Characteristics of Concrete Produced With Burnt Clay as Coarse Aggregate

[*a]Dahiru, D., [a]Usman, J., [b]Yusuf, U. S.
[a]Department of Building, Ahmadu Bello University, Zaria, Nigeria
[b]Department of Building, Modibbo Adama University of Technology, Yola, Nigeria
[*]Correspondence email: drdaudadahiru@yahoo.com

Abstract

Aggregate is the principal ingredient for concrete, and studies have predicted that excessive use of it would lead to insufficient quantity for future large constructions. This study investigate the use of burnt clay as alternative aggregates for concrete production. First clay was exposed to elevated temperature in the range of 1200 – 6000 C. Thereafter 3 sets of burnt clay aggregate were prepared then they were subjected to tests to determine the specific gravity, moisture content, water absorption, bulk density, impact value and crushing value test. These aggregates were subjected to compressive strength, impact value and crushing value tests. Result showed that the specific gravity of these aggregates exposed to between 600-1200^{o}C*, were between 2.11- 2.43. Whereas the bulk densities were between 973.7-1012 kg/m*^{3}*for burnt clay aggregates exposed to between 600 -1200*^{o}C*. The moisture content of the burnt clay aggregates were in the range 1.749-1.833; Water absorption for the three sets of burnt clay aggregates was between 8.303-8.378 for clay aggregates heated to a range of 600-1200*^{o}C*. The compressive strength for the three types of 100mm concrete cubes produced using the burnt clay aggregates after 28 days of curing, were between 10-11.2 N/mm*^{2}*.While the compressive strength after 56days of curing, were between 13.20- 17.40N/mm*^{2}* for concrete produced with burnt clay aggregates subjected to elevated temperatures of 600-1200*^{o}C*. The impact and crushing values of the crushed burnt clay aggregates ranges from 14- 33%. It was concluded that there is no significant difference between the quality of concrete produced with burnt clay aggregate and the conventional concrete (control sample). Hence, study recommended the use of burnt clay aggregate and durability properties of concrete be investigated.*

Keywords: Coarse Aggregates, Properties, Concrete, Burnt Clay, Water Absorption

INTRODUCTION

Aggregates are the mass of crushed stone, gravel, sand materials predominantly composed of individual particles, but in some cases clays and silts are used as filler in the production of mortar and concrete. In the past, Aggregates were regarded as chemically inert materials however it has been observed that some of the Aggregates are chemically active while certain aggregates exhibit chemical bond at the interface of aggregate and paste. However, its physical, thermal and sometimes chemical properties influence the performance of concrete. (Gupta & Gupta. 2006; Neville, 2008 & Shetty 2009). Some physical properties of aggregate that must be known before mixing concrete are shape and texture, size gradation, specific gravity. According to Mehta and Montero (2007) Aggregate component exert considerable influence on the strength, dimensional stability and durability of concrete. The compressive strength of concrete depends on many factors such as the water to cement ratio, degree of compaction, ratio of cement to aggregate, bond between mortar and aggregate, grading, shape, strength, size and texture of the coarse aggregate (Beshr *et al* 2003 and Rocco & Elices, 2009). In addition, it plays a major role in determining the cost and workability of concrete mixtures. It assists in reducing the amount of cement paste required in the mix. Aggregates have greater volume stability than cement paste. Therefore, maximizing the amount of aggregate, to certain extent, improves the quality and economy of the mix (Mehta & Montero 2007 and Shetty 2009). Aggregatesare used in construction as an underlying material for foundation and pavements, a major ingredient in mortar, Portland cement and asphalt concretes.

Aggregate is one of the major construction materials that have attracted the attention of researchers in recent years for many reasons. It is an important constituent used in the production of the most widely used construction materials - concrete. In Portland, concrete has 60-75% of the volume and 79% to 85% of the weight are made up of aggregates in asphalt concrete, aggregates constitute 75% to 85% of the volume and 92% to 96% of the mass (Mamlouk & Zaniewski, 2011). This shows excessive consumption of aggregate. According to Mbamali (2007) quarrying practice in Nigeria is unplanned and unregulated hence, unsustainable. Gyang and Ashani (2010) in Ibrahim (2016) noted that the extraction of mineral resources from the ecosystem for further production disrupt the earth crust and result to loss of biodiversity. Furthermore, it is predicted that in future, aggregate may not be available in large quantity for heavy construction (Shetty, 2009). Apart from the naturally occurring aggregates, such as sand, crush rock ,alternative construction materials such as brick or crushed air cooled blast furnace slag, pumice, furnace clinker, coke breeze, sawdust, foamed slag, expanded clay and shales, expanded slatesare used for making concrete (Arora & Bindra 2005; Gambhir, 2006; Neville 2008). Lyons (2007) noted that steel or polypropylene fibres or gas bubbles, may be incorporated into the mix for special purposes.

