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Effect of Combining Maize Straw and Palm Oil Fuel Ashes in Concrete as Partial Cement Replacement in Compression

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Abstract

The high energy consumption connected with cement manufacturing, as well as the depletion of limestone resources and the release of carbon dioxide, which contributes to global warming, are all important issues that must be addressed. Partially replacing cement with agricultural wastes in concrete, which reduces cement output, is an innovative solution to this problem. This paper examined the effect of combining Palm Oil Fuel Ash (POFA) and Maize Straw Ash (MSA) as partial replacement of cement on the compressive strength of Grade 20 concrete at 0 - 30 % POFA and 0 - 30 % MSA using Historical data under the Response Surface study in Design-Expert software. The concrete cubes were tested at 7, 28, and 56 days of curing. It was discovered that there was a decrease in the compressive strength of the concrete with the percentage increase in the quantity of the POFA and MSA for all the curing days considered. However, there was a progressive increase in the compressive strength with an increase in the days of curing. The optimum combination of percentages of POFA, MSA and cement that gave a strength greater than the target compressive strength of 20 N/mm^2 in 56 days is 30 % POFA and 16.6 % MSA and 53.4 % Cement at 0.58 water-cement ratio.

Keywords: Cement replacement, Concrete, Compressive strength, Maize straw ash, Palm oil fuel ash

Introduction

Concrete comprises of cement, coarse and fine aggregates with water to aid binding. Cement makes up about 10 - 15 % of the total mass of concrete [1]. Production of cement not only involves high consumption of energy at high temperatures (roughly in the range of 1,500 °C) but also produces poisonous gases among which includes CO_2, CH_4 and NO_3 into the atmosphere [2] Efforts have been made to reduce raw materials consumption, ensure environmentally friendly operations and improve the quality of cement. To achieve this, consideration is being given for partial replacement for cement using waste materials such as maize straw and rice husk [3-6]. Research has shown that these agricultural wastes contain highly reactive silica which reacts with calcium hydroxide in concrete, resulting in compact concrete microstructure [7].

Due to the increase in population and industrialization, the production of waste materials and the extinction of natural sources have increased alongside the high demand for building materials [8]. High energy demand associated with the production of cement as well as the depletion of limestone deposits and emission of carbon dioxide which causes global warming are major problems which researchers strive to find solutions. These have resulted in the search for alternative materials to replace existing building materials. Hence, the rapid development of new technology in material science.

Globally, researchers have made significant contributions to identify potential applications of by-products as a replacement to construction materials. Particularly, research has been geared towards improving the properties of cement and potential replacement of cement in concrete. Agricultural and industrial wastes possess pozzolanic properties conforming to the requirement in BS EN 197-1 [9] and have been studied and applied as partial replacements for cement [10]. According to Okwadha [11]; Ugwuanyi and Onuamah [12], the use of plant ashes such as those obtained from maize cob, sawdust, and

sugarcane bagasse as cement replacement should be encouraged for use in concrete to reduce environmental degradation associated with the mining of cement manufacturing materials. This would also reduce the construction budget associated with the high cost of cement since blended concrete of higher strength can be made with longer curing periods [13].

Maize straw ash is the burnt residue of the leaves, stalks, and cobs of maize plants left on the field after harvest [14]. MSA possesses substantial pozzolanic properties and a large amount of silica [15]. However, only a few studies have been conducted on its use in concrete.

POFA is a by-product obtained from the burning of palm tree wastes such as palm kernel shells, palm oil fiber, and palm oil husk. They are commonly disposed of in open spaces triggering environmental pollution problems resulting in health hazards. Owing to its high pozzolanic properties and abundance, many studies have been conducted to evaluate its use in construction [16-17]. Pone *et al*. [18] reported that POFA performed well as a pozzolan in concrete just like Silica fume. They recommended its use up to 5 % in concrete for precast and prestressed girders.

There has been no study on the effect of combining POFA and MSA in concrete. Hence, this work investigates the combination of POFA and Maize Straw Ash (MSA) as a suitable replacement for cement and its strength properties in concrete.

