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Optimal Raw Material Mix for the Production of Rice Husk Ash Blended Cement

Akeem Ayinde Raheem[1*] and Mutiu Abiodun Kareem[1]

[1]Civil Engineering Department, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.

*Corresponding E-mail: aaraheem@lautech.edu.ng

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Abstract

Rice husk is the residue left after the grain is removed. Previous studies considered the conversion of rice husk into useful material by incorporating its ash into cement on site. However, the mixing on site was arbitrary. In this study, the optimization of Rice Husk Ash (RHA) blended cement in a cement factory was carried out. Fourteen (14) experimental runs of RHA-blended cements were generated using three-factor D-optimal design (RHA, Ordinary Portland Cement (OPC) clinker and gypsum). The chemical compositions of RHA, OPC-clinker and RHA-blended cements produced were determined using X-ray fluorescence analyzer. The physical properties of the RHA-blended cement produced were also determined. Design-Expert 6.0.8 was used to optimize the RHA-blended cement. The optimum mixture components for the production of RHA-blended cement were 12.45% RHA, 83.44 % OPC-clinker and 4.11 % gypsum. The D-optimal design was effective in enhancing the properties of RHA blended cement.

Keywords: *Rice husk Ash (RHA), Pozzolan, Ordinary Portland cement (OPC), Blended cement*

1.0 Introduction

Rice husk ash (RHA) which is the focus in this work is obtained after burning rice husk which is the major by-product of the rice milling industries. The husk covers the grains and it contains about 50 % cellulose, 25-30 % lignin and 15-20 % silica [1]. It is commonly found in rice producing countries. In Nigeria, rice husk is produced in most northern and the north central states where rice is grown. Some of the states are: Niger, Kaduna, Kano, Benue, Nasarawa, Kogi and Kwara [28]. The husk is mostly indigestible to human and for this reason, they are generally regarded as residue, which are being burnt or disposed to the environment in an uncontrolled manner thereby causing pollution (27]. Thus, finding use for this by-product is an environmental-friendly method of disposal of large quantities of materials that would otherwise pollute land, water and air.

2.0 Literature Review

The current cement production rate of the world, which is approximately 1.2 billion tons/year, is expected to grow exponentially to about 3.5 billion tons/year by 2015 [32]. This increasing demand for cement is expected to be met by partial cement replacement [13]. In the quest for alternative binder or cement replacement material, ashes from agricultural residues generally regarded as waste and found to possess pozzolanic properties have been used to replace cement. Some of the wastes that had been widely studied are; rice husk ash Rice [12,17,22,25,27]; corn cob ash [2, 42,43,44,45]; oil palm residue ash [24,31]; saw dust ash (18,40,46,47]; Groundnut husk Ash [16] and bagasse ash [36]. Their uses are receiving more attentions since they result in enhanced properties of the blended cement concrete [24].

Statistical mixture design methods have been used in designing, formulating, developing and analyzing new scientific studies and products such as detergents, gasoline, foods, and metal alloys. They have seen little applications in cement and concrete industry. Some reported application of these methods in cement and concrete industries include optimization of concrete mixture proportion using statistical mixture method [35], and the application of D-optimal for optimization of Portland cement, fly ash, silica fume and calcium carbonate [3].

Previous studies showed that researchers [17, 25, 30] have worked on the mixture of RHA and OPC obtained by trial and error methods at the point of need, without considering blending of RHA, OPC-clinker and gypsum obtained using statistical design method during factory production of the cement. This research focused on the production of blended cement by incorporating RHA into the mixture of OPC-clinker and gypsum using D-optimal design method to generate the mixture before the production. The emphases are on the conversion of waste to useful products by substituting it during cement production in order to minimize OPC-clinker consumption.

The statistical mixture experiment provides the opportunities for the understanding of the interaction of the mixture components in relation to several responses, which cannot be possible to understand by the conventional trial-and-error method with cost effective mixture proportions. The D-optimal design provides the opportunity for the optimization of any property subject to constraint on other properties and this has an important implication for the specifications and production.

The D-optimal design is a statistical approach for use with categorical factors as an alternative to the general factorial design option Design Expert, 2013 [15]. The D-optimal design chooses an ideal subset of all possible combinations, based on the model that you specify. D-ptimal design like Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for the modelling and analysis of problems in which a response of interest is influenced by several variables [4, 23, 41]. Analysis of the mixture experiment requires determination of the regression model that relates the response variable to components, and then use of a model for the prediction of optimization. [33] derived the polynomial equation (Eq. (1)) for mixture problems and termed it as canonical polynomial. Assuming, the mixture experiments have q factor $x_{1,}\ x_{2}, \ldots ,x_q$ defined on the regular q simplex S^{q-1}. If ϵ denotes random error, the simplest is an additive polynomials mixture model when $f(\times)' = (x_1, x_2, \ldots, x_q, x_1x_2, x_1x_3, \ldots, x_{q-1}x_q)$ and n=2 the second degree Scheffé's polynomial mixture model is

$$E(Y) = \eta = \sum_{i=1}^{q} \beta_i x_i + \sum_{i<j}^{q} \beta_{ij} x_i x_j + \epsilon \ldots n \quad (1)$$

Where:
n = number of responses in the measure
x = mixture component
β= constant
ϵ = random error term

When a polynomial models have been obtained, optimization may be performed using mathematical (numerical) or graphical (contour plot) approaches [35]. Numerical optimization requires defining an objective function (called desirability or score function) that reflects the levels of each response in terms of minimum (zero) to maximum (one) desirability. The desirability lies between 0 and 1, and its represents the closeness of a response to its ideal value. If a response falls within the unacceptable interval, the desirability is 0 and if it falls within the ideal intervals or the response reach an ideal value, the desirability is 1 [4]. The numerical optimization requires constraints for the desired response values [3]. For this reason, the specification from standards must be taken into consideration.