Research has shown that the use of recycled coarse aggregates as well as alternative construction materials are used to replace the scarcely gravels. Daura (2015) assessed the suitability of using recycled steel slag as coarse aggregate in concrete and concluded that recycled steel slag can be used to produce concrete. Yussuff (2015) carried out investigation on the suitability of scrap rubber tyres as coarse aggregate in concrete. Result of the study shows that rubber concretes can be used for masonry construction works and where moderate strength is required. Based on result of such a study, it was concluded that over burnt bricks can be used for concrete. Adejo (20017) evaluated the properties of concrete made with recycled concrete aggregate using metakaolin based geopolymer. Kabir (2017) assessed the properties of concrete made with ceramic waste as aggregate. Analysis of these and numerous early studies reveal that, compared with concrete mixtures containing natural aggregate, the concrete made with recycled aggregates generally gave at least two – thirds of the compressive strength and modulus of elasticity. Besides that, it gives adequate workability and durability. Result show that with proper method of process in recycled concrete aggregate, there is no loss in the quality of concrete using this type of aggregates (Mehta & Montero 2007). Also result of studies showed that pumice, broken bricks and ceramic waste can be use as coarse aggregate in concrete production. However a major obstacle associated with the use of rubble and host of other waste as aggregate for concrete, is the cost of crushing, grading, dust control and separation of undesirable constituents.

The use of municipal wastes and incinerator residues as likely sources of concrete aggregate were also investigated. Glass, paper, metals and organic materials were the main constituents of municipal waste considered. However it was noted that the presence of crushed glass in aggregate tends to produce unworkable concrete mixtures and there is high alkali content which affects the long term durability and strength of concrete. Additionally, metals such as aluminum react with alkaline solutions and cause excessive expansion while paper and organic wastes, with or without incineration, cause setting and hardening problems in Portland cement concrete. Thus it was concluded that municipal wastes are not suitable for making aggregate for use in structural concrete (Mehta & Montero, 2007).

Laterite is one of the materials that have gained much attention for use as construction materials. Currently, there is shift in emphasis in the construction industry that favours low impact construction which requires the use of materials that are widely and readily available – the most appropriate local source of a material is the site (earth), renewable, requires minimum processing and maintenance, have low embodied energy, low negative impact, etc. According to Lyons (2007) certain clay when used for brick production, contains carbonaceous which reduces the amount of fuel required to burn the bricks. In addition, more than a third of the world's population lives in unfired earthen homes of one sort or another. Lasisi and Osbunade (1984) in Lawal (2015) noted that walls of over 75% of residential homes in rural areas are being constructed with laterite soils in various forms. Relatively little energy is used to acquire the raw material and there is rarely any pollution associated with its extraction, manufacture or disposal (Halliday 2008).

In view of the fact that 45% of energy generated is used to power and maintain buildings and 5% to construct them. That is why much attention is also paid to the development of construction materials that use little or no energy in the mining, production, use and disposal of such material. The possibility of replacing coarse or fine aggregates in concrete with laterite has been the subject of quite a number of studies. These include, among others, researches by Osunade & Babalola (1991), Falade, (1994),Gambo (2000), Osunuibi, *et al.* (2013), Raju & Ramakrishna (2006) and Olubisi (2013). Result of studies show that laterite concrete compares favourably with conventional concrete. However not all laterite are exactly the same. As such there is the dire need to assess the suitability of the various types of laterites for use as aggregates. This is a study on the evaluation of properties of concrete produced with burnt clay aggregates. Details of the experiment undertaken are presented as follows:

MATERIALS AND METHODS

Materials

The materials used in this study are; Ordinary Portland cement, OPC, fine aggregate, coarse aggregate, burnt clay aggregates and water. Details of these materials are presented as follows:

Cement

OPC manufactured by Dangote Cement Company in Nigeria was obtained from local dealers in Zaria and used throughout the production of cubes specimens. Tests were undertaken so as to ensure that it complies with the British standards BS 12 (1996) and EN 197-1 (2000).