Materials and methods

The material used in this study was POFA, MSA, cement, aggregate **(**fine and coarse**)**, and water**.** Ordinary Portland cement **(**Dangote cement brand**)** of grade 32.5 N with a specific gravity of 3.10, which conforms to NIS 444**-**1 [19], was used for this research. Coarse aggregate of 12.5 mm diameter and fine aggregate of sizes ranging from 0.1 to 1 mm diameter conforming to the requirement in BS EN 12620:2002+A1:2008 [20] was utilized. Potable water of pH 7 as recommended by Neville [21] and Odeyemi *et al.* [6] was used for the concrete mix. Samples of POFA and MSA used in the research after sieving are shown in **Figure 1**.



(a) POFA after sieving.



(b) MSA after sieving.

Figure 1 POFA and MSA after sieving.

Particle size distribution of the fine aggregates utilized for this research was conducted as stipulated in BS EN 12620:2002+A1:2008 2008 [20] The percentage of the particles passing through the sieves (**Table 1**) was plotted against the particle diameters and presented in **Figure 2**. The fineness modulus for the fine aggregate was obtained from Eq. (1) while the uniformity coefficient, which reveals the grading of the aggregate, was calculated from the graph using Eq. (2);

$$Fineness\ modulus = \frac{Total\ cummulative\ percentage\ retained}{100} \quad (1)$$

$$C_u = \frac{D_{60}}{D_{10}} \quad (2)$$

where: C_u is the Uniformity coefficient, D_{60} represents the diameter of particles matching 60 % fines passing through the sieves on the cumulative particle-size distribution curve while D_{10} represents the diameter of particles matching 10 % fines passing on the cumulative particle-size distribution curve. If the $C_u$of the soil sample is less than 4.0 it can be deduced that the material sample is uniformly graded but if C_u of the sample is greater than 4.0 the material is well graded [21-23].

Table 1 Sieve analysis details for fine aggregate.

Diameter of sieve (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
1.000	340.11	453.69	113.58	22.7	77.3
0.850	333.29	373.54	40.25	8.1	69.2
0.600	313.52	436.44	122.92	24.6	44.7
0.500	299.5	369.29	69.79	14.0	30.7
0.300	278.79	386.57	107.78	21.6	9.1
0.250	271.84	287.51	15.67	3.1	6.0
0.180	269.78	289.79	20.01	4.0	2.0
pan	371.65	381.65	10	2.0	0.0
		TOTAL	**500**	100.0	

POFA was gotten from the byproduct of palm trees. The fiber itself was gotten after oil had been extracted from the palm fruits for oil production. The fiber was then gathered and sun-dried. The ash (POFA) was gotten from the controlled burning of dried palm oil fibers at a temperature of 650 °C for 2 h as recommended by Mehmannavaz *et al.* [24] and Odeyemi *et al.* [6]. The ash was allowed to cool for a day and then sieved using a 90 µm sieve. MSA was gotten from the remains of the maize plant after the maize has been harvested. The dry straws were uprooted, and the root cut off and then subject to controlled burning at 650 °C for 2 h as recommended by Mehmannavaz *et al.* [24] and Odeyemi *et al.* [6]. The ash was allowed to cool for a day and then sieved using a 90 µm sieve. The POFA and MSA samples were examined in the laboratory for X-Ray Fluorescence (XRF) analysis to determine their chemical composition.

The absolute volume method as specified by BS EN 206:2013+A1:2016 [25], Neville [21] and Shetty [22] was adopted for the design mix with a characteristic of 20 N/mm^2. Concrete cubes of 100 mm by 100 mm by 100 mm were cast. The cubes were cured by immersion in water for 7, 28 and 56 days, respectively since concrete containing pozzolanic materials is known to gain strength slowly at the early days of curing [26-28]. The cubes were then crushed in batches to check for their compressive strength in accordance with BS EN 12390-3:2009 [29].

The experimental setup was designed using Design expert (version 10) software. It was used in designing the percentages at which POFA and MSA can be used to partially replace cement to achieve a concrete compressive strength of M20, using a range of 0 - 30 % for both POFA and MSA.

Results and discussion

Chemical composition of ashes

The XRF analysis was used to analyze the elemental composition of the samples. The method employed in the analysis was the energy-dispersive analysis (ED-XRF) and the machine model used to determine the basic chemical composition of POFA and MSA was the Shimadzu EDXRF-702HS. **Tables 2** and **3** show the chemical compositions as well as loss of ignition of POFA and MSA, respectively.

Table 2 XRF result of POFA.