The desired response parameters were defined as minimum and maximum as the set goal (objective) of each component to be achieved. Technical numerical values were defined as lower, upper and upper. The overall desirability D combines the individual desirability that measures how well the combined goals satisfied all responses. The maximum value of D can give the most desirable point in the mixture region for all the properties simultaneously. If varying degrees of importance are assigned to the different responses, the objective function is presented in Eq. (2).

$$D = (d_1^{r_1} \times d_2^{r_2} \times .... \times d_n^{r_n})^{\frac{1}{\Sigma r_i}} \left(\prod_{i=1}^{n} d_i^{r_i}\right)^{\frac{1}{\Sigma r_i}} \quad (2)$$

Where:
n = number of responses in the measure.
r = different responses

The numerical optimization finds a point that maximizes the desirability function of equation 2.

3.0 Methodology

The materials and method involved in executing the research are discussed in the following sections.

3.1 Materials

Locally available rice husk in Nigeria was collected from Rice Milling Industries in Ogbomoso (Oyo State). RHA was produced by burning dried rice husks using the mud kiln at the Fine and Applied Art Department, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria. The burning process continued with the temperature (measured with the aid of Thermocouple) increasing to 600 ^{o}C in about 8 h, when the rice husk turned to ash [21]. The ash was sieved after it has cooled down using 45µm sieve to obtain ash that is fine enough to react perfectly with ordinary portland cement clinker and gypsum.The analysis of the ash was carried out as specified in BS EN 196-2:1995 [9] using X-ray flourescence spectometer (Model QX 1279). The ordinary portland cement clinker (OPC-clinker) and the gypsum used for producing the blended cement were obtained from Lafarge, West Africa Portland Cement Company (WAPCO), Sagamu Plant, Ogun State, Nigeria. This is the clinker used by the company to produce Ordinary Portland cement (OPC).

3.2 Design of Experiment

The experiments were designed by using Design Expert (version 6.0.8). D-optimal Design was applied for the experimental design of RHA-blended cement mixture before production by considering the proportion limits of CEM II-type cement. The percentage of the raw materials range were 5 to 25% for RHA, 70 to 90% for OPC-clinker, and 3 to 5% for gypsum, respectively. Fourteen (14) experimental (mixtures) runs were generated by the design while four (4) out of these were replicated to provide an estimate of repeatability. Table 1 shows the pecentages of each component of RHA-blended cement mixtures as geneated by the Design Expert (version 6.0.8).

Table 1: Experimental design of RHA-blended cement

Run Order	Components		
	RHA (%)	OPC Clinker (%)	Gypsum (%)
1	25.00	70.00	5.00
2	25.00	70.00	5.00
3	5.00	90.00	5.00
9	5.00	90.00	5.00
4	15.00	80.00	5.00
5	25.00	72.00	3.00
6	25.00	72.00	3.00
7	11.25	85.25	3.50
8	20.25	76.25	3.50
10	7.00	90.00	3.00
14	7.00	90.00	3.00
11	20.25	75.25	4.50
12	25.00	71.00	4.00
13	15.50	80.50	4.00

3.3 Cement Mixtures

The various percentages of the mixture components generated was converted to grams as shown in Table 2, so that batching can be done by weight in grams before milling. A total of 4000g of the mixture of these materials was prepared at a time as the total weight of charged per batch calibrated for the milling machine at Lafarge (WAPCO) Sagamu works. Fourteen (14) mixtures of RHA-blended cements were prepared in line with the experimental design. The equipment used for cement milling was the Laboratory ball mill (Model R. PM1400/50, Serial Number 93021.A). The ball mill was charged with the required weight of clinker, RHA and gypsum after which it was firmly tightened and put in operation for one (1) hour.

Table 2: Mix Proportion in Terms of Weight of Components

Run Order	**Components**		
	RHA (g)	**OPC Clinker (g)**	**Gypsum (g)**
1	1000	2800	200
2	1000	2800	200
3	200	3600	200
9	200	3600	200
4	600	3200	200
5	1000	2880	120
6	1000	2880	120
7	450	3410	140
8	810	3050	180
10	280	3600	120
14	280	3600	120
11	810	3010	180
12	1000	2840	160
13	620	3220	160

3.4 Testing Procedure

The chemical characteristics of the blended cements produced considered are chemical composition (SiO_2 and Al_2O_3). The physical characteristics of RHA-blended cements that were considered are initial and final setting times, compressive strength at 2, 7, 28, 56 and 90 curing ages. All the tests were carried out in accordance with the practice at WAPCO, Sagamu Works. The standards applied for all the tests in the study are [8,9,10].

4.0 Results And Discussion

The results obtained from the various experiments carried out are discussed below.