Fine Aggregate

The fine aggregate used was river sand obtained within Zaria It was sieved with a 5mm B5 112 (1971) sieve, so as to remove the impurities and larger aggregates. Before, the fine aggregate was used; it was subjected to sieve analysis in accordance to the BS 933 Part 1 (1997).

Coarse aggregates

The coarse aggregates used for the production of the control samples (normal concrete) were crushed granite stones obtained from single quarry site along Zaria-Sokoto road, opposite Nigerian College of Aviation Technology, NCAT, Zaria. Sieve analysis was carried out on the coarse aggregates used in the experiment in accordance to BS 933 Part I (1997).

Burnt clay coarse aggregate

The coarse aggregates used in the production of sample specimen, was the burnt clay. It was sourced clay which was mixed and allowed to soak water for 1week, a reasonable quantity was taken, mixed and punched with hand to form a homogenous mixture then cast into the rectangular wooden frame cubes of 4 compartment chambers to produced 4 cubes at a time in the department of building laboratory, Ahmadu Bello University, Zaria, Nigeria and was further taken to Industrial Development Center, (IDC) Zaria, Nigeria, laboratory to be fired to 1200^{o}C, 800^{o}C, 600^{o}C. The aggregate were manually crushed, washed and sieved to remove dirty and unwanted particles. The aggregates were used in a saturated surface dried condition.

Water

The water used to produce concrete samples was clean, fresh water, free from injurious oils, chemicals and vegetable matter or other impurities as it was obtained directly in the laboratory. It is portable water.

Tools / apparatus used

The tools and apparatus used for the experiment tests were : Weight scale, Mixing board, Herd scoop, Tapping rod, Pycnometer, Trowels, Head pan, Measuring cylinder, Stand sieves (20 mm-pans), Aggregate impact testing machine, 100 x 100x 100mm cubes mould, Crushed value testing machine, 4 compartment chamber wooden frame rectangular mould.

METHODS

Various tests were undertaken in order to assess the properties of the individual constituents of concrete and concrete sample specimens. Details are as follows:

Sieve Analysis

The particle size distributions for both the coarse and fine aggregate were determined using sieve analysis in accordance with BS 812-103.1 [1985].The weight retained on each sieves were recorded. The weights passing and the percentage passing were determined. The weight retained was sum together and compared with the weight of the sample at the beginning of the analysis.

Bulk Density

The test of bulk density of the burnt broken bricks samples was carried out in accordance with BS 812 [1995].The bulk density was determined based on saturated surfaced dry.

Bulk Density (SSD) = $\frac{W_1-W}{V}$ (1)

Moisture Content and Absorption Capacity

The moisture content and absorption capacity of the aggregates were determined in accordance to the provision of BS 812: Part 2: 1975. Thus Moisture content was computed using the relationship below:

Moisture content =$\frac{Air\ weigt-Oven\ dry\ weight}{Oven\ dry\ weight} \times 100$ (2)

Specific Gravity

The specific gravity (Gs) of both the coarse and fine aggregates was determined by using the pycnometer method in accordance to BS 812-2 (1995).

Specific gravity (S.G_{SSD}) = $\frac{B}{B+C-D}$ (3)

Where: B = Mass of saturated surface dry sample in air
C = Mass of jar or vessel file with water
D= Mass of vessel with burnt broken bricks and water to the calibration.

Mechanical Properties of Aggregates

Aggregate Impact and Crushing values tests

The tests were carried out to determine the impact and crushing values the burnt clay aggregates based on the provisions of BS 812: Part 112: 1990 and hence its suitability for making concrete.

Concrete Production

Mix Design

The final mix design entails the use of absolute volume batching with nominal mix of 1:1.5:2 and a water-cement ratio of 0.40 to produce two sets of concrete samples, - set A and B. The set A are concrete cubes and cylinders produced with clay aggregates that were subjected to elevated temperatures of: 600^{o}C, 800^{o}C and 1000^{o}C. While set B, are normal concrete (control samples). A mixing machine of horizontal rotary drum mixer with a revolution of 7turns/minutes and manual vibration method were used to produce the concrete.

$$\text{Absolute volume of material (a.v)} = \frac{ratio\ of\ material\ in\ mix \times density\ of\ material}{specific\ gravity\ of\ material \times 100} \quad (4)$$

$$\text{Quantity of material (kg/m3)} = \frac{ratio\ of\ material\ in\ mix \times density\ of\ material}{total\ absolute\ volume} \quad (5)$$

Testing of Hardened Concrete

Tests carried out on the hardened concrete were the determination of the density of the hardened concrete, the compressive strength and tensile strength.

DENSITY OF CONCRETE

The density in kg/$m^3$was determined by firstly air-drying the cured cubes, weighing and computing the density using the relationship;

$$\text{Density of concrete} = \frac{Mass\ of\ cube\ in\ kg}{Volume\ of\ cube\ in\ m^3} \quad (6)$$

Compressive Strength

The hardened concrete samples were subjected to the compressive strength test after 7, 14, 21, 28 and 56 curing days. Three samples of 100mmx100mmx100mm concrete cubes and cylinders were used for the tests. The preparation of the samples and testing were carried out in accordance to the appropriate British standards such as BS 1881 (1986), BS 1881 (1988), BS 812 1990) and American Standard Testing Methods (ASTM).This was carried out at the Concrete Laboratory, Department of Building, Ahmadu Bello University, Zaria - Nigeria.

Limitation of the Study

Due to shortage of burning furnace, burning of clay could not be beyond 1200^{o}C

RESULTS AND DISCUSSION

The results of various tests carried out are presented under the following headings:

Physical properties

The results of physical properties tests are presented in Table 1.

Table 1: Physical Properties of the crushed burnt clay Aggregates

Properties	Crushed Burned Brick		
	600°C	800°C	1200°C
Specific Gravity	2.11	2.23	2.43
Bulk Density [*kg/m³*]	973.70	985	1012.33
Moisture content	1.749	1.775	1.833
Water Absorption	8.303	8.360	8.378

Specific Gravity

As it can be observed from Table 1, the specific gravity of crushed burnt clay was determined at three different temperatures. The average value of specific gravity for burnt clay aggregates exposed to 600°C, 8000C and 12000°C are: 2.11, 2.23 and 2.43, respectively. According to Duggal (2012) Specific gravity of aggregates generally is indicative of its quality. A low specific gravity may indicate high porosity and therefore poor durability and low strength. Although Neville (2008) and Mamlouk & Zaniewski (2011) are of the view that it is used for concrete mix design but the actual value of the specific gravity of aggregate is not a measure of its quality. However, when the values of specific gravity of burnt clay aggregates are related to other properties of the burnt clay aggregates or even the properties of concrete produced with it (such as compressive strength), it can be inferred that they are clear reflection of many properties of the burnt clay aggregates hence the quality of these aggregates. This also agrees with the observation made by Gambhir (2006) that specific gravity gives valuable information on the quality and properties of aggregates- the higher the specific gravity, the harder and stronger it will be. The values of specific gravity are relatively low compared to the specific gravity of natural aggregates that lies between 2.6 – 2.7. For the burnt aggregates subjected to elevated temperatures of 600°C, 800°C and 12000°C, they are in the range of specific gravity of 2.11–2.43 they classed as medium weight aggregate.

Bulk Density of the Coarse Aggregates

From Table 1, it can be observed that aggregates obtained from burnt clay, exposed to temperatures of 600°C, 800°C and 1200°C have average bulk density of : 973.70kg/m^3, 985kg/m^{3}and 1012.33 kg/m^{3}respectively. These values are, comparatively, lower to most other values of natural aggregates. For the fact that bulk density of aggregates is a function of the particles shape and size, packing, the grading and moisture content. The values of bulk density shows that coarse aggregates obtained from clay, have fewer voids. This is because bulk density has inverse relationship with number of voids.

Grading of the aggregates

Result of the Sieve analysis carried out on the three (3) sets of burnt aggregates, are presented in Tables 2 - 4.

