PERFORMANCE CHARACTERISTICS OF SOME LOCALLY AVAILABLE BRANDS OF ORDINARY PORTLAND CEMENT IN NIGERIA

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Abstract

The study investigates the performance characteristics of some locally available brands of Ordinary Portland Cement in Nigeria in order to determine their suitability for normal concrete works. Various tests such as the density, fineness, consistency, setting time, soundness and chemical composition were carried out. The compressive strengths of mortar and concrete cube for the selected brands of the Portland cement were also determined. For the mortar cube, mixing proportion of 1:3 of cement to sand with water/cement ratio of 0.40 was used while in concrete cube test, one design mixing proportion of 1: 2: 4 with water/cement ratios of 0.50 and 0.60 were considered. The cubes were crushed at different ages to determine the strength development with time for the various cement brands. All the results showed that majority of the brands of cement satisfied the minimum British standard codes requirement for normal concrete works. However, the rate of strength development varies in the different brands considered.

Keywords: Concrete, Ordinary Portland Cement, Compressive Strength, Chemical Composition

Introduction

Every year a huge amount of ordinary Portland cement is produced and used in the construction of residential and public buildings, roads, bridges and drainages as well as rehabilitation of infrastructure. In Nigeria, the use of low quality cement in structural and construction works may cause loss of lives and properties as witnessed in some parts of the country. As a result of this, performance characteristics of Ordinary Portland Cement has become an important and critical factor, even though a number of tests are performed in the laboratories of cement industries to ensure that the cement is of the desired characteristics and it conforms to the requirement of the relevant standard (Natalya, 2003). Independent analysis can be performed to check the characteristics of cement in the Nigerian market.

The cement to be used in construction must have certain characteristics in order to play its part effectively in structures. When these characteristics lie within a certain specified range of standard values, the engineer is confident that cement performance will be satisfactory. Besides, based on these characteristics, it is possible to compare the quality of cement from different sources.

The characteristics of a type of Ordinary Portland Cement are dependent on its mineralogical composition, its fineness, duration of storage and ambient temperature (Vinod, 2009). Fineness of the cement on the other hand determines its degree of hydration, the water/cement ratio and consequently the workability and rate of development of strength in concrete elements.

The major constituents of ordinary Portland cement are tricalcium silicate ($3CaO.SiO_2$), dicalcium silicate ($2CaO.SiO_2$), tricalcium aluminate ($3CaO.Al_2O_3$) and tetracalcium aluminoferrate

($4CaO.Al_2O_3.Fe_2O_3$) (Natalya, 2003). The abbreviated symbols for these compounds in the global cement industry are C_3S, C_2S, C_3A and C_4AF respectively (Natalya, 2003). A high ratio of C_3S leads to faster gain of strength of the hardened cement paste in the first 7 days by which time about 70% of the strength is attained. A high ratio of C_2S on the other hand results in slow gain of strength in the first few days while C_3A and C_4AF control setting and heat evolution during hydration (Vinod, 2009). It may be realized that the actual proportions of the various compounds vary considerably from cement to cement, region to region because of the possible differences in the composition and proportioning of the raw materials used during cement manufacture (Vinod, 2009). The properties of cement, such as its setting time and strength, are adjusted by the addition of gypsum and by grinding to specific degrees of fineness (Wagner & Vassilopoulos, 2000). There are several brands of Ordinary Portland Cement available in the market but their chemical compositions are the same. Variations in physical properties occur due to variation in the amount of chemical constituents (BS 12, 1978).

Ordinary Portland Cement loses its activity, that is, its compressive strength at 28 days, even when stored under most favourable conditions for a long period. After 3 months of storage, the loss of activity could be about 20% and after one year, it could be up to 40% (Komar, 1970). With the long period of shipment of some brands of cement imported to the country, the possibility of loss of activity may not be ruled out.