4.1 Chemical Composition Of RHA and Clinker

Table 3 shows the elemental oxides present in rice husk ash RHA samples. The results indicate that all samples of RHA had combined percentages of silica (SiO_2) and Alumina (Al_2O_3) of more than 70%, a requirement which a good pozolan for the manufacture of blended cement should meet [10, 11, 19, 20]. The requirement of ASTM C 618 for a combined $SiO_2 + Al_2O_3 + Fe_2O_3$ of more than 70% was also satisfied. Thus, RHA is a suitable material for use as a pozzolan.

Table 3: Chemical composition of rice husk ash (RHA)

Chemical constituents	Percentage composition (%)			Average
	Sample 1	Sample 2	Sample 3	
SiO_2	81.04	86.51	78.87	82.14
Al_2O_3	1.80	0.61	1.61	1.34
Fe_2O_3	1.01	0.60	2.20	1.27
CaO	1.60	0.71	1.33	1.21
MgO	2.25	1.53	2.11	1.96
SO_3	0.45	0.02	0.03	0.17
Na_2O	0.16	0.05	0.21	0.14
K_2O	2.35	1.89	2.03	2.09
P_2O_5	5.26	4.20	9.87	6.44
Total $SiO_2 + Al_2O_3$	82.84	87.12	80.48	83.48

Table 4 shows the chemical composition of the clinker used. Values obtained for the elemental oxides are in agreement with the range of values reported in [7,19,39]. The composition also satisfied the reequirement in the available standards [5,11,37]. Thus the clinker is quite suitable for cement production.

Table 4: Chemical composition of the clinker used

Chemical constituents	**Percentage composition (%)**			**Average**
	Sample 1	**Sample 2**	**Sample 3**	
SiO_2	20.54	20.78	20.85	20.7
Al_2O_3	5.37	5.05	5.41	5.28
Fe_2O_3	3.26	3.48	3.12	3.29
CaO	62.97	62.89	61.82	62.5
MgO	2.59	2.59	2.69	2.62
SO_3	0.26	0.26	0.37	0.30
Na_2O	0.09	0.10	0.10	0.0
K_2O	0.10	0.07	0.15	0.11
LSF	95.06	94.31	92.01	20.72
SR	2.38	2.44	2.44	2.4
AR	1.65	1.45	1.73	1.61
Free lime	1.10	0.95	0.90	0.98

4.2 Regression Model and Analysis of Variance for D-Optimal Design

The average values for SiO_2, Al_2O_3, initial and final setting times and compressive strength at 2, 7, 28, 56 and 90 curing ages are shown in Table 5. D-optimal design experimental data obtained was used to evaluate the functional relationship between RHA-blended cements experimental factors (RHA, OPC Clinker and Gypsum) to corresponding responses (SiO_2, Al_2O_3, initial and final setting times, and compressive strength at 2, 7, 28, 56 and 90 curing ages. The second order polynomial equation was fitted between the responses and the input variable of RHA (A), OPC Clinker (B) and gypsum (C).

The developed model shows the influence of each factor and combined factors on the characteristics of RHA-blended cement. The results of Analysis of variance (ANOVA) of the mixture cubic model amd the empirical model obtained are presented in Table 6. However, interactions between the parameters of RHA-blended cement are highly significant (confidence level = 99.99 %) with p values of 0.0001. Furthermore, the values of “Prob > F” less than 0.0500 indicate model terms are significant. The Model F-value of 63660000.00 and 35.24 for the responses implies the models are significant. In this case, AB, AC, BC, ABC, AB(A-B), AC(A-C), BC(B-C) in the (R^2) for all the responses. 1.000 is R^2 values for equations which revealed that the regression models are statistically reliable, dependable and significant. The values of predicted multiple correlation coefficients for the models (pred.R^2 =0.9521 and 0.833439) are in reasonable agreement with the value of the adjusted multiple correlation coefficients (adj.R^2 = 1.000). Adequate precision measures the signal to noise ratio of the data in the model. A ratio greater than 4 is desirable.The ratios for the models are 636600000; indicating an adequate and reliable regression model.

Table 5: Results of responses of the experimental design

Run Order	**Responses**								
	SiO2 (%)	**CaO (%)**	**Initial Setting Time (min)**	**Final Setting Time (min)**	**2-day Strength (N/mm2)**	**7-day Strength (N/mm2)**	**28-day Strength (N/mm2)**	**56-day Strength (N/mm2)**	**90-day Strength (N/mm2)**
1	32.18	50.76	115	180	8.59	15.63	15.89	27.88	33.59
2	32.18	50.76	115	180	8.59	15.63	15.89	27.88	33.59
3	23.4	60.52	220	360	6.77	14.06	23.70	24.94	25.78
9	26.52	56.18	440	725	9.89	15.37	18.23	28.38	37.50
4	33.07	48.14	65	135	9.38	10.16	21.87	33.27	34.38
5	33.07	48.14	65	135	9.38	10.16	21.87	33.27	34.38
6	26.14	56.39	135	225	8.86	15.10	26.82	28.38	37.50
7	31.84	50.76	25	45	4.95	11.46	24.74	22.66	23.44
8	23.4	60.52	220	360	6.77	14.06	23.70	24.94	25.78
10	24.65	59.20	220	360	11.46	15.89	26.57	25.09	25.00
11	33.36	48.52	175	360	8.59	17.45	15.89	18.50	23.44
12	27.70	56.12	445	530	9.12	13.80	17.18	22.17	22.65
13	24.65	59.20	220	360	11.46	15.89	26.57	25.09	25.00
14	30.32	50.80	395	540	9.64	14.06	25.52	17.97	24.22

Table 6: Regression Equations and their Statistics

Response variables	**Regression equations**	**R^2_{adj} %**	**Mean square error**	**Lack-of-fit p-value**
SiO_2(%)	$\mathrm{SiO2} = -32.69330 \ast A - 7.26116 \ast B + 85759.98052 \ast C + 0.72692 \ast A \ast B - 1316.73537 \ast A \ast C - 1346.49845 \ast B \ast C + 9.56994 \ast A \ast B \ast C + 6.09527E - 003 \ast A \ast B \ast (A - B) + 4.53226 \ast A \ast C \ast (A - C) + 4.94789 \ast B \ast G \ast (B - G)$	100	28.75	0.0001
CaO(%)	$\mathrm{CaO} = + 183.69407 \ast A + 63.85931 \ast B - 6.85657E + 005 \ast C + 4.78497 \ast A \ast B + 10487.94903 \ast A \ast C + 10778.19588 \ast B \ast C - 76.22394 \ast A \ast B \ast C - 0.047074 \ast A \ast B \ast (A - B) - 35.63762 \ast A \ast C \ast (A - C) - 39.70851 \ast B \ast C \ast (B - C)$	100	54.00	0.0001
Initial setting time (min)	$\text{Setting Time} = +10114.03793 \ast A + 3452.24087 \ast B - 3.84347E + 007 \ast C - 252.27331 \ast A \ast B + 5.88823E + 005 \ast A \ast C + 6.03709E + 005 \ast B \ast C - 4276.79467 \ast A \ast B \ast C - 2.41510 \ast A \ast (A - B) - 2013.12904 \ast A \ast C \ast (A - C) - 2220.47640 \ast B \ast C \ast (B - C)$	100	203.93	0.0001
Final setting time (min)	$\text{Final Setting Time} = 9044.66451 \ast A + 2620.10256 \ast B - 2620.10256E + 007 \ast C - 213.19694 \ast A \ast B + 4.43572E + 005 \ast A \ast C + 4.55069E + 005 \ast B \ast C - 3219.65078 \ast A \ast B \ast C - 1.86658 \ast A \ast B \ast (A - B) - 1516.71931 \ast A \ast C \ast (A - C) - 1673.68416 \ast B \ast C \ast (B - C)$	100	321.07	0.0001
Compressive strength at 2 days, N/mm^2	$\text{2day Compressive Strength} = + 35.69731 \ast A + 2.61820 \ast B - 40980.97132 \ast C - 0.51766 \ast A \ast B + 642.59517 \ast A \ast C + 637.86112 \ast B \ast C - 4.64995 \ast A \ast B \ast C - 1.85943E - 003 \ast A \ast B \ast (A - B) - 2.38524 \ast A \ast C \ast (A - C) - 2.30015 \ast B \ast C \ast (B - C)$	100	9.79	0.0001
Compressive strength at 7 days, N/mm^2	$\text{7day Compressive Strength} = + 3.82298 \ast A - 11.38883 \ast B + 1.33011E + 005 \ast C - 0.15381 \ast A \ast B - 2049.10039 \ast A \ast C - 2088.61846 \ast B \ast C + 14.93361 \ast A \ast B \ast C + 5.51797E - 003 \ast A \ast B \ast (A - B) + 7.07202 \ast A \ast C \ast (A - C) + 7.67609 \ast B \ast C \ast (B - C)$	100	17.26	0.0001
Compressive strength at 28 days, N/mm^2	$\text{28 day compressive strength} = - 713.52625 \ast A - 238.34568 \ast B + 2.57292E + 006 \ast C + 18.50987 \ast A \ast B - 39332.00697 \ast A \ast C - 40449.33516 \ast B \ast C + 285.79951 \ast A \ast B \ast C + 0.17923 \ast A \ast B \ast (A - B) + 133.45765 \ast A \ast C \ast (A - C) + 149.05689 \ast B \ast C \ast (B - C)$	95.95	21.58	0.0019
Compressive strength at 56 days, N/mm^2	$\text{56 day compressive strengt} = -439.35041 \ast A - 169.05761 \ast B + 1.80678E + 006 \ast C + 12.13959 \ast A \ast B - 27591.80669 \ast A \ast C - 28409.09211 \ast B \ast C + 200.41060 \ast A \ast B \ast C + 0.12206 \ast A \ast B \ast (A - B) + 93.36202 \ast A \ast C \ast (A - C) + 104.72463 \ast B \ast C \ast (B - C)$	100	25.28	0.0001
Compressive strength at 90 days, N/mm^2	$\text{90 day compressive strength} = - 367.29742 \ast A - 170.59972 \ast B + 1.79355E + 006 \ast C + 10.97443 \ast A \ast B - 27374.13734 \ast A \ast C - 28207.54744 \ast B \ast C + 198.82848 \ast A \ast B \ast C + 0.11556 \ast A \ast B \ast (A - B) + 92.48879 \ast A \ast C \ast (A - C) + 104.0357 \ast B \ast C \ast (B - C)$	100	21.91	0.0001

4.3 Response Trace Plots

Once the model is obtained, it can be interpreted graphically using response trace plots [35]. Trace plots have been widely used in mixture experiment to measure the effects of mixture components on the response [14]. The response trace plots for each response are shown in Figure 1-9. Each figure consists of three overlaid plots, one for each component. For a given component, the fitted value of the response is plotted as the component is varied from its low to high setting in the constrained region, while the other components are held in the same relative ratio as a specified reference point.