S/N	Parameters	Formulae	% Composition
1	Silicon Oxide	SiO_2	60.62
2	Aluminum Oxide	Al_2O_3	3.59
3	Ferric Oxide	Fe_2O_3	3.69
4	Titanium Oxide	TiO_2	0.73
5	Calcium Oxide	CaO	7.28
6	Lead Oxide	Pb_2O_5	3.73
7	Magnesium Oxide	MgO	3.24
8	Sulphite	SO_3	1.96
9	Sodium Oxide	Na_2O	0.66
10	Potassium Oxide	K_2O	7.49
11	Manganese Oxide	MnO	0.63
12	Nickel Oxide	NiO	0.20
13	Chromium Oxide	Cr_2O_3	0.23
14	Copper Oxide	CuO	1.37
15	Loss of Ignition	LOI	2.62

Table 3 XRF result of MSA.

S/N	Parameters	Formulae	% Composition
1	Silicon Oxide	SiO_2	38.49
2	Aluminum Oxide	Al_2O_3	3.98
3	Ferric Oxide	Fe_2O_3	0.82
4	Titanium Oxide	TiO_2	0.21
5	Calcium Oxide	CaO	10.39
6	Lead Oxide	Pb_2O_5	0.24
7	Magnesium Oxide	MgO	5.72
8	Sulphide	SO_3	3.59
9	Sodium Oxide	Na_2O	0.09
10	Potassium Oxide	K_2O	22.46
11	Manganese Oxide	MnO	2.07
12	Chromium Oxide	Cr_2O_3	0.04
13	Chloride	Cl^-	3.48
14	Loss of Ignition	LOI	6.60

The results from the XRF analysis show that both POFA and MSA have a percentage content of Silicon oxide (SiO_2) greater than 25 %. Both ashes also possess a high percentage content of Aluminum Oxide (Al_2O_3), Ferric oxide (Fe_2O_3) and Calcium oxide (CaO) which are major compounds in cement. Based on these criteria, they are suitable as pozzolans in concrete [9]. However, POFA has a higher content of SiO_2 (60.62 %) than MSA (38.49 %).

Particle size distribution

The result of the particle size distribution for the fine aggregate is presented in **Figure 2**. The dimension of the aggregate range between 0.10 to 1 mm indicating that they fall within the category of fine and medium sand [21]. The aggregate's fineness modulus was obtained as 2.99. The fineness

modulus for fine aggregates ranges from 2.3 - 3.1 [30]. This result is within the acceptable limit for fine aggregates. The $C_u = 3$ means that the fine aggregate is uniformly graded.

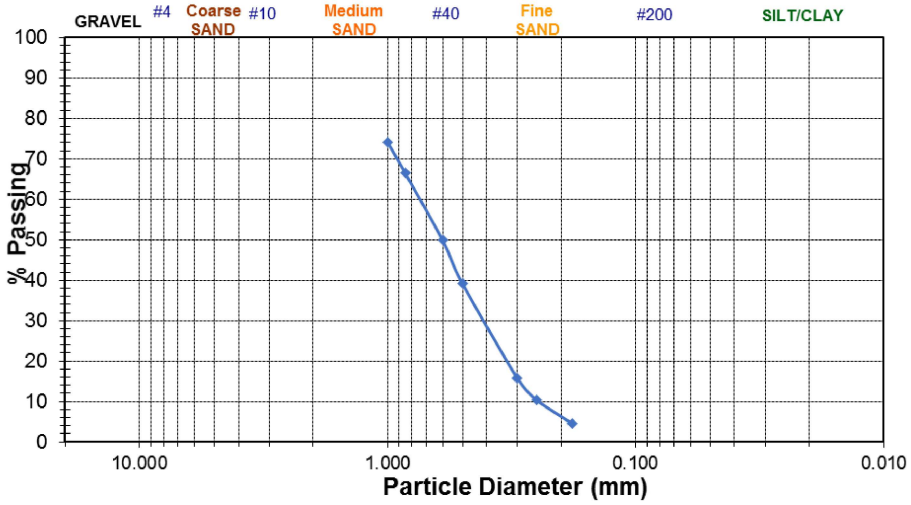


Figure 2 Particle Size distribution for Fine Aggregate.