The abundance of various brands of Ordinary Portland Cement in Nigeria, with few produced in the country, while others are imported from various countries. At times in bulk and at other times already bagged, calls for tests to be carried out with a view to ascertaining their suitability in accordance with national codes and standards.

Experimental Procedure

Material Collection: Five brands of Ordinary Portland Cement were investigated; three of which were bought in Ede while the remaining two were bought in Lagos. The brands are Elephant cement (EC), Dangote cement (DC), Diamond cement (DI), Purechem cement (PC) and Burham cement (BC). The fine aggregate used for the experiment is river sand which was obtained from Osun River while crushed granite purchased from a quarry site at Ede was used as coarse aggregate. Sieve analysis and measurement of relative density was done for the fine and coarse aggregates. Appropriate sets of sieves were used for the sieve analysis of the fine and coarse aggregates as outlined in BS 882 (BS 882: Part 2, 1973).

Production of Mortar Cubes

The mortar cubes were obtained by mixing cement with sand in the proportion of 1 : 3 with water / cement ratio of 0.4. Three 70.7mm mortar cubes were tested at each curing age of 3, 7, 14 and 28 days. The sand used passed through 850µm sieve and was retained on 600 µm sieve. Before mixing, the mould and its base were clamped together on a table of the vibrating machine to reduce the leakage of mortar. After mixing, the mortar was placed in the mould and compacted with the vibrating machine for about 2 minutes. Immediately after vibration, the hopper was removed and the mould was placed on a level surface. In order to reduce evaporation, the exposed top of the cubes was covered with a flat impervious sheet. After 24 hours, the moulds were removed and the mortar cubes submerged in water for the purpose of curing. The mortar cubes were then left in the water until just prior to the compressive strength test.

Production of Concrete Cubes

The mixing bowl and paddles were wiped clean with a damp cloth and different types of cement, sand and granite in the ratio of 1 : 2 : 4 were weighed into the mixing bowl. Two different water / cement ratio of 0.50 and 0.60 were used for the mixing of the concrete. Twelve (12) pieces of clean 150 x 150 x 150mm cube steel moulds were set on the working bench and all bolts were tightened using the spanner. The base of the mould was greased with engine oil and also the joints of the two halves. The mould was then filled with the prescribed concrete mix in three layers. Each layer of concrete was compacted with about 35 strokes of a 25mm steel rod until full compaction was achieved. When the mould was filled up, its top surface was levelled off with a trowel. The cubes were then stored undisturbed for 24 hours at room temperature 25^{0}C. At the end of this period, the cubes were removed from the mould and put in storage water tank for further curing in accordance with BS 4550 (BS 4550; Part 3, 1978). The temperature of the water used for curing was 22^{0}C. Crushing of the concrete cubes was later carried out at the ages of 7, 14, 21 and 28 days. In all, 120 concrete cubes were cast and tested.

Determination of Specific Gravity

The specific gravity of cement was measured using a density bottle, water bath and displacement liquid (kerosene) in accordance with BS 4550 (BS 4550; Part 3, 1978). The density of the displacement liquid was initially determined, then the mass of the density bottle was then obtained. For the determination of the specific gravity of cement, about 8 grammes to 10 grammes of cement was placed in the density bottle after weighing the bottle and the stopper alone. The mass of the cement was then derived. Sufficient displacement liquid was next added to cover the cement adequately.

Determination of Consistency, Setting Time and Fineness of Cement

The consistency of cement was measured using a Vicat apparatus. 400g of cement sample was weighed and spread out on a steel plate for about 30 minutes to cool to the temperature of the mixing room (27 ± 50^{0}C). A water content of 30% of the mass of dry cement was added as a start. The mixture was mixed for 4 ± 0.25 minutes by using a trowel to give a paste and was immediately transferred into the mould on the steel plate. The top of the mould was smoothened off as quickly as possible with the aid of the trowel. The mould and paste were placed under the plunger in the Vicat apparatus and the plunger lowered gently to contact the surface of the paste. This material was released quickly and allowed to sink into the paste. The scale reading of the Vicat apparatus was then noted after 1 minute and recorded. If the plunger penetrates to a point 5 to 7mm above the bottom of the mould, the water/cement ratio is taken as the consistency and if not, a new water/cement ratio is taken and the procedure repeated.