The parabolic nature of the curves illustrates that the estimated response value is quite sensitive to changes from the reference point that are made in mixture proportions. Figure 1 indicates that increasing the amount of RHA and OPC-clinker increased the SiO_2 content of RHA-blended cement, while gypsum had no significant influence on SiO_2 content of RHA-blended cement. Figure 2, 3 and 4 illustrate that increasing the amount of RHA and OPC-clinker has a negative influence while gypsum content had great influence on CaO content, the initial and final setting time of RHA-blended cement. Figure 4 indicates that the addition of RHA and OPC-clinker first decline and later impove the 2-day compressive strength of RHA-blending cement while gypsum shows no significant influence.

Figure 6,7,8 and 9 shows that RHA and OPC-clinker had positive influence on 7-day, 28-day, 56-day and 90-day compressive strength of RHA-blended cement, while gypsum had has no significant influence on SiO_2 content of RHA-blended cement.

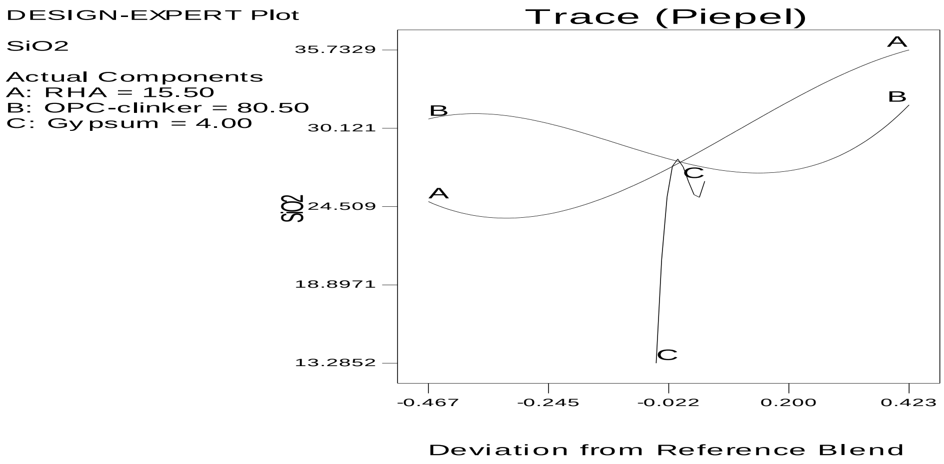

Figure 1: Trace plot for SiO_2

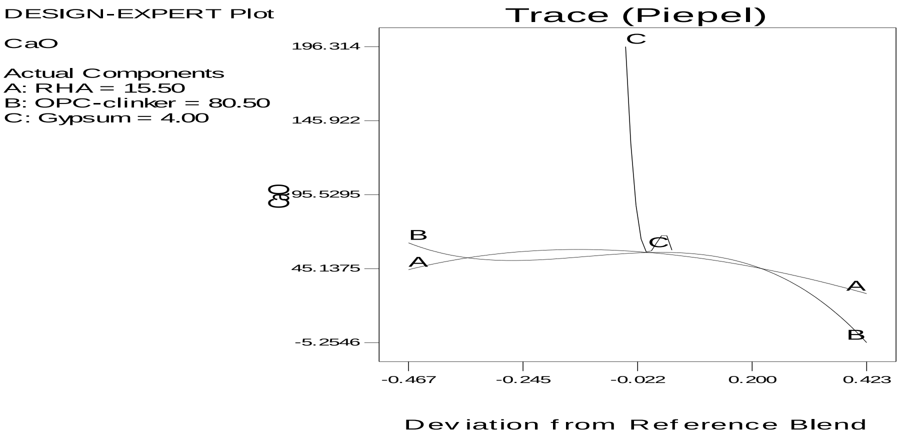

Figure 2: Trace plot for CaO

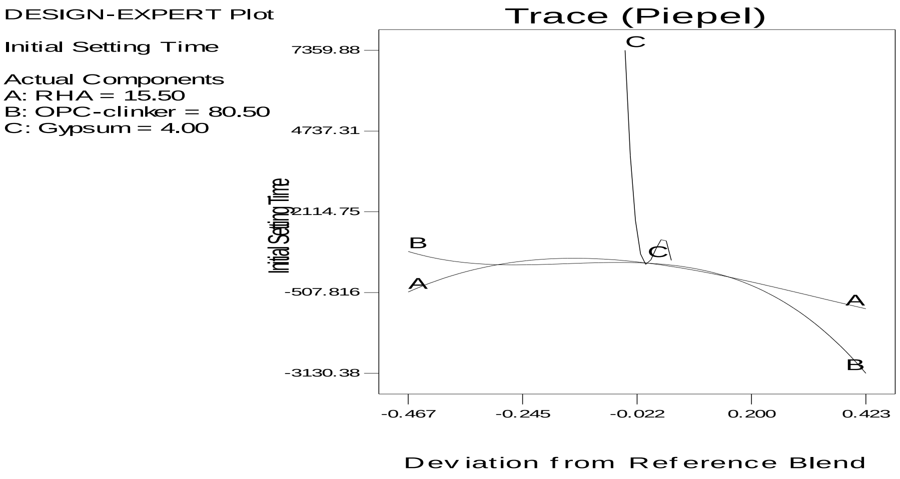

Figure 3: Trace plot for Initial settting time

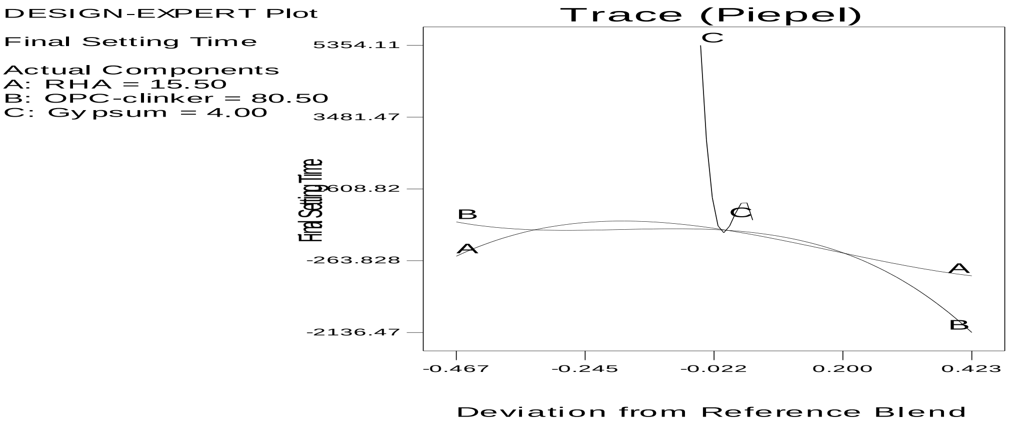

Figure 4: Trace plot for Final setting time

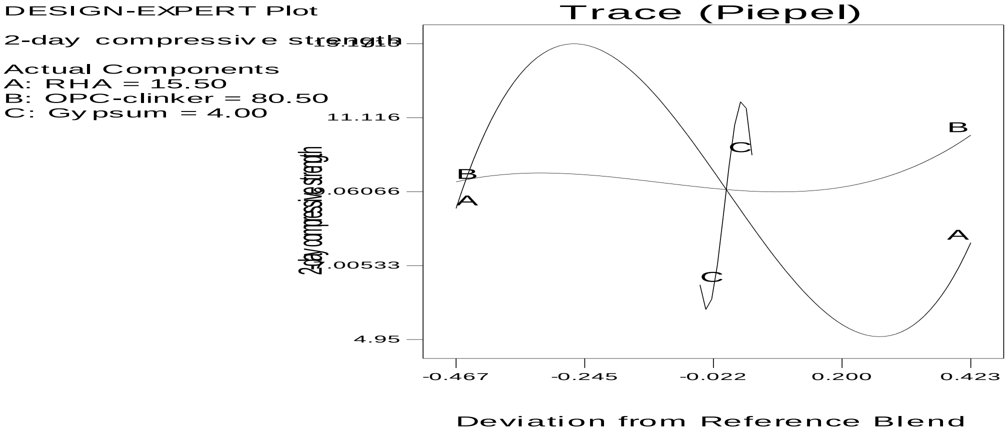

Figure 5: Trace plot for 2-day compressive strength

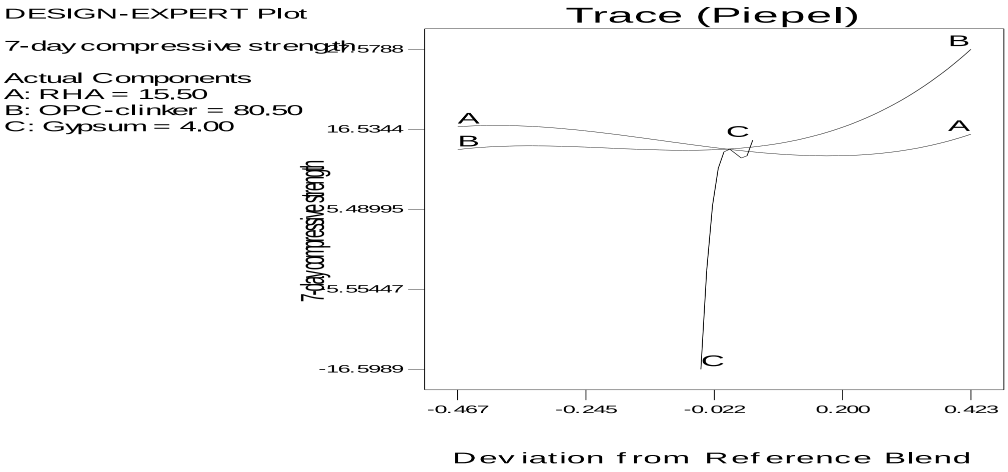

Figure 6: Trace plot for 7-day compressive strength

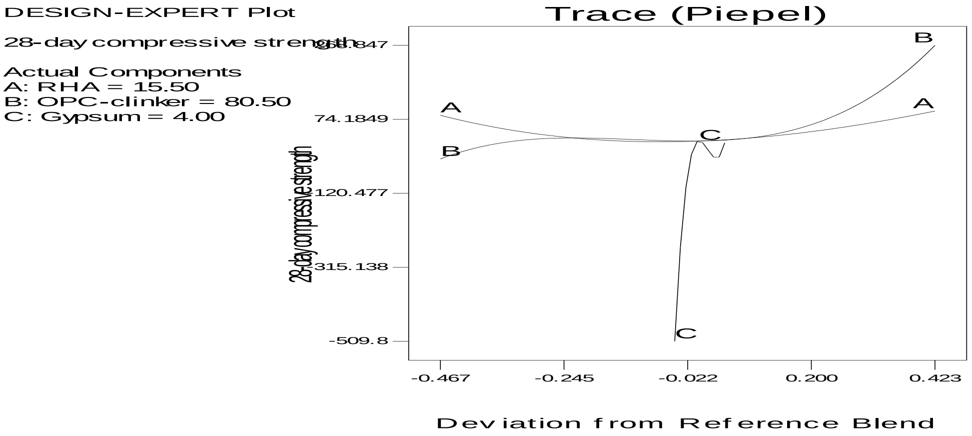

Figure 7: Trace plot for 28-day compressive strength

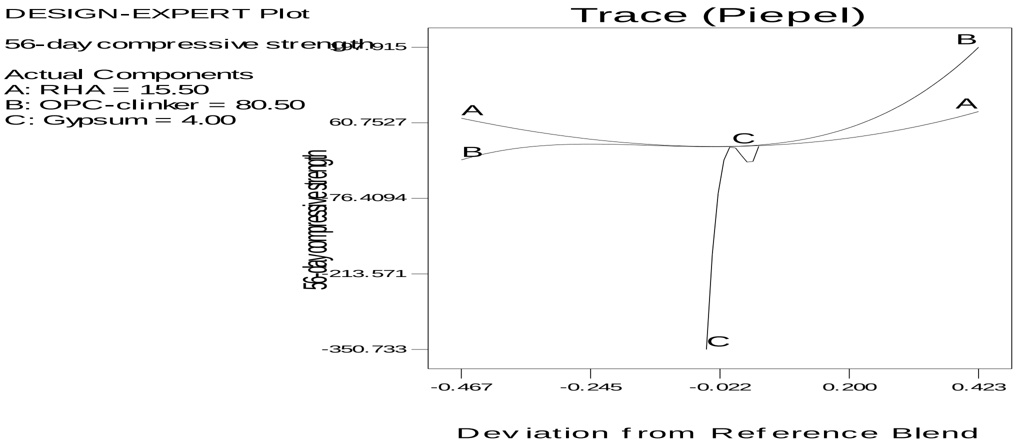

Figure 8: Trace plot for 56-day compressive strength

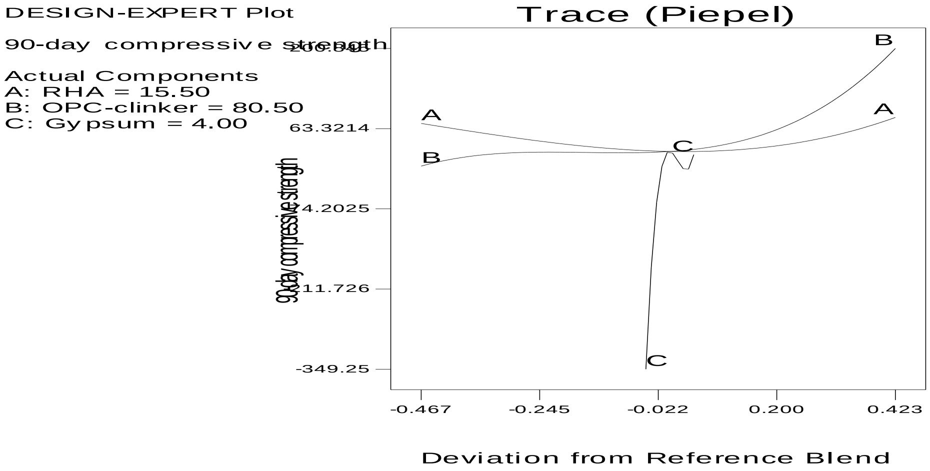

Figure 9: Trace plot for 90-day compressive strength

4.4 Multi Response Optimization using Desirability Function

The goal of optimization is to find a good set of conditions that will meet all the goals. It is not necessary that the desirability value is 1.0 as the value is completely dependent on how closely the lower or upper limits are set relative to the actual optimum. The constraints for the optimization of individual characteristics are given in Table 7. Goals and limits are established for the responses in order to accurately determine their impact on it's desirability. A set of 3 optimal solutions is derived with specific design constraints for SiO_2, Al_2O_3, initial and final setting times and compressive strength at 2, 7, 28, 56 and90 curing ages. The set of condition having maximum overall desirabilility is selected as the optimum condition and is given in Table 8.