Results for compressive strength test of concrete

The compressive strength of the cubes was gotten for 7, 28 and 56 days, respectively, the results (**Tables 4 - 6**) were analyzed using Historical data of the Response Surface study in Design Expert 10.0 software. The results obtained are shown in **Tables 3**, **4** and **5**, respectively for 7, 28, and 56 days.

Table 4 Compressive strength result for 7 days.

S/N	w/c ratio	OPC %	POFA %	MSA %	COMPRESSIVE STRENGTH (N/mm^2)
1	0.58	100	0	0	17.7
2	0.58	70	30	0	6.5
3	0.58	70	15	15	6.2
4	0.58	40	30	30	5.3
5	0.58	70	0	30	6.2
6	0.58	70	22.5	7.5	7.2
7	0.58	70	7.5	22.5	5.7

Table 5 Compressive strength result for 28 days.

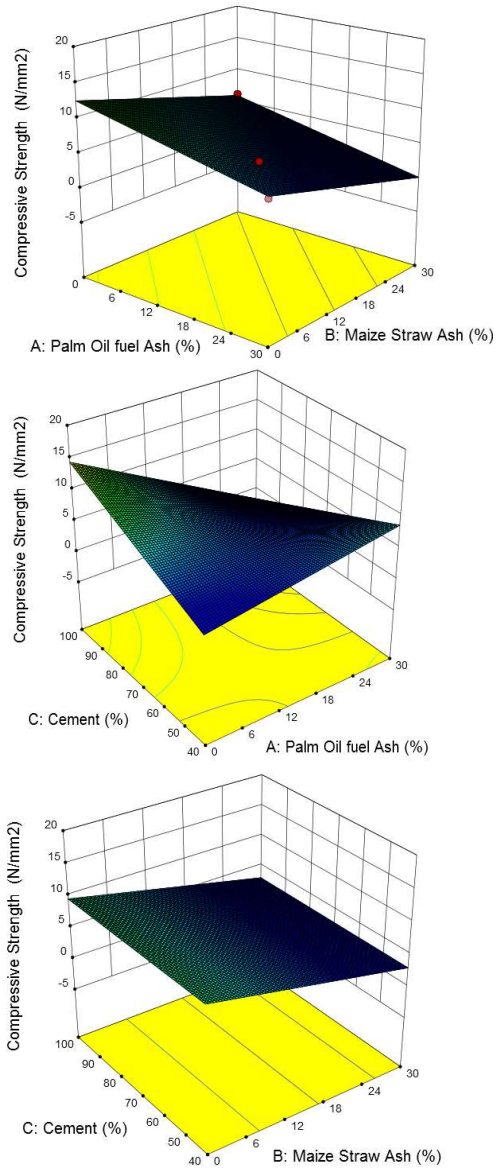
S/N	w/c ratio	OPC %	POFA %	MSA %	COMPRESSIVE STRENGTH (N/mm^2)
1	0.58	100	0	0	25.5
2	0.58	70	30	0	17.3
3	0.58	70	15	15	9.5
4	0.58	40	30	30	9.6
5	0.58	70	0	30	10.3
6	0.58	70	22.5	7.5	13.3
7	0.58	70	7.5	22.5	11.4

Table 6 Compressive strength result for 56 days.