For the setting time as stated in BS 4550 (BS 4550: Part 3, 1978), a sample of cement paste of standard consistency was prepared and the time of first mixing the water with cement was noted. Excess paste was immediately transferred into the mould in one layer by using hand trowel. The top of the mould was smoothened and levelled. The mould was placed under the initial set needle of cross – sectional area of 1mm and the needle was lowered gently on to the surface of the paste and was quickly released by allowing it to sink to the bottom. These tasks were repeated several times at regular intervals of 10minutes in different positions of mould until the paste had stiffened sufficiently for the needle not to penetrate deeper than 5mm above the bottom of the mould. The time interval between the addition of water and the initial setting time was recorded. Finally, the needle was replaced with a 1mm square needle fitted with a metal annular attachment and this probe was allowed to come gently in contact with the surface of the cement paste at an interval of 15minutes. The final set was reached when the needle makes an impression on the surface.

The permeability apparatus using the manometer and the flowmeter was used for the determination of fineness as described in the same British Standard.

Determination of Soundness of Cement

Soundness test was carried out using 'Le Chatelier' apparatus as described in BS 4550 (BS 4550; Part 3, 1978). The test was carried out as follows:

The cement paste was prepared as of a standard consistency and filled into the expansion mould or Le Chatelier mould, placed on a glass plate. The split end of the mould was gently closed by tying it with a piece of cotton as the operation was being carried out. The surface of the paste was well smoothened and levelled with the blade of a gauging trowel. It was then covered with another piece of glass and was immediately immersed in clean water. A 50g weight was placed on top of the plate for compaction.

After 24 hours, the mould was removed from the water and the distance between the pointers was measured using a meter rule. The mould was re – immersed in water again and was brought to boiling point within 30minutes and afterwards allowed to boil for one hour. This specimen was then kept in the water and allowed to cool. The distance between the pointers was again measured. The difference between the two measurements represents the value for soundness.

Determination of Oxide in Cement

The oxide composition of cement was determined using the procedure outlined in the European Standard EN 196 (European Standard EN 196 – 2, 1994). The procedure involves weighing approximately 100g of cement, which was sieved and transferred to a clean dry flask with an airtight closure. This was subsequently used for the various tests that were carried out.

To determine the main constituents of cement, 1g of the sample was weighed and decomposed with 3g of sodium peroxide. The mixture was then heated to about 500^0C while 50ml of concentrated hydrochloric acid (HCl) and 1ml of hydrogen tetra oxo sulphate (vi) acid (H_2SO_4) were added. This solution was then used for the determination of the main oxide composition of cement. The sulphate composition and insoluble residue were also determined separately from the other main constituents. The quality of the cement products were then calculated from the oxide concentrations of the cement using Bogue's equations (Ali, Khan, & Hossain, 2008; Neville, 2010; Shetty, 2009). The equations are as follows:

$$C_3S = [(4.071.CaO) - (7.6.SiO_2) - (6.718.Al_2O_3) - (1.43.Fe_2O_3) - (2.852.SO_3)] \quad \text{- - - - eq.1}$$

$$C_2S = [(2.867.SiO_2) - (0.7544.C_3S)] \quad \text{- - - - eq.2}$$

$$C_3A = [(2.650.Al_2O_3) - (1.692.Fe_2O_3)] \quad \text{- - - - eq.3}$$

$$C_4AF = [3.043.Fe_2O_3] \quad \text{- - - - eq.4}$$

To determine the loss in ignition, 1g of the sample was further weighed in a platinum crucible capacity of 25 – 30ml at a temperature of 25^0C. This material was then heated in a muffle furnace at a temperature between 900 – $1,000^0$C, cooled and weighed (W_1). The loss in weight was checked by a second heating at same temperature for 5 minutes and the content reweighed. This process was repeated until a constant weight (W_2) was attained. The loss in weight was recorded as the loss in ignition. Percentage loss on ignition was calculated as follows:

$$\% \text{ Loss of ignition} = \left(\frac{W_1 - W_2}{W_1}\right) x\, 100 \quad \text{--------} \quad \text{eq.5}$$

Where:

W_1 = weight of sample heated,

W_2 = Weight of the same sample heated until a constant value of weight attained.

