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Suitability of Locally Produced Calcined Clay as Partial Replacement for Cement in Production of High Perfomance Concrete

J.C. Ezeh[1], O.M. Ibearugbulem[2], E.S. Umukoro[3]
[123]*Department of Civil Engineering, Federal University of Technology, Owerri, Nigeria.*

Abstract:
The use of clay soil subjected to thermal treatment at 800^oC to produce calcined clay as partial replacement for ordinary portland cement in production of high performance concrete was investigated in this paper. Proportioning of concrete mixes was carried out as per BS 5328: Parts 1, 2, 3 and 4, 1997 and based on the optimum packing density of aggregates, using calcined clay and superplasticizers as admixtures. Calcined clay contents of 5%, 10%, 15% and 20% by weight of ordinary portland cement was used for the concrete specimens preparations with a 0.28 water cement ratio. Strength development of the concrete produced was investigated.Results showed that at 91 days, replacement level of 10 percent produced the maximum compressive strength value of 71.14N/mm^2, hence the use of up to 10% calcined clay replacement for ordinary portland cement content in production of high performance concrete for most effective compressive strength development was recommended.

Key Word*: Calcined clay, High performance concrete, Compressive strength*

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I. Introduction

Portland cement is the key binder for concrete production. However, the high cost of Portland cement and the resulting high cost of construction coupled with the high emission rate of CO_2 (a greenhouse gas) during its production, led to the use of Supplementary Cementitious Materials (SCMs) to reduce the demand on Portland cement vis-à-vis increasing the strength and durability of concrete to give a higher performance. Low-cost or large scale housing can best be achieved by the replacement of costly conventional cementitious materials such as Portland Cement (PC) with innovative and sustainable materials such as the pozzolans; even though the various cementitious alternatives may not be capable of replacing totally the PC at the moment, but they can however partially be replaced in a variety of construction applications such as in mortar and concrete mixtures [1, 2].The amount of natural pozzolan used varies significantly based upon the activity of the pozzolan.Day [3]asserted that some natural pozzolans are used in a range of 15 to 35% based upon the mass of the total cementitious material in the concrete; also more reactive natural pozzolans can be used in lower concentrations of 5 to 15% by mass of total cementitious material; however, such low concentrations may increase expansion resulting from the altered silica reaction in the presence of some alkali-reactive aggregates. The optimal amount of natural pozzolan depends on where the concrete is used and the specifications for the work. Neville et al. [4]stated that when pozzolana is added to hydrating cement (Silicate-Pozzolana + $Ca(OH)_2$ + H_20), a gel of the cementitious substance of Calcium (a strong gel) is produced and that the reaction is referred to as the Pozzalanic Reaction of the Pozzolan. In the same direction, Thevash [5]averred that the pozzolanic activity of a pozzolan is due to the siliceous compounds in the pozzolana reacting with the $Ca(OH)_2$ to form stable substances. The pozzolanic reaction converts the soluble $Ca(OH)_2$to C-S-H, which increases the overall strength and durability of the concrete.

According to Dadu [6], the most effective method for evaluating the performance of a concrete containing a natural pozzolan and establishing proper mixture proportions for a specific application is the use of trial batches and a testing program. Because some natural pozzolans perform better than others and project requirements differ, optimum proportions for a given combination of pozzolan and Portland cement cannot be predicted. When used as a replacement for a portion of Portland cement, natural pozzolan replaces an equal volume or equal mass of the cement. For the reason that the density of natural pozzolans is typically less than the density of Portland cement, mass replacement results in a greater volume of total cementitious materials than when volume replacement is used at a given percentage. The mass of natural pozzolan employed may be greater than that of the replaced cement if the concrete is proportioned for optimum properties and maximum economy. It is no doubt that with the development of human civilization, concrete will continue to be a dominant construction material in the future and consequently the cost and demand for its main constituent (cement) is expected to increase accordingly.According to Shetty [7], the economic attraction (with significant reduction in cost of construction) in the use of pozzolanic materials was one of the major economic drives as both the ancient and the modern structures of Portland pozzolanic cement concrete showed that the pozzolans were generally located in the vicinity of the structure, and the large amounts of concrete involved were sufficient to support the extraction costs for the partial replacement of the OPC in the concrete mixtures. In addition to economic benefits, addition of the pozzolan was found to decrease the permeability and increase the resistance to sulphate waters of concrete; reductions in expansion due to alkali aggregate reaction, higher ultimate strength and provision of overall enhancement in the durability of the concretes were also achieved with the utilization of the pozzolans in the concrete mixtures.Thus, in line with the concept of producing cheaper alternative cementitious materials, the object of this study is to locally produce calcined clay by employing local technology and then investigating the suitability of the produced clay pozzolanic mineral in producing high performance concrete.

II. Materials And Methods

The materials used for this study includes ordinary portland cement (OPC), calcined clay, coarse aggregate, fine aggregate, superplasticizer and water. Calcined clay used was locally produced from clay soil retrieved from Amaokwe Community Ishiagu in Ivo LGA of Ebonyi State. Ordinary Portland Cement (OPC) of Dangote Cement brand of grade 42.5N was used. The specific gravities of OPC and calcined clay were found to be 3.15 and 2.07 with an average particle sizeof 24 and 12.5 μm respectively. A summary of the chemical composition of the calcined clay (conforming to EN 197-1: 2000) is given in Table 2. The coarse aggregate used in this investigation were crushed, well graded with a maximum size of 12.5mm with a specific gravity of 2.52, while the fine aggregates constitutes of river sand with a specific gravity of 2.59. The superplasticizer used in this study is CONPLAST SP430 with a specific gravity of 1.18 @ 25^{o}C produced by FOSROC.Water used was potable, clean, fresh, and free from impurities.It was taken from borehole water tap. The mix designed was based on packing density of aggregates and on BS 5328: Parts 1, 2, 3 and 4, 1997 and IS 10262: 2009. Six (6) different specimens of concrete were produced for 72 molds of size 150 x 150 x 150 mm indicating a total of twelve (12) molds for each specimen (three each for the 7, 28, 56, and 91 days compressive test). The Ordinary Portland Cement (OPC) was replaced by the calcined clay at 5, 10, 15 and 20% for a constant water-cement ratio of 0.28 which is made possible through the addition of the super plasticizer. Before mixing the concrete, binders were kept dry and placed in a moisture-proof area to prevent the initiation of hydration and difficulties in handling. Fine and coarse aggregates were soaked in water24 hours prior to use, drained and kept in open place for 1 hour to attain a saturated surface-dry condition. All the concrete materials were stored at ambient temperature in the range of 25^o to 30^{o}C. This is to ensure that all surfaces of the aggregate particles were coated with binder paste and the ingredients were blended into a uniform mass.A summary of the mass proportioning is presented in Table no 1.

Table no 1: Mix Proportions for Different Specimens

Specimen	% Replacement Using Calcined Clay	W/C	L/CM	Water (kg)	Super plasticizer (kg)	Cement (kg)	Calcine Clay (kg)	Coarse Aggregate (kg)	Fine Aggregate (kg)
CC0	0	0.28	0.31	6.95	0.74	24.50	0	44.10	30.25
CC5	5	0.28	0.31	6.95	0.74	23.28	1.23	43.84	30.03
CC10	10	0.28	0.31	6.95	0.74	22.05	2.45	43.53	29.80
CC15	15	0.28	0.31	6.95	0.74	20.83	3.68	43.26	29.63
CC20	20	0.28	0.31	6.95	0.74	19.60	4.90	42.90	29.40

CC0 indicates control mix with 0% calcined clay replacement
CC5,10,15,20 indicates mix with 5, 10, 15 and 20% calcined clay replacement respectively.
L/CM = Liquid/Cementitious Material Ratio

Optimum Packing Density of Aggregate

The optimum packing density of the combined aggregate was determined using the range of coarse and fine aggregate proportion as $0.45 \leq x_c \leq 0.65$ and $0.35 \leq x_f \leq 0.55$ respectively, with$x_c + x_f = 1$. The best blend of packing density was achieved using five(5) combinations of the selected ratio of fine aggregate to coarse aggregate and the resulting average packing bulk densities for the different combinationsare as shown in Table no2. Figure no 1 shows the graph of the packing bulk density against the fine aggregate.The optimum packing density from the graph is 1907.88 (kg/m^3), which corresponds to 0.60x_c and 0.40x_f(coarse and fine portion) respectively.

Table no2: Average Packing Bulk Densities for Different Combinations

S/n	Coarse aggregate portion x_c	Fine aggregate portion x_f	Packing Bulk Density Measured (kg/m^3)
1	0.65	0.35	1892.22
2	0.60	0.40	1907.88
3	0.55	0.45	1890.16
4	0.50	0.50	1820.04
5	0.45	0.55	1719.55

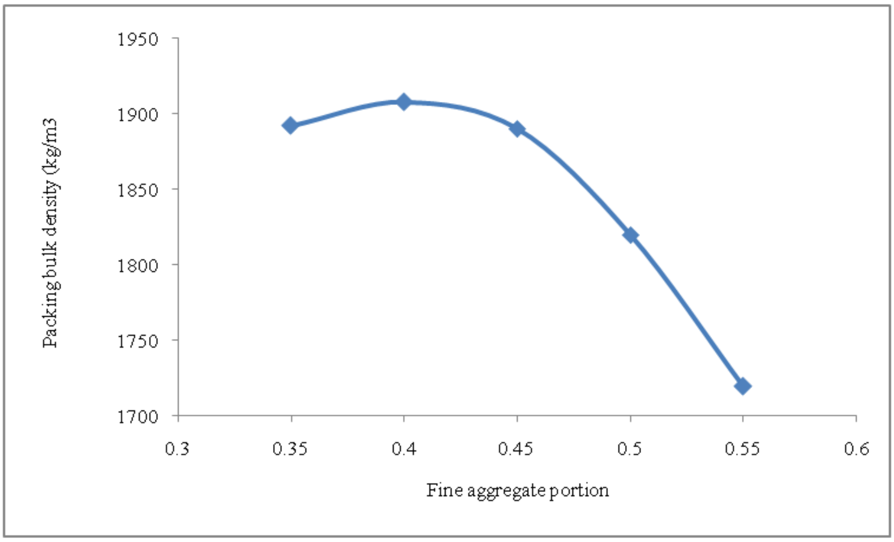

Figure no 1:Packing Bulk Density Vs Fine Portion

III. RESULTS

The results for the physical properties and chemical composition of the calcined clay is shown in Table no3. Specimens were tested to determine the consistency and setting time of the calcined clay pozzolanic cement(Table no4), the workability of the fresh concrete and their densities after 24 hours (Table no5) and the characteristic compressive strength of high performance concrete (Table no6).Figure no 2 gives the relationship between compressive strengths development for all specimens while Figure no 3 gives the relationship between compressive strength and calcined clay replacement.

Table no3: Physical Properties and Chemical Composition of Calcined Clay

Properties/Composition	Calcined Clay
Specific Gravity	2.07
Mean Particle Diameter, µm	12.5
SiO_2, %	40.3
Al_2O_3, %	22.6
Fe_2O_3, %	16.0
CaO, %	7.6
K_2O, %	5.1
MgO, %	4.2
SO_3, %	2.6
MnO, %	0.1
Na_2O, %	0.07

Table no4: Consistency and Setting times of Calcined Clay Pozzolanic Cement

Specimen	PCPR		W/C	Consistency	Setting Time (Mins)	
	%	%		%	Initial	Final
CC0	100	0	0.25	25.4	132	260
CC5	95	5	0.26	26.2	139	278
CC10	90	10	0.29	28.8	146	283
CC15	85	15	0.30	30.4	161	295
CC20	80	20	0.32	32.0	168	303

CC0 indicates control mix with 0% calcined clay replacement
CC5,10,15,20 indicates mix with 5, 10, 15 and 20% calcined clay replacement respectively
PC - Portland Cement
PR – Percentage Replacement

Table no5: Slumps and Densities of the various Concrete Mixes

Specimen	PCPR		Slump	Density
	%	%	mm	kg/m^3
CC0	100	0	150	2580
CC5	95	5	125	2575
CC10	90	10	115	2565
CC15	85	15	100	2556
CC20	80	20	90	2520

CC0 indicates control mix with 0% calcined clay replacement
CC5,10,15,20 indicates mix with 5, 10, 15 and 20% calcined clay replacement respectively
PC - Portland Cement
PR - Percentage Replacement

Table no6: Compressive Strength Results for Specimens

Specimen		Cube Compressive Strength of Concrete (N/mm^2)			
		7days	28days	56days	91days
CC0	0%	28.83	50.77	51.53	53.07
CC5	5%	15.37	60.37	66.14	68.17
CC10	10%	21.06	63.43	70.20	71.14
CC15	15%	17.34	59.44	63.70	67.35
CC20	20%	17.26	59.00	62.27	64.70

CC0 indicates control mix with 0% calcined clay replacement
CC5,10,15,20 indicates mix with 5, 10, 15 and 20% calcined clay replacement respectively

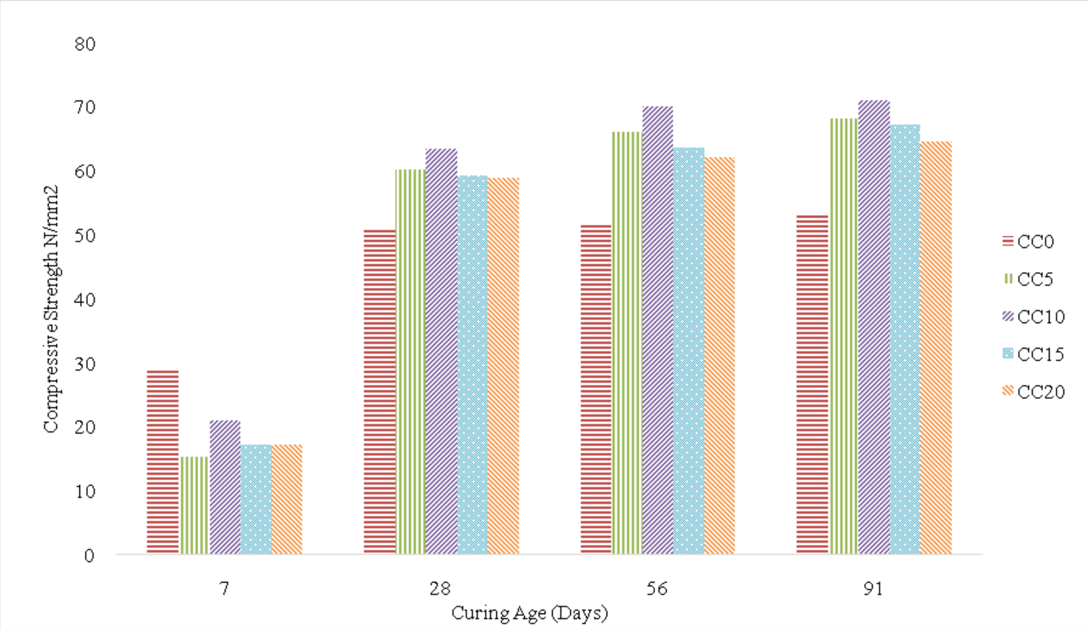

Figure no2: Relationship Between Compressive Strengths Development for All Specimens

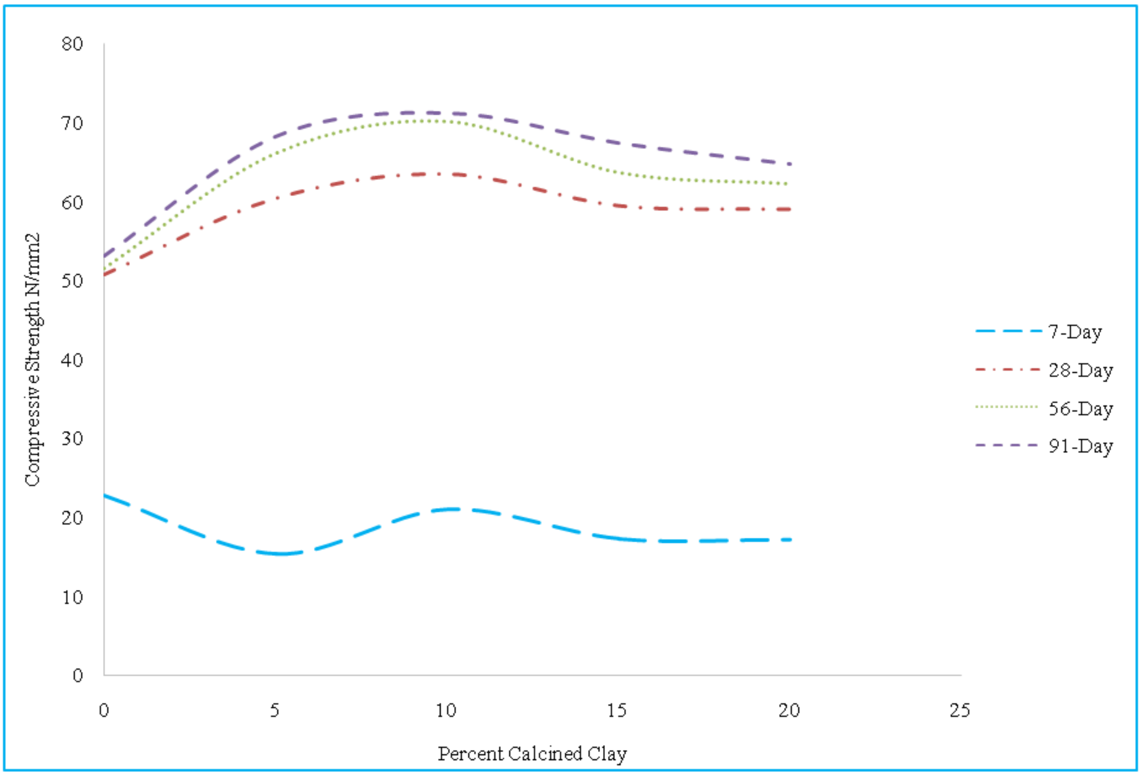

Figure no3: Relationship Between Compressive Strength and Calcined Clay Replacement

IV. DISCUSSION

The analysis of the oxides composition of the calcined clay showed that the sum of the major oxides is 78.9%, which is in line with ASTM C618 requirement for the sum of silica, alumina and iron oxides to be above 70% for natural pozzolans. The total sum of the minor oxides obtained is 19.67%; these values satisfied ASTM C618 (2005) for the materials to be used in concrete.The results of the initial and final setting time of the cementitious mixture containing the calcined clay gave an average of 154 and 290 minutes respectively; this satisfied ASTM C595 (2006) and BS EN 197-1 (2000) requirements of the minimum of 45 minutes and a maximum of 7 hours for the initial and final setting times respectively.

The results of workability of the fresh concrete containing the calcined clay gave an average of 108mm with the control slump having a value of 150mm, this could be attributed to the fact that the high surface area of the calcined clay increased the water demand for the cement-pozzolana system and therefore for a given water-cement ratio and cement content, the workability of the mix is reduced.The unit weights after 24 hours generally recorded a decreasing trend, i.e., a gradual fall in density with increasing calcined clay content; this trend was expected because the calcined clay particles have a lower specific gravity compared to the ordinary portland cement.The results of the compressive strength of concrete containing the calcined clay shows that increase in calcined clay content, increases the compressive strength of concrete with optimum replacement level at 10% after which the compressive strength starts to decline with further increase in replacement level.

V. CONCLUSIONS

The compressive strength results obtained in the study shows that high strength concrete can be achieved from the addition of admixtures such as calcined clay at a reduced water-cement ratio with the aid of superplasticizer to enhance the workability of the concrete produced. The following specific conclusions are drawn from the study.

i. The value for compressive strength observed for mixes with additives gained higher 28th day strength.

ii. The 91-day strength of concrete with calcined clay gave a strength of 71.21N/mm2 at 10% replacement level,which is the highest obtained in the study.

iii. The percentage difference in strength at 91-day compressive strength between 10% replacement level and zero replacement was about 25.40%.

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