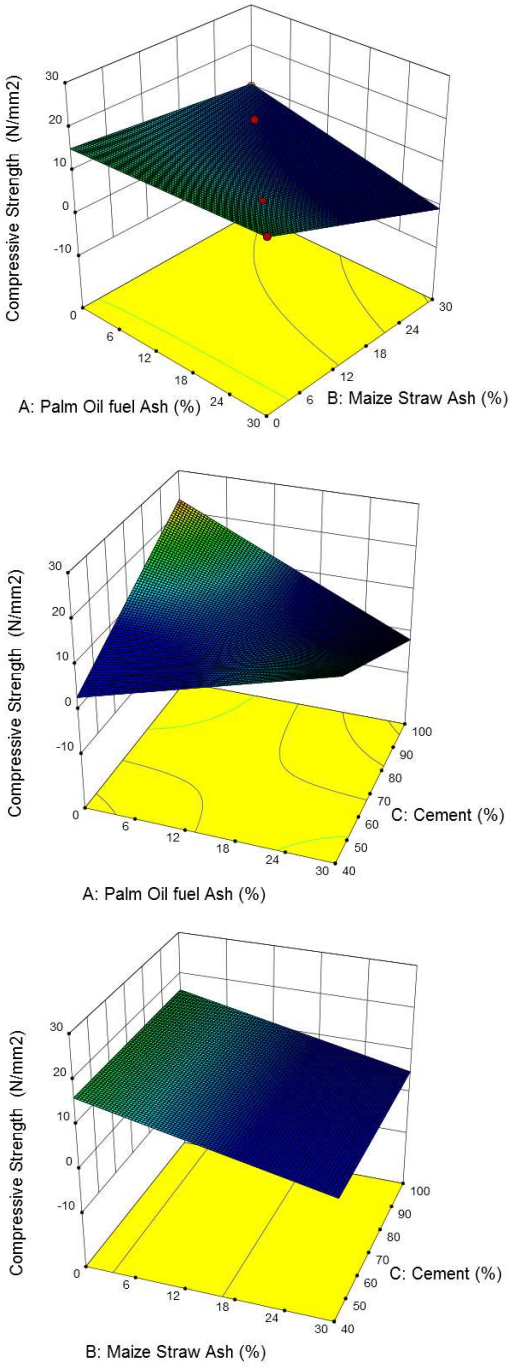
S/N	w/c ratio	OPC %	POFA %	MSA %	COMPRESSIVE STRENGTH (N/mm^2)
1	0.58	100	0	0	33.8
2	0.58	70	30	0	20.4
3	0.58	70	15	15	12.4
4	0.58	40	30	30	13.7
5	0.58	70	0	30	11.7
6	0.58	70	22.5	7.5	16.3
7	0.58	70	7.5	22.5	14.9

Compressive strength

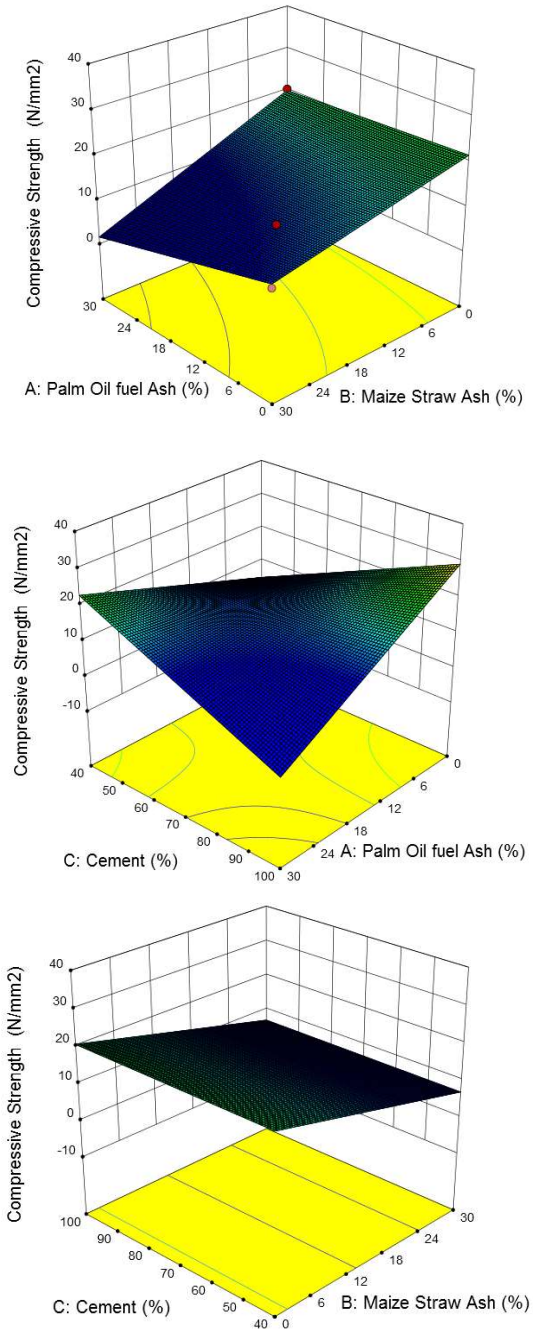
From **Figures 3(a)**, **3(b)** and **3(c)**, It was deduced that there was a decrease in the compressive strength of the concrete with the percentage increase in the quantity of the POFA and MSA for all the curing days considered. However, there was a progressive rise in compressive strength with advancement in the days of curing.



(a) Compressive strength at 7 days.



(b) Compressive strength at 28 days.



(c) Compressive Strength results at 56 days.

Figures 3 (a) - (c) Compressive strength result 7, 28 and 56 days.

Optimization of materials

In optimizing the material combinations, the objective was to maximize the compressive strength of the concrete and the percentages of POFA and MSA while the percentage of cement was minimized (i.e. increasing the quantity of the POFA and MSA in the concrete). It was discovered that the optimum

combination of percentages of POFA and MSA that will give a compressive strength of 21.94 N/mm^2 in 56 days are 30.0 % POFA, 16.6 % MSA and 53.4 % cement.

The Model that relates compressive strength to the percentage of POFA, MSA and Cement is given in Eq. (1). This model has a *p*-value of 0.0459, indicating that it is significant;

$$\text{Compressive Strength} = 13.97 - 3.15A - 6.90B - 2.34AB - 12.12AC \quad (1)$$

where A = Percentage of POFA and B = Percentage of MSA and C = Percentage of Cement

This result has a combined desirability value of 0.712 as presented in **Figure 4**.

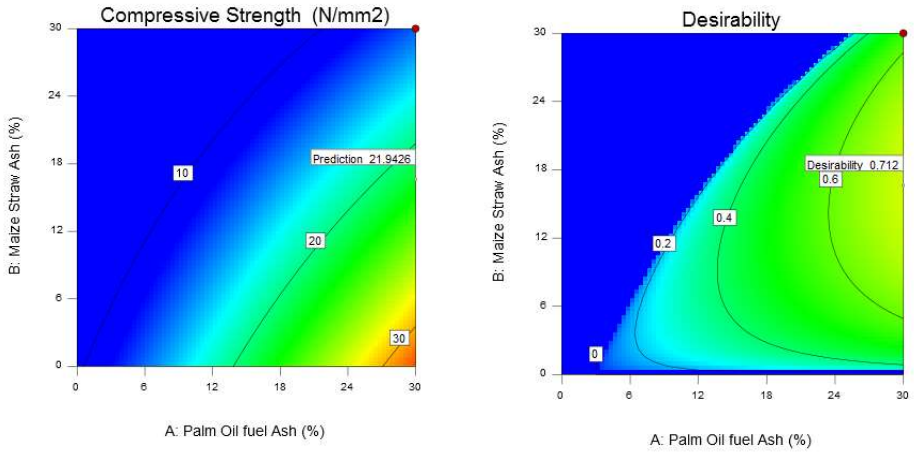


Figure 4 Desirability of the result.

Validation of results

The Predicted versus the Actual data for the compressive strength is shown in **Figure 5**. The figure reveals that both the predicted and actual data are close as shown by the linear graph. The colour range indicates the lower and upper boundaries of the compressive strengths of the concrete. The R^2 value of 0.97 and an Adjusted R^2 value of 0.93 also validate the results obtained. The Adequate Precision ratio of 12.37 is greater than 4. This indicates that the model is adequate to navigate the design space [3,31].

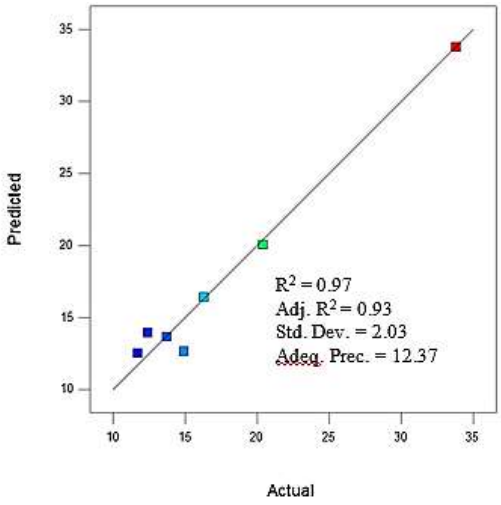


Figure 5 Predicted vs. Actual results.

Conclusions

This investigation led to the following conclusions: Palm Oil Fuel Ash and Maize Straw Ash can be used to substitute cement in concrete to some extent. The best alternative for cement in Grade 20 concrete is 30 % Palm Oil Fuel Ash and 16.6 % Maize Straw Ash.

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