Table 2: Results for sieve analysis of crushed burnt clay aggregates (1200°C)

Sieve Size (mm)	Weight Retained(g)	Weight Passing(g)	Percentage Passing (%)	Percentage Retained (%)	Grading Zone II
20.00	8	9752	0.11	0.08	95 – 100
10.00	2970	6782	41.53	30.0	55 – 6
5.00	4107	2675	57.84	42.0	35 – 45
2.36	1107	1568	46.12	11.3	28 – 35
1.18	479	1089	19.95	4.90	-
600	282	807	11.75	2.80	-
300	177	603	7.37	1.80	-
150	173	457	7.20	1.70	-
Pan	457	0	0	0	-

Table 3: Results of sieve analysis of crushed burnt clay aggregates (800°C)

Sieve Size (mm)	Weight Retained(g)	Weight Passing(g)	Percentage Passing (%)	Percentage Retained (%)	Grading Zone II
20.00	23	13624	99.8	0.16	95 – 100
10.00	6390	7234	53.0	46.8	55 – 6
5.00	3027	4207	30.0	22.1	35 – 45
2.36	2302	1905	13.9	16.8	28 – 35
1.18	600	1305	9.50	4.30	-
600	405	900	6.50	2.90	-
300	243	657	4.80	1.70	-
150	177	480	3.50	1.20	-
Pan	480	0	0	0	-

Table 4: Results of sieve analysis of crushed burnt clay aggregates (600°C)

Sieve Size (mm)	Weight Retained(g)	Weight Passing(g)	Percentage Passing (%)	Percentage Retained (%)	Grading Zone II
20.00	0	7574	100	0	95 – 100
10.00	3630	3944	52	47.9	55 – 6
5.00	1983	1961	25.8	26.1	35 – 45
2.36	747	1241	16.3	9.80	28 – 35
1.18	373	841	11.1	4.90	-
600	254	587	7.7	3.30	-
300	145	442	5.8	1.90	-
150	87	355	4.6	1.10	-
Pan	355	0	0	0	-

Sieve Analysis

The results of the sieve analysis for all the three sets of aggregates showed that the aggregates fall in the grading zone II. This means that the aggregates are neither too fine nor too coarse. The grading of the fine aggregate has much greater effects on the workability of concrete than does the grading of coarse aggregates.

Impact Value Test and Crushing Value Test

The Impact and Crushing Values Tests for the clay aggregates exposed to elevated temperature of 600°C, 800°C and 1200°C, are presented in Table 5

Table 5: Summary of the mechanical properties of the aggregates

Properties	Crushed Bricks Aggregate (^oC)			Natural Gravel Aggregate
	1200	800	600	
Impact Values	14.00%	20. 20%	29.00%	10.43%
Crushing Values	22.60%	28.60%	33.00%	20.50%

From Table 5, the impact and crushing values of the crushed burnt clay aggregates range from 14% - 29% and 22.60% - 33% respectively. This is below the impact and crushing values for the natural aggregates. Neville (2008) noted that direct correlation between the crushing value and the performance of aggregate in concrete or strength of the concrete is not possible, yet it gives an idea of resistance of the aggregate to failure by impact – which is closely related to the crushing value.

