452442.475	29389985.536
C_3	98376.437	99806.482	-311.656	1026.786	97129.367	1054289.216
C_4	94552.772	94548.057	-4135.321	-4231.639	17100878.505	17906769.755
C_5	97431.398	97582.933	-1256.695	-1196.763	1579281.938	1432241.997
C_6	101393.703	101467.354	2705.610	2687.658	7320326.302	7223504.808
C_7	100284.145	100291.329	1596.052	1511.633	2547382.476	2285033.924
C_8	104916.719	105119.647	6228.626	6339.951	38795783.758	40194976.992
C_9	96753.881	96765.811	-1934.212	-2013.885	3741175.468	4055733.330
C_{10}	97537.704	97579.814	-1150.389	-1199.882	1323394.499	1439717.134
C_{11}	98352.812	98413.155	-335.281	-366.541	112413.246	134352.402
C_{12}	95277.358	95287.268	-3410.735	-3492.428	11633112.194	12197054.266

C_{13}	102288.138	102374.681	3600.045	3594.985	12960325.106	12923916.192
C_{14}	98946.438	98348.216	258.345	-431.480	66742.218	186175.105
C_{15}	102477.8987	102568.38	3789.806	3788.684	14362628.406	14354125.442
∑	1480321.393	1481695.442			139256789.0201	145132882.4968
Y	98688.093	98779.69613				
S_{0bs}					9946913.5014	
S_{pre}						10366634.4641
F value					1.042196101	

LEGEND

Y_o, y_p are responses observed and predicted respectively

$Y = \sum y/n$

F value = 10366635.1082 / 9946913.5014 = 1.042196101

The F-value obtained from standard statistical table is 2.4, since 1.0422 is less than 2,4

Hence the model is adequate for the prediction of the cost of Scheffe's optimized recycled aggregate concrete.

Table 8 Quantity of Materials in kg per m^3 of Natural Aggregate Concrete

S/N	Concrete mixes	Water	Cement	Sand	Granite
1	0.5:1:1.31:3.53	189.274	378.549	495.899	1336.278
2	0.55:1:1.46:4.02	187.767	341.394	498.435	1372.404
3	0.6:1:1.62:4.38	189.474	315.789	511.579	1383.158
4	0.65:1:1.78:4.82	189.091	290.909	517.818	1402.182
5	0.45:1:1.15:3.11	189.142	420.315	483.363	1307.180
6	0.525:1:1.385:3.775	188.482	359.013	497.233	1355.273
7	0.550:1:1.465:3.955	189.383	344.333	504.448	1361.836
8	0.575:1:1.545:4.175	189.171	328.992	508.293	1373.544
9	0.475:1:1.230:3.32	189.212	398.340	489.959	1322.490
10	0.575:1:1.540:4.200	188.653	328.093	505.263	1377.990
11	0.600:1:1.620:4.42	188.482	314.136	508.901	1388.482
12	0.5:1:1.305:3.565	188.383	376.766	491.680	1343.171
13	0.625:1:1.700:4.600	189.274	302.839	514.826	1393.060
14	0.525:1:1.385:3.725	189.902	361.718	500.980	1347.400
15	0.55:1:1.465:3.965	189.112	343.840	503.725	1363.324
Control					
16	0.5495:0.9990:1.4619:3.9727	188.8560	343.3432	502.4359	1365.3650
17	0.5828:0.9990:1.5684:4.2373	189.3360	324.5482	509.5310	1376.5848
18	0.6328:0.9990:1.4119:3.8162	221.3910	349.5095	493.9664	1335.1332
19	0.5750:1:1.5425:4.1875	188.9117	329	506.7762	1375.7700
20	0.5500:1:1.4650:3.960	189.2473	344	504.0860	1362.5806
21	0.5250:1:1.3850:3.760	188.9055	360	498.3508	1352.9235
22	0.5375:1:1.4250:3.8650	188.9418	352	500.9154	1358.6232
23	0.5000:1:1.3075:3.5325	189.2744	379	494.9527	1337.2240
24	0.5600:1:1.4960:4.0560	188.9764	337	504.8369	1368.7289
25	0.55:1:1.4640:3.9720	188.9493	344	502.9488	1364.5577

26	0.5450:1:1.4490:3.9230	189.0993	347	502.7613	1361.1681
27	0.5650:1:1.5110:4.1010	188.9369	334	505.2808	1371.3808
28	0.5200:1:1.3700:3.7110	189.0623	364	498.1063	1349.2501
29	0.5450:1:1.4485:3.8845	190.1716	349	505.4376	1355.4522
30	0.5175:1:1.3635:3.6865	189.1131	365	498.2718	1347.1793

Table 9: Cost of Materials In kg per m^3 of Natural Aggregate Concrete

S/N	Concrete Mixes	Water	Cement	Sand	Granite	Total cost
1	0.5:1:1.31:3.53	757.098	87066.246	3223.344	16703.470	107750.158
2	0.55:1:1.46:4.02	751.067	78520.626	3239.829	17155.050	99666.572
3	0.6:1:1.62:4.38	757.895	72631.579	3325.263	17289.474	94004.211
4	0.65:1:1.78:4.82	756.364	66909.091	3365.818	17527.273	88558.545
5	0.45:1:1.15:3.11	756.567	96672.504	3141.856	16339.755	116910.683
6	0.525:1:1.385:3.775	753.927	82572.924	3232.012	16940.912	103499.776
7	0.550:1:1.465:3.955	757.532	79196.557	3278.910	17022.956	100255.954
8	0.575:1:1.545:4.175	756.683	75668.266	3303.907	17169.294	96898.149
9	0.475:1:1.230:3.32	756.846	91618.257	3184.730	16531.120	112090.954
10	0.575:1:1.540:4.200	754.614	75461.381	3284.211	17224.880	96725.085
11	0.600:1:1.620:4.42	753.927	72251.309	3307.853	17356.021	93669.110
12	0.5:1:1.305:3.565	753.532	86656.201	3195.918	16789.639	107395.290
13	0.625:1:1.700:4.600	757.098	69652.997	3346.372	17413.249	91169.716
14	0.525:1:1.385:3.725	759.608	83195.177	3256.368	16842.502	104053.655
15	0.55:1:1.465:3.965	756.447	79083.095	3274.212	17041.547	100155.301
Control						
16	0.5495:0.9990:1.4619:3.9727	755.4238	78968.9393	3265.8332	17067.0619	100057.258
17	0.5828:0.9990:1.5684:4.2373	757.3442	74646.0914	3311.9513	17207.3096	95922.696
18	0.6328:0.9990:1.4119:3.8162	885.5639	80387.1777	3210.7815	16689.1646	101172.688
19	0.5750:1:1.5425:4.1875	755.6468	75565	3294.0452	17197.1253	96811.499
20	0.5500:1:1.4650:3.960	756.9892	79140	3276.5591	17032.2581	100205.591
21	0.5250:1:1.3850:3.760	755.6222	82759	3239.2804	16911.5442	103665.067
22	0.5375:1:1.4250:3.8650	188.9418	80850	3255.9502	16982.7902	101277.188
23	0.5000:1:1.3075:3.5325	757.0978	87066	3217.1924	16715.2997	107755.836
24	0.5600:1:1.4960:4.0560	755.9055	77615	3281.4398	17109.1114	98761.755
25	0.55:1:1.4640:3.9720	755.7973	79015	3269.1669	17056.9711	100097.109
26	0.5450:1:1.4490:3.9230	756.3973	79803	3267.9485	17014.6017	100842.330
27	0.5650:1:1.5110:4.1010	755.7475	76912	3284.3249	17142.2600	98094.691
28	0.5200:1:1.3700:3.7110	756.2491	83624	3237.6913	16865.6264	104483.260
29	0.5450:1:1.4485:3.8845	760.6862	80256	3285.3446	16943.1521	101245.071
30	0.5175:1:1.3635:3.6865	756.4522	84050	3238.7667	16839.7411	104885.207

3.5 The comparison of cost of Scheffe's optimized recycled aggregate concrete and normal concrete is as shown in Table 10

Table 10: The Comparison of Cost of Scheffe's Optimized Recycled Aggregate Concrete and Natural Aggregate Concrete

S /No	Normal Concrete	Scheffe's optimized recycled aggregate concrete	Cost Difference (#)
1	107750.1577	106898.4227	851.735

2	99666.57183	97959.60171	1706.97012
3	94004.21053	91398.94737	2605.26316
4	88558.54545	85067.63636	3490.90909
5	116910.683	112812.609	4098.074
6	103499.7756	102198.3545	1301.4211
7	100255.9541	98448.2066	1807.7475
8	96898.14942	94554.07814	2344.07128
9	112090.9544	109700.9129	2390.0415
10	96725.08544	94551.46958	2173.61586
11	93669.10995	90998.95288	2670.15707
12	107395.2904	104616.6405	2778.6499
13	91169.71609	88103.47003	3066.24606
14	104053.6549	100888.6209	3165.034
15	100155.3009	96416.04585	3739.25505
16	100057.2582	98283.40422	1773.85398
17	95922.69645	93448.585	2474.11145
18	101172.6876	98376.43697	2796.25063
19	96811.49897	94552.772	2258.72697
20	100205.5914	97431.39785	2774.19355
21	103665.0675	101393.7031	2271.3644
22	101277.1878	100284.145	993.0428
23	107755.836	104916.7192	2839.1168
24	98761.75478	96753.88076	2007.87402
25	100097.1085	97537.70398	2559.40452
26	100842.3305	98352.81191	2489.51859
27	98094.69138	95277.358	2817.33338
28	104483.2601	102288.1382	2195.1219
29	101245.0712	98946.43792	2298.63328
30	104885.2075	102477.8987	2407.3088
∑	3028080.408	2954935.362	73145.0458

It can be seen from Tables 6 and 9 that the overall cost of Scheffe's optimized recycle aggregate concrete considering all the mix proportions is ₦ 2,954,935.36k while the total cost of natural aggregate concrete considering all the mix proportions is ₦ 3,028,080.41k, The difference between the total cost of Scheffe's optimized recycle aggregate concrete mixes and the total cost of natural aggregate concrete mixes is ₦ 73,145.05k showing that the Scheffe's optimized recycle aggregate concrete mixes are more economical looking at the overall cost savings of ₦73,145.05k. The per – mix cost difference is shown in Table 10 with the savings ranged from ₦ 850 - ₦ 4,098. It can also be observed that the cost of each concrete mix depends on the component proportions. Mixes with high percentage of RCA and high W/C ratio were cheaper because their RCA content and W/C ratio reduced the amounts of expensive cement and coarse aggregate.

Considering the optimal mix ratio, The Cost Benefit = $\frac{116910.683 - 112812.609}{116910.683} \times 100 = 3.51\%$

While the Overall Cost Benefits (considering all the mix proportions) = $\frac{73145.05}{3028080.41} \times 100 = 2.42\%$

CONCLUSION

The model developed in this study was for the prediction of the cost of Scheffe's optimized recycled aggregate concrete. The mathematical model with the computer program developed in this study can determine the cost benefits of Scheffe's optimized recycled aggregate concrete when the mix ratios are specified and vice versa The formulated model was tested for adequacy at 5% level of significance and was found to be adequate. Scheffe's optimized recycled aggregate concrete was more economical compared to natural aggregate concrete. The cost benefit of the optimal mix ratio was 3.51% while overall cost benefit considering all the mix ratios was 2.42%. The cost model is reliable, easy to use and saves time compared to the response surface methods such as the least square method.

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