Table 7: Range of the components and responses for desirability

Name	**Goal**	**Lower Limit**	**Upper Limit**	**Lower Weight**	**Upper Weight**	**Importance**
RHA	maximum	5	25	1	1	3
OPC-clinker	minimum	70	90	1	1	3
Gypsum	Is equal to 4.11	3	5	1	1	3
SiO_2(%)	Target = 23.4	23.4	33.36	1	1	3
CaO(%)	Target= 60.52	48.14	60.52	1	1	3
Initial setting time (min)	Target = 45	25	445	1	1	3
Final setting time (min)	Target = 375	45	725	1	1	3
Compressive strength at 2 days, N/mm^2	maximum	4.95	11.46	1	1	3

Name	**Goal**	**Lower Limit**	**Upper Limit**	**Lower Weight**	**Upper Weight**	**Importance**
Compressive strength at 7 days, N/mm^2	maximum	10.16	17.45	1	1	3
Compressive strength at 28 days, N/mm^2	maximum	15.89	26.82	1	1	3
Compressive strength at 56 days, N/mm^2	Maximum	17.97	33.27	1	1	3
Compressive strength at 90 days, N/mm^2	Maximum	21.87	37.5	1	1	3

Table 8: Optimal Set of Condition with highest desirability

RHA (%)	**OPC Clinker (%)**	**Gypsum (%)**	**SiO_2 (%)**	**CaO (%)**	**Setting Time (min.)**		**2 days Strength (N/mm^2)**	**7 days Strength (N/mm^2)**	**28 days Strength (N/mm^2)**	**56 days Strength (N/mm^2)**	**90 days Strength (N/mm^2)**	**Desirability**
					Initial	**Final**						
12.45	83.44	4.11	26.33	51.54	180.77	401.04	11.32	16.36	43.57	39.91	50.11	0.662

4.5 Ramp Function and Bat Function Graph

The ramp function graph shown in Fig. 10 was drawn using Design expert and it shows the desirability for each factor and each response. The red dots on the ramps indicate settings of input factors and the resulting predictions for each response. The Bar graph shows graphically how well each factor and response achieved its goal and the desirability of the optimum mixture components and responses.

The result of the optimization provides Three (3) solutions for the optimum mixture components, responses and desirability. According to [3], the maximum desirability (D) can give the most desirable point in the mixture region for all the properties simultaneously. Hence, the solution having maximum overall desirability of 0.662 with the ramps shown in Fig. 10 is the optimization result for the optimization of RHA-blended cement.

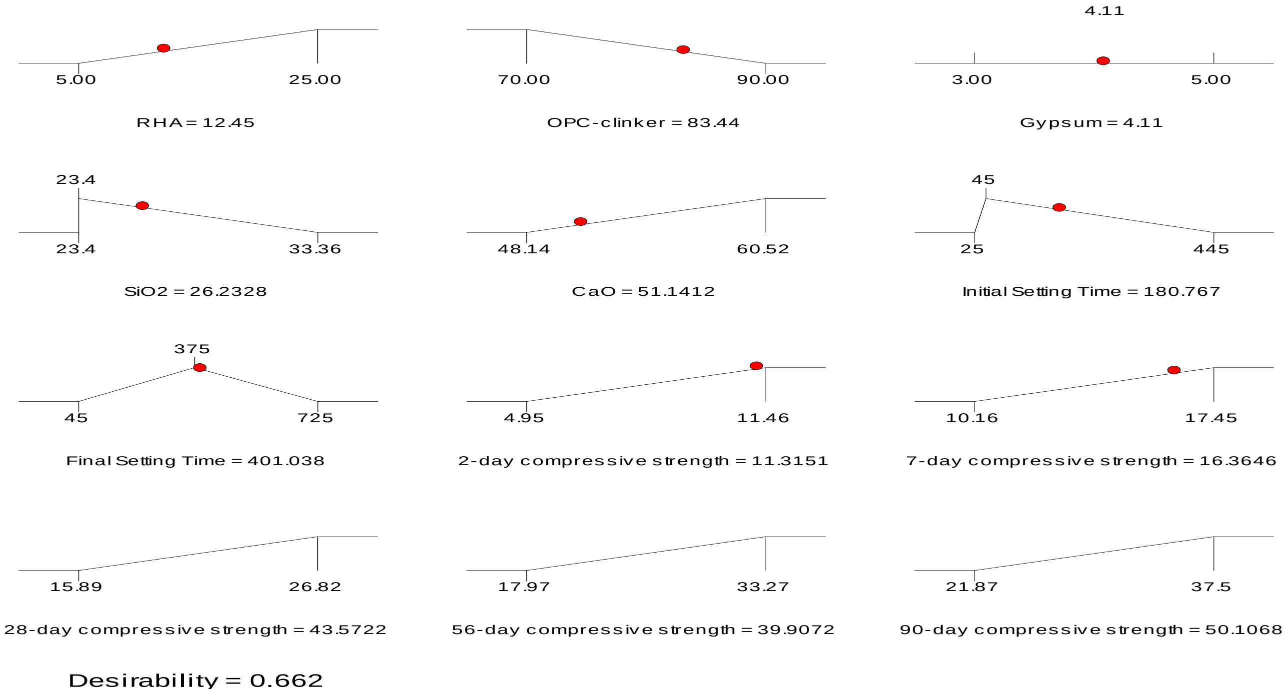

Figure 10: Ramp graph showing desirability for responses

5.0 Conclusions

From the results of the various tests performed, the following conclusions can be drawn:

(i) Rice husk ash (RHA) is a suitable material for use as a pozzolan, since it satisfied the requirement for such a material.
(ii) The D-optimal design was effective in optimizing the properties of RHA-blended cement.
(iii) Numerical optimization determined the optimum mixture components for the production of RHA-blended cement to be 12.45 % for RHA, 83.44 % for OPC-clinker and 4.11 % for gypsum.

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