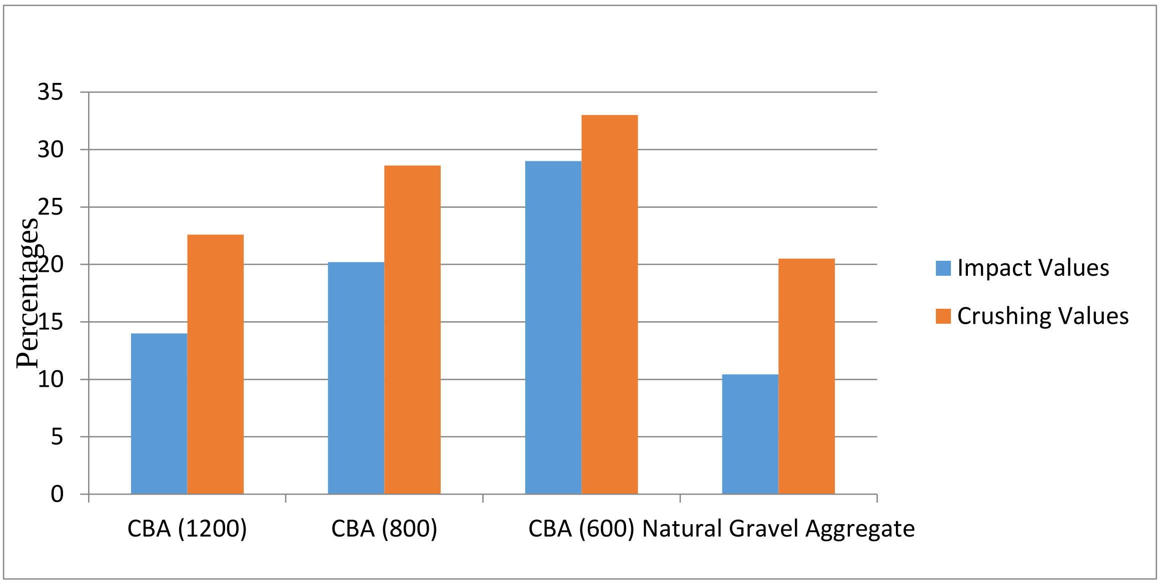

Figure 1: Mechanical properties of aggregates

It can be seen that in all the three sets of aggregates, there is an inverse relationship between the temperature and the impact and crushing values with the rise in temperature. In view of the fact that higher values denote low resistance, to abrasion, this shows that it has fair resistance to failure by impact and wearing. Most especially when these values are compared with the prescription contain in BS 882 (1992) that allowable values should not exceed: 25% when the aggregate is to be used in heavy duty floors, 30% when the aggregate is to be used in concrete for wearing surfaces; and 45% when it is to be used in other concretes. The crushing value is rather insensitive of the variation in strength of the weaker aggregates. One important fact that should be noted is that these result proves one important fact: that the higher the exposure of the clay aggregate to elevated temperature, the higher, the impact and crushing values of burnt clay aggregates and hence, the stronger the aggregates.

Hardened Concrete

The results of various tests carried out on hardened concrete, are presented and discussed under the following headings:

Density

The density obtained from the sample A ranges from (2040 – 2380) kg/m^3, with average density of 2218kg/m^3, the concrete of samples B ranges from (2020 – 2360)kg/m^3, with average density of 2207 kg/m^3. The densities obtained from using crushed burnt clay aggregate to produce concrete showed that it is within the range of normal weight concrete which is between 2240-2400kg/m^3 as stated (Neville & Brooks 2010). It indicated that the samples fall within the range of medium weight concrete.

Table 6: Summary of average density of concrete

S/N	Average density (*kg/m³*)		
	1200 °C	800 °C	600 °C
1	2214	2209	2206

COMPRESSIVE STRENGTH

The details of the result of the compressive strength test of concrete samples produced with natural aggregates (control) and concrete prepared with burnt clay aggregates is presented in Table 7.

Table 7: Compressive strengths of the concrete

Curing days	Average compressive strength (*N/mm²*)			Average compressive strength (*N/mm²*) for the Normal Control
	1200 °C	800 °C	600 °C	0 °C
7	10.80	11.50	11.00	16.00
14	15.40	13.40	13.20	20.00
21	12.80	11.20	10.80	23.60
28	11.20	11.05	10.00	24.00
56	17.40	15.40	13.20	24.30

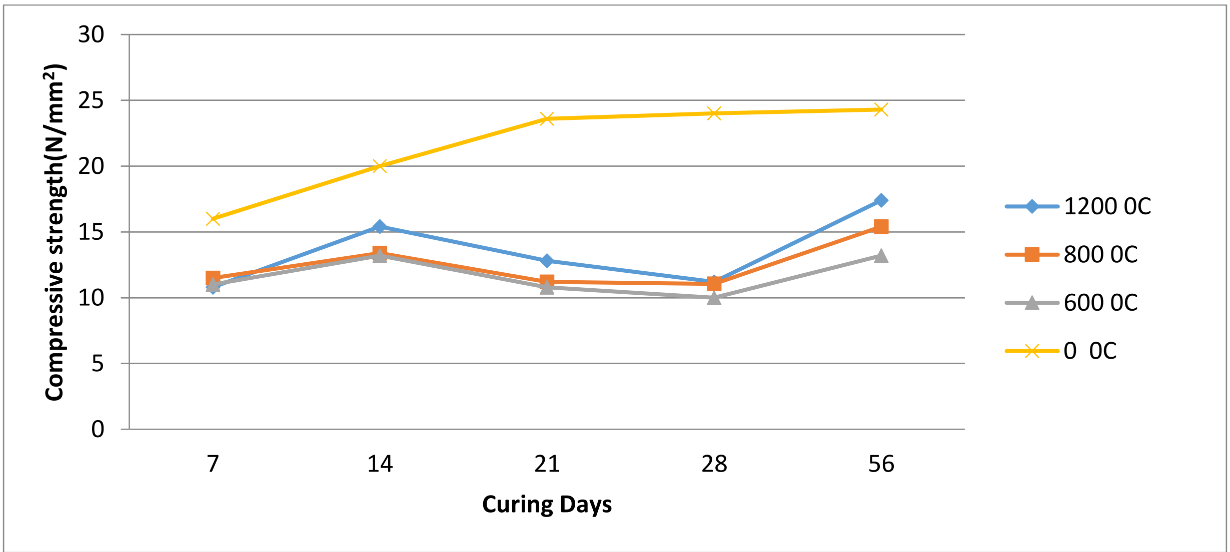

Figure 2: Compressive strength of concrete cubes produced with clay aggregates exposed to 600°C, 800°C and 1200°C

Result of the compressive strength test shows that concrete produced with burnt clay aggregates exposed to elevated temperatures of 600°C, 800°C and1200°C are: 10N/mm^2, 11.05 N/mm^2 and 11.20N/mm^2 respectively. This shows, clearly, that there is direct relationship between the quality of concrete and the temperature that the clay aggregates used in the production of such concrete samples, were exposed to.

Thus, when clay aggregate is exposed to high temperature and used in the production of concrete, such a concrete, has higher compressive strength,

SUMMARY

The study evaluated the properties of concrete produced with burnt clay aggregates with a view to establishing its suitability for use in concrete production. Highlights of the major findings are as follows:

i. The aggregates have the specific gravity between 3.00 and 2.00with the bulk density of 963.00kg/m^3 and 1037.00kg/m^3 based on saturated surface dried sample as compared with the normal weight aggregate with specific gravity of 2.5 – 3.5 and bulk density of 1600kg/m^3 which classified the former as lightweight aggregate and the latter as relatively medium weight aggregate.
ii. Water absorption capacity of 8.384% and 8.225% indicate high porosity of the aggregates.
iii. The mechanical properties of the aggregate revealed that broken clay with impact value of 29% and crushing value of 33%.
iv. The density of concrete produced with burnt clay aggregates ranges from 2206kg/m^3 - 2214kg/m^3.
v. The compressive strength test result after 28 days shows that concrete produced with burnt clay aggregates exposed to elevated temperatures of 600°C, 800°C and 1200°C are: 10N/mm^2, 11.05 N/mm^2 and 11.20N/mm^2 respectively. While the control sample has a higher strength of 24N/mm^2

CONCLUSION AND RECOMMENDATIONS

I. The study has conclusively revealed that burnt clay aggregates can be used for the production of concrete. However, the quality of such concrete falls below the normal concrete.
II. When the broken clay aggregate were used as coarse aggregate to produce concrete, such concrete falls within the medium weight category.
III. It was also established that temperature has great influence on the quality of burnt aggregate. The higher the temperature the higher the compressive strength.

Based on the results of this study, the following recommendations were made:

I. Due to the high absorption capacity of the burnt clay aggregate as compared to normal aggregate, water should be added to the mix when not used as saturated surface dried samples.
II. The burnt bricks aggregates can be used for other structural element rather than hard wearing surface such as road and pavement construction.
III. Depending on the mixed proportion used the burnt bricks aggregate concrete can be used for either structural, insulation or as concrete for masonry works.

Future directions

I. Durability properties of concrete produced with burnt clay aggregates should be investigated
II. Ways of enhancing the properties of clay aggregates for the production of concrete without heating, should be investigated
III. Properties such as elastic properties should be determined which are important component in the calculation of the deflection of structural members between stress and strain.
IV. The effect of burnt clay aggregate on the cement hydration should be determined.

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