Test Results and Discussions

Chemical Composition: Differences in the behaviour of the various brands of Ordinary Portland Cement were determined by their chemical composition and fineness. The oxide and compound composition obtained for the various brands of the tested Portland cement is shown in Table 1. The compounds were formed as a result of the chemical changes, which took place within the kiln during the production of the Portland cement. The results showed that two silicates; tricalcium silicate (C_3S) and dicalcium silicate (C_2S) are the most stable of the compounds and together constitute 75 – 80% of the tested cement.

The highest percentage of C_3S (63.74%) was obtained with the Dangote brand of cement. It consequently had the lowest C_2S of 5.30%. The percentage composition of the C_3S and C_2S affect the rate of strength development in cement while it is to be noted that the higher the lime content, the higher the percentage of C_3S. Also the lower the clay content in terms of SiO_2, the lower the percentage of C_2S in the cement. All the brands of the cement investigated satisfied the oxide composition limits as recommended by the British Standard except the sulphate (SO_3) content of Purechem brand with 3.43%, which exceeded the upper limit of 3%.

According to the European Standard (EN 197 – 1), the sum of the properties of CaO and SiO_2 in cement should not be less than 50% by mass. Similarly, the ratio by mass of CaO to SiO_2 should not be less than 2.0. From the results obtained, the sum of CaO and SiO_2 in all the brands of cement investigated exceeded 50% by mass and have ratios above 2.0 (European Standard EN 197 – 1, 2000).

From the compound composition, it would be expected that Dangote brand could be useful where early strength development is necessary while Elephant and others, hydrate slowly and may be more active after 7 days of curing. In view of their high percentage of C_2S, they may give greater resistance to chemical attack and a smaller drying shrinkage than Dangote Portland cement. The high percent of tricalcium aluminate (C_3A) in Burham, Purechem and Diamond brands may make them susceptible to sulphate attack.

Table 1: Oxide and compound composition of the various brands of cement

Constituent (oxide/compound)	Percentage composition (%)					Composition limits (BS12)
Oxide Composition	Elephant	Purechem	Dangote	Diamond	Burham	
CaO	62.28	60.67	63.74	61.86	62.94	60 – 67
SiO_2	21.02	20.18	18.62	19.01	20.97	17 -25
Fe_2O_3	3.88	3.94	3.67	3.83	2.96	0.5 – 6.0
Al_2O_3	6.02	6.13	6.09	5.74	6.03	3 - 8
SO_3	1.81	3.43	2.83	2.92	2.45	1 - 3
MgO	1.86	1.55	2.48	2.46	2.75	0.1 - 40
Insoluble Residue	0.50	0.57	1.20	0.68	0.53	≤ 1.5
Loss on Ignition	1.05	2.98	3.26	2.03	3.01	≤ 4.0
Compound Composition						
C_3S	42.64	37.02	63.74	55.60	45.13	
C_2S	28.10	29.93	5.30	12.56	26.07	
C_3A	9.39	9.58	9.93	8.73	10.97	
C_4AF	11.81	11.99	11.17	11.65	9.01	

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Fineness and Setting Times

The values of specific surfaces and setting times obtained for the various brands of cement are shown in Table 2. The rate of hydration depends on the total surface area of cement available to react with water. The specific surface therefore contributes to the initial and final setting times as well as to early development of strength, to a certain extent. High percentage of C_3S and C_3A lead to more rapid setting.

BS 12 (BS 12, 1978) recommends a minimum specific surface area of 225m^2/kg, an initial setting time of not less than 45 minutes and final setting time of not more than 10 hours. These minimum code requirements were satisfied by the various brands of cement investigated and they can thus be considered for normal concrete works.

Table 2: Specific surface and setting times for the various brands of cement

Cement Brands	Specific Surface (m^2/ kg)	Initial Setting Times (Minutes)	Final Setting Times (Minutes)
Elephant	360.0	118	244
Purechem	375.0	120	255
Dangote	385.0	135	260
Diamond	330.0	115	176
Burham	335.0	130	185

Soundness

In the soundness test that was carried out, the expansion of the various brands of cement were 1.58, 2.46, 0.85, 2.34 and 2.29mm for Elephant, Purechem, Dangote, Diamond and Burham cement respectively. Dangote cement had the smallest expansion indicating low impurities. The chemical composition of this brand of cement would have resulted in rapid hydration. BS 12 (BS 12, 1978) recommends an expansion of not more than 10.0mm for Ordinary Portland Cement. All the brands of cement investigated met this requirement.

Density

The densities of the Ordinary Portland Cement samples obtained for Elephant, Purechem, Dangote, Diamond and Burham brands are 3590kg/m^3, 3330 kg/m^3, 3420 kg/m^3, 3480 kg/m^3 and 3250 kg/m^3 respectively. Thus, showing differences in the variation in the densities by less than 10%. Table 3 shows the variation in the densities of the concrete cubes prepared with varying water/cement ratios for the different brands of the Ordinary Portland Cement. The density of the concrete cubes do not follow the same pattern as the density of the cement samples. This may be attributed to the grading sizes of the aggregate as well as the level of compactness of the concrete cubes. It is to be noted that the density of the concrete cubes for various brands of cement do not depend on the water/cement ratio.

Table 3 : Variation in densities of concrete cubes with varying water/cement ratios for the different brands of cement

Brand of Cement	Density of Cement (kg/m^3)	Average w/c Ratio of 0.5	Density of Concrete Cubes w/c Ratio of 0.6
Elephant	3590	2469	2510
Purechem	3330	2518	2492
Dangote	3420	2814	2744
Diamond	3480	2666	2672
Burham	3250	2542	2584

Compressive Strength

Table 4 shows the compressive strength results of the mortar cubes obtained from the different brands of Portland cement. It shows that the mortar cube strength increases as the days of curing increases and the values of all the brands at 3 days were lower than 23N/mm^2, prescribed by the British Standard, except Diamond cement which was 23.96N/mm^2. At 28 days, there was significant improvement in strength development as shown in Figure 1 with values of 37.45N/mm^2, 34.24N/mm^2, 32.39N/mm^2, 31.18N/mm^2 and 30.53N/mm^2 for Diamond, Dangote, Elephant, Purechem and Burham cement. All the brands showed values lower than the stipulated 41N/mm^2 for Ordinary Portland Cement but higher than the value of 28N/mm^2 for low – heat Portland cement.

The compressive strength of the concrete cubes of the various brands of Portland cement at different ages for different water/cement ratios are expressed graphically in Figures 2 and 3. As expected there was improvement in strength with age in all the brands of cement. At 7 days, the concrete cube crushing strength of water/cement ratio of 0.50 showed that the Elephant cement had the highest strength of 24.53N/mm^2 followed by Burham cement with 23.68N/mm^2. With the C_3S content of 42.45% for Elephant and 49.37% for Burham cement, such a high strength would not have been expected at 7 days. The high CaO composition of Elephant and Burham cement would have contributed to their higher initial strength. The Dangote and Purechem cement with higher C_3S composition gave 20.32N/mm^2 and 22.45N/mm^2 respectively. The comparatively lower strength of the Dangote cement may be attributed to its low measured density, which would have retarded the hydration process.

The 28 days compressive strength for the same water/cement ratio showed Diamond cement topping the list with 31.81N/mm^2 followed by Burham cement with 31.02N/mm^2. The higher strength of these two brands of cement at 28 days clearly shows the influence of the high content of their C_2S (29.45% and 27.32% respectively). Next is the Elephant cement with 30.27N/mm^2. The high 28 days strength is also attributable to the high C_2S content (24.58%). However each brand of Portland cement showed varying response to change in water/cement ratio.

Table 4: Compressive Strength of Mortar Cubes at Different Ages for Different Brands of Ordinary Portland Cement

Brand of Cement	Compressive Strength (N/mm^2)		
	3 days	7 days	28 days
Elephant	20.87	27.15	32.39
Purechem	21.31	28.73	31.18
Dangote	22.42	30.46	34.24
Diamond	23.96	32.19	37.45
Burham	19.80	25.32	30.53
BS 12 Value	23.00		41.00

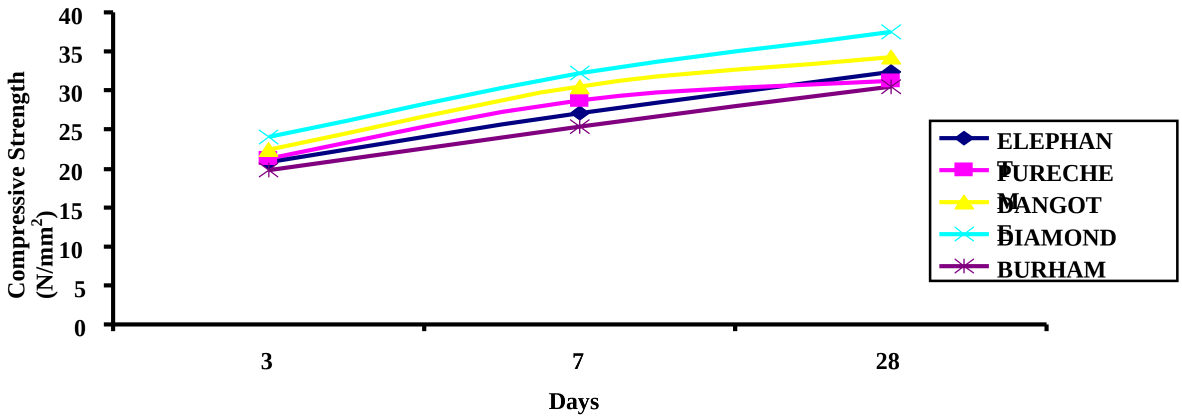

Figure 1: Compressive strength – time characteristic of mortar cubes for the various brands of ordinary portland cement

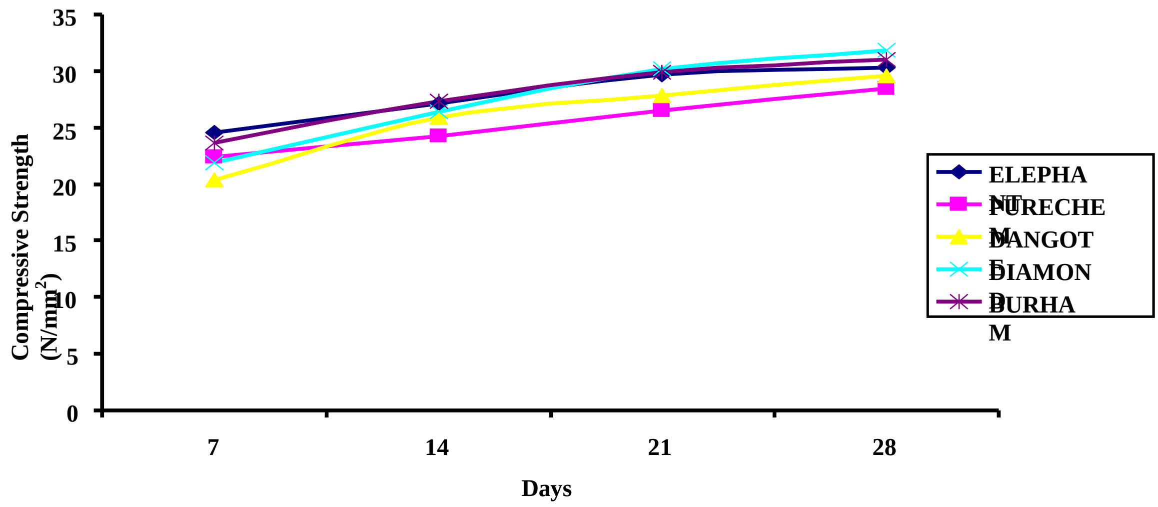

Figure 2: Compressive strength – time characteristic of concrete cubes from various brands of ordinary portland cement with water/cement ratio of 0.5

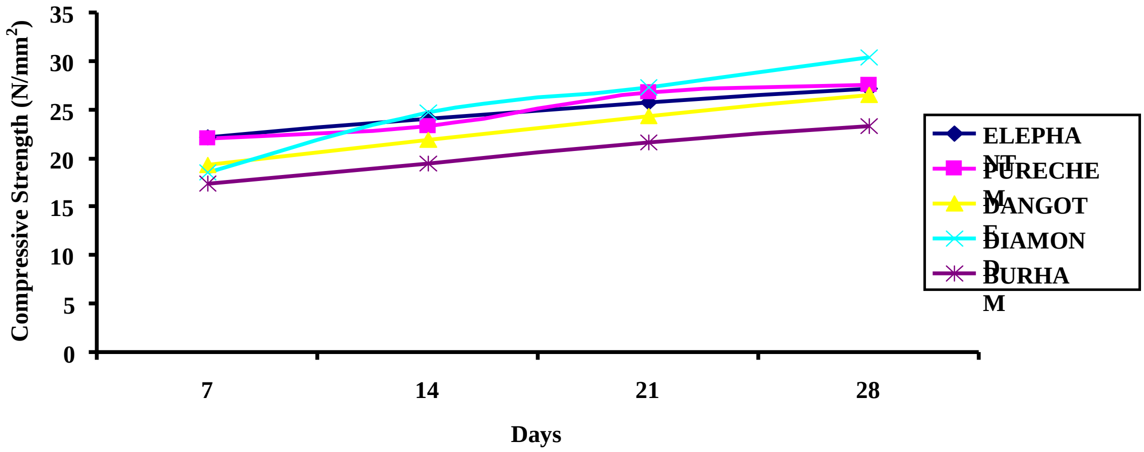

Figure 3: Compressive strength – time characteristic of concrete cubes from various brands of ordinary portland cement with water/cement ratio of 0.6

Conclusions

Based on the investigation and experimental results, the following conclusions can be made:

(i) All the brands of Ordinary Portland Cement considered satisfied the chemical composition limits, specific surface, expansion and initial and final setting time requirements outlined in the relevant British Standards except the sulphate content of Purechem cement which exceeded the 3% composition limit.

(ii) All the cement brands showed improvement in compressive strength with age.

(iii) The compressive strength of the concrete cubes for all the cement brands decreased as the water/cement ratio increased.

(iv) Variation in the density of the various brands of cement of less than 10% was observed. However the densities of the concrete cubes obtained did not follow the same pattern as the densities of the brands of cement.

(v) The Dangote cement with its compound composition would be more suitable where rapid strength development is required whereas the Burham cement ought to have exhibited characteristics similar to that of Dangote cement but for the observed loss of activity while the other brands of cement would however be suitable for mass or general concrete works and concrete works in arid regions. However Purechem cement cannot be recommended for concrete works in farmland.

Recommendations

Based on the investigation and experimental results, the following recommendations can be made:

(i) Five brands of cement were investigated and apart from these five, several other brands are available in the Nigeria market. It is therefore necessary for the Nