International Journal of Engineering Research And Management (IJERM)
ISSN : 2349- 2058, Volume-03, Issue-03, March 2016

Investigation of Pulverized Bentonitic Clay (PBC) As Partial Replacement of Cement in Concrete

Olutoge F.A., Okeyinka O.M., Manu P., Akintunde A. P.

***Abstract*—The prevalent need for alternative eco-friendly building materials and the demands for improved concrete strength have compelled researchers to intensify work on substitutes to cement for the purpose of investigating their usefulness as absolute or partial replacement of cement. This project investigates the possible use of Pulverized Bentonitic Clay (PBC) sourced from Nigeria as a partial replacement of cement in concrete production. The experimental work involved the use of concrete mix design aimed at strength of 25N/mm^2 as control sample. The ordinary Portland cement used for the mixture was replace with 0%, 5%, 10%, 15% and 20% Pulverized Bentonitic Clay (PBC). 150mmx150mmx150mm concrete cubes specimen were cast from mixture of binder, fine aggregate and coarse aggregate using mix ratio 1:1.5:3.The cube specimen were subjected to compressive strength test at 7, 14, 21, and 28 days curing ages. The compressive strength of the ordinary Portland cement/Pulverized Bentonitic Clay (PBC) concrete generally decreases as the percentage of Pulverized Bentonitic Clay (PBC) content increases. The maximum compressive strength of 25.50 N/mm^2 was recorded for the 5% PBC-cement cube specimen at 28 day curing age. Addition of bentonite clay resulted in poor early stage and good later stage compressive strength compare to the control mixture. The maximum value of 25.50N/mm^2 for the 5% replacement level is found suitable and recommended having attained a 28-day compressive strength of more than 25.0N/mm^2. The findings indicate that the use of 5% Nigerian bentonite clay as partial replacement of cement is suitable for concrete work in which later stage strength is required. The split tensile strength of concrete containing 0%-20%PBC satisfies the minimum requirement for structural grade lightweight concrete. Addition of PBC had a negative effect to the workability of a fresh concrete. It generally lowered the workability of the concrete.**

***Index Terms*— Pulverized Bentonitic Clay (PBC), Compressive strength, Split tensile strength, Slump, Concrete.**

Manuscript received March 18, 2016

Olutoge F.A., Department of Civil Engineering, University of Ibadan, Ibadan, Nigeria

Okeyinka O.M., Department of Civil Engineering, University of Ibadan, Ibadan, Nigeria

Manu P., Faculty of Engineering and Technology, University of West of England, Bristol, United Kingdom.

Akintunde A. P., Department of Civil Engineering, University of Ibadan, Ibadan, Nigeria,

I. INTRODUCTION

The challenge of huge housing shortage in Nigeria had escalated from bad to worse in recent times due to expensive construction cost, increasing population and civilization. According to a recent report, the housing deficit in Nigeria was estimated to be between 16million units and 17million units [1]. With a current population of over 170million, an estimated minimum of 1million additional housing unit was projected per annum to offset the 17million units housing shortfall in Nigeria [1]. In an attempt to meet up with infrastructure needs in Nigeria, lots of construction is presently taking place and much more is anticipated in backdrop of recently forecast of global construction growth which envisaged Nigeria as one of the world's fastest growing construction markets from 2012 to 2025, with an average annual growth of 8% [2]. It is therefore expected that demand for construction materials in the next coming years will be enormous. Cement is the most essential ingredient of the construction industry. Also, cement is widely noted to be the most expensive constituent of concrete and its high cost has been due to both the limited raw materials and the industrial processes involve in its production [3]. The continuous increase in cement price [4] directly affects the overall cost of building construction projects in Nigeria.

In the bid to solve this problem, many researchers have carried out studies on the possible use of locally available materials to either partially or totally replace the cement which is the conventional binder in concrete. Ref. [5] reported that integration of additional binder into cement for concrete production have been ascertain as an efficient alternative measure for production of durable concrete and this had encouraged the utilization of blended cements in many parts of the world. Bentonite clay is a locally available mineral in Nigeria, It exist in various grades across the Nigeria's sedimentary basins and basement [6] .The use of bentonite clay in construction as a mineral hydraulic barrier in diaphragm walls, foundations, tunneling, horizontal directional drilling and pipe jacking has been reported in the literature [7]. Various findings on the use of bentonite clay as replacement of cement were reported by previous research. Ref. [8] reported based on an investigation of mortar cubes containing Jehangira bentonite as replacement of cement that acceptable mortar and concrete were obtained at 40% and 25 % bentonite substitution respectively [8]. On the other hand, Ref. [9] reported that bentonite substitution above 20% leads to significant strength reduction. In agreement with the suggestion of Ref. [10], there is the need for further research to investigate the effect of incorporating other percentages of bentonite in cement.

However, there is presently no recorded findings on the performance of concrete containing bentonite clay sourced in Nigeria, despite the huge availability in the North-east quadrant of Nigeria (Borno, Yobe, Taraba, Gombe, Bauchi and Adamawa States) with estimated probable reserve of over 700million tonnes [11]. In order to explore the visibility feasibility of developing low cost concrete using bentonite source from OKitipupa Ondo state Nigeria, this study was conducted to investigate the mechanical properties of concrete containing Nigerian Bentonite as partial replacement of cement and the optimum bentonite replacement required.

II. EXPERIMENTAL DETAILS

A. Materials

The materials used in this study include; cement bentonite/clay bentonite, coarse aggregate, and fine aggregate. Portable water and distilled water which were used as reagents throughout the experimental work

1) Binders

The binding materials used for this study consisted of Ordinary Portland Cement, and Bentonite/Bentonitic clay. Cement used was Ordinary Portland Cement of grade 42.5 type R with physical properties that meet the requirements of ASTM C150 Type I cement. The bentonite materials were sourced from Ore in Okitipupa local government area of Ondo state, Nigeria. The physical and chemical properties of the bentonite are shown in table1 and table 2 respectively.

Table 1: Physical properties of Bentonite

Properties Description	**Properties**
Specific gravity	2.44
Bulk density	1.53g/cm^3
Particle size	Passing 150µm sieve

Table 2: Chemical composition of Bentonite

Oxides	**% Composition**
SiO_2	50.00
AL_2O_3	19.90
Fe_2O_3	3.90
CaO	1.00
Mgo	0.32
K_2O	0.53
Na_2O	0.67
TiO_2	1.10
MnO	2.00

2) Aggregates

The coarse aggregate used was granite of size 12.5 mm (1/2 inch), and the fine aggregates was (sand) with particle size ranging from 4.75mm-0.003mm .The aggregate used had minimum inherent strength requirement for structural concrete [12]. The fine aggregate used was sieved and all debris was removed,

B. Mix Proportioning and mixing procedure

The detail of the mix proportions used for concrete production are shown in table 4. A constant water/binder ratio of 0.5 was used for all the mixtures. Cementitious materials, coarse aggregate, granite crusher sand, and water were batched by weight on a laboratory balance to an accuracy of 100 g. The water reducing agent was batched by volume and mixed into the mixing water so as to ensure uniform dispersion during concrete mixing. The materials were added into 50 L pan mixer in the order of; crusher sand, OPC, and coarse aggregate respectively. These materials were then mixed in their dry state for 1 minute. Water with added binders and water reducing agent, were introduced into the mix over a period of 1 minute. Mixing was continued for another 1 minute. A slump test was performed to ensure that the mix fell within the desired slump range.

Table 4: Mixture proportions for categories of concrete mixtures

Categories of concrete mixtures	**Quantity of PBC added to cement (%)**	**Binder**		**Sand (kg)**	**Granite (kg)**	**Water (kg)**	**water/binder ratio**
		Cement (kg)	**PBC (kg)**				
Control	0	436	0.00	654	1308	218	0.5
5%PBC mix	5	414.2	21.8	654	1308	218	0.5
10%PBC mix	10	392.4	43.6	654	1308	218	0.5
15%PBC mix	15	370.6	65.4	654	1308	218	0.5
20%PBC mix	20	348.8	87.2	654	1308	218	0.5

C. Casting and Compaction

Prior to the commencement of casting of concrete samples, the 150mm x 150mm x 150 mm cube molds were cleaned and sparingly covered with a lubricant, so as to allow easy removal of hardened samples. The molds were loosely filled with mortar and hand-pressed on a mechanical vibrating table for 10 seconds. Sufficient concrete was added to fill the mold, and then held on the vibrating table for further period of 10 seconds. After compaction, excess concrete were removed and the surface was dressed by means of a trowel. Then, the cube was stored undisturbed for 24 hours at room temperature. At the end of this period, the mold was stripped and the cube was further cured in water.

Figure 1: Concrete Cubes after Demoulding

D. Curing

After compacting, the molds containing the freshly cast concrete were covered with moist cloth for 24 hours to preserve the initial moisture condition of the sample, after which the hardened prisms were removed from their molds and placed in a water curing tank. The temperature of curing water was maintained at 23 ± 2 0C with a built in thermostat and a small circulation pump. All the samples were stored in the curing tank until testing period.

The tank was periodically filled with water to cater for the loss of water which occurred as a result of evaporation and removal of samples. The curing carried out for the various ages viz; 7, 14, 21 and 28 days, by soaking cubes in metallic tanks into which water has been poured. However the mix containing bentonite was subjected to curing in open air and sprinkled with water regularly. It was then covered by cement bag to shield same from direct sunlight and prevent excessive evaporation; which would affect its strength development.

E. Concrete Properties Studied

The tests performed to study the behavior of concrete properties with or without gypsum and bentonite binders were: slump test, split tensile strength test, compressive strength test, and flexural test. Table 5 shows the details of the test schedule for the concrete which include; property tested, the total number of samples prepared for each test, the test methods, and the mold sizes.

Table 5: Detail Test schedule for Concrete

Properties Tested	Sample sizes	Test ages (days)	No. of cube Samples per	Total No. of cube samples	Test methods
Workability	Fresh concrete	After mixing	-	-	ASTM C 143
Split tensile strength	150 mm cubes	28	8	16	ASTM C 496
Compressive strength	150 mm cubes	7,14, 21,and 28	16	64	ASTM C 143

A. Testing of concrete

The fresh concrete was subjected to workability test and the hardened concrete specimens were subjected to compressive strength and split tensile strength test at 28days curing age.

1) Workability

Workability was measured by slump test according to ASTM C 143 [13]. The slump mold is a cone, which is 300 mm high with open base of 203 mm diameter and a smaller opening of 102 mm diameter at the top. The tools used consisted of slump mold, steel tamping rod, and flat steel plate, were wiped with a damp cloth. A steel base plate was placed on a level surface. The slump mold was placed on the steel plate and held firmly, by standing on its foot pieces. The slump mold was then filled with concrete in three layers of about equal depth. Each layer was tamped 25 times with the rounded end of the tamping rod. After tamping the final layer, excess concrete was struck off by means of a trowel and by rolling motion of the tamping rod, such that the mold is completely filled and levelled. The mold was firmly held down by its handles, keeping it steady while stepping off the foot pieces. The mold was then lifted carefully away from the concrete. Cone mold was inverted near slumped concrete. The slump was measured by determining the vertical difference between the top rim of the mold and the average highest point of the surface of slumped concrete as shown in Figure 2.

Fig. 2: Slump Measurement

2) Compressive strength test

The compressive strength test was carried out on concrete samples based on ASTM C 143 Method 863 [13]. At testing age, samples were removed from the curing tank and weighed after excess water had been wiped off the surface. The mass of sample was recorded to the nearest gram. During testing, the samples were then put in a bowl of water, to keep them wet for testing. The samples were centrally placed in a compression testing machine and load was applied at a rate of 13.5 KN/s. The uniaxial load was applied perpendicular to the direction of casting. Failure load was recorded to the nearest one KN. Cubes were tested using Amsler type 103 compression testing machine, which has a load capacity of 2000 KN. Compressive strengths were determined at curing ages of 7, 14, 21 and 28 days, Fig.3 (a and b) show the loading to failure of samples during testing.

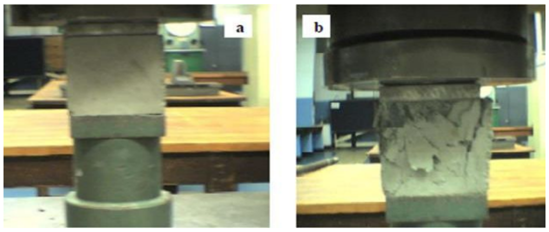

Fig 3: (a) Loaded Compressive Strength Sample. (b) Failed Compressive Strength Sample.

3) Split tensile strength test

Split tensile test was carried out on concretes based on ASTM C 496 [14] using 150 mm cubes. A centre line was drawn on the opposite sides of the cube samples. During testing, the cube sample was placed in position in the Tinus Olsen testing machine, which has a loading capacity of 600 KN. Steel bars of 16 mm diameter, sealed on steel plates were placed on the centre line drawn on the opposite sides of the cube samples. Compressive forces were applied along the two opposite centre line, such that the splitting along these lines was caused by the principal tensile stress in the plane joining the loaded lines as shown in Figure 4 (a and b). Loading was applied continuously at the rate of 13.5KN/seconds over the entire load application until fracture. The split tensile strengths were determined at 28 days curing age.

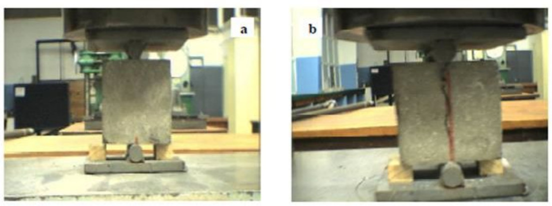

Fig 4: (a) Loaded split tensile strength sample. (b) Failed split tensile strength sample.

III. RESULTS AND DISCUSSIONS

A. Slump Test

Figure (5) present the result of slump test conducted on the concrete mixes studied. True slumps were achieved for all the concrete mixes. The slump decreases with increasing PBC percentage content in the concrete. The control sample (with 0% PBC content) displayed the highest slump of 55mm while the sample with the highest PBC content exhibited the lowest slump of 38 mm. This findings indicate that an increase in the PBC content lowers the workability of a fresh concrete. This is mainly because of the fact that PBC powder absorbs water.

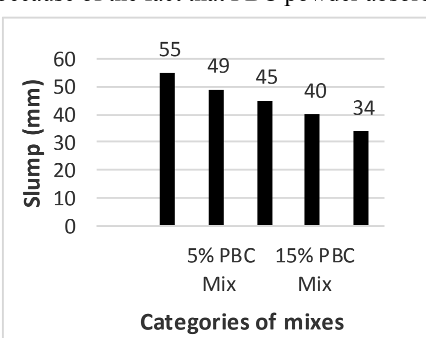

Fig. 5: Slump for the Various Mix

B. Mechanical Characteristics

Mechanical characteristics of a hardened concrete is established through test of its compression, tensile strength. Based on the results obtained in the tests carried out, it can be stated that an increase in the percentage replacement of cement weight by the PBC improves the mechanical strength of a hardened concrete.

1) Compression Strength

From the results of compressive strength test, it was noted that an increase in the PBC content in the concrete mix resulted in an increase in the compressive strength of hardened concrete. As presented in figure (6) the compressive strength also increases with increasing curing days for all replacement percentage of the PBC, The compressive strength displayed by the concrete specimen containing PBC was higher compared to that displayed by the conventional concrete (control). The compressive strength test showed that concrete incorporating 0%-5% of the PBC as cement replacement produced a negligible 2% higher compressive strength compared with the control sample prepared with the same water to binder ratio. At substitution above 5% PBC, the compressive strength of concrete decreased. This result is similar to findings reported by [15], and [16].

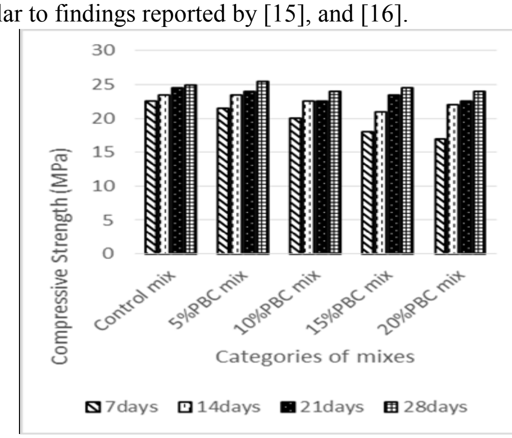

Fig 6: Compressive strength of PBC concrete mixes compare to the control mix

2) Tensile Strength

Figure 7 presents the results of the 28 days tensile tests on cylinder specimens. The Split tensile strength of concrete containing PBC satisfies the minimum tensile-splitting strength of 290 psi (2.0 MPa) requirement for structural-grade lightweight aggregates concrete in accordance with ASTM C330 specification [17]. The maximum split tensile strength of 3.15MPa was recorded at 5% PBC replacement and it is lower than the 3.30MPa displayed by the control sample and the lowest tensile strength of 2.1MPa obtained at 20% replacement satisfies the minimum requirement for structural-grade lightweight aggregates concrete. This indicates that the addition of 0%-20% PBC as partial replacement of cement is capable of producing concrete with desirable split tensile strength. However, the split tensile strength decreases with increasing PBC content. This finding is similar to the conclusion made by Ref. [9] regarding the optimum bentonite replacement in concrete.

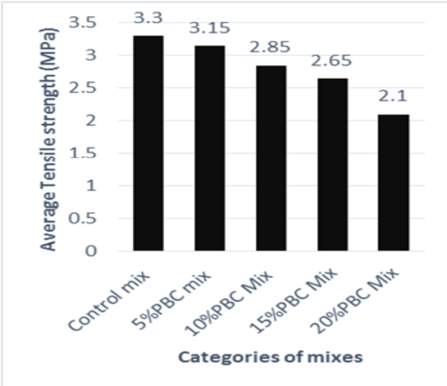

Fig 7: Split Tensile strength of PBC concrete mixes compare to the contol mix

CONCLUSIONS

Based on the findings of the study, it was concluded that:

The compressive strength of the ordinary Portland cement / Pulverized Bentonitic Clay (PBC) generally decreases as the percentage of Pulverized Bentonitic Clay (PBC) content increases. The maximum compressive strength of 25.50 N/mm^2 was recorded for the 5% PBC-cement cube specimen at 28 day curing age. Addition of Bentonite resulted in poor early stage and good later stage Compressive strength compare to the control mixture.

The split tensile strength of concrete containing 0%-20%PBC satisfies the minimum requirement for structural grade lightweight concrete. Also, an increase in the PBC reduces the tensile strength of the concrete. The highest tensile strength was obtain at 5% PBC replacement of cement. Addition of PBC has a negative effect on the workability of the fresh concrete. It generally lowered the workability of the concrete.

ACKNOWLEDGMENTS

First author acknowledges with thanks, the opportunity given by Prof. Paul Olomolaiye and the entire Faculty of Engineering and Technology of the University of the West of England to spend research scholarship and facilities of UWE to prepare this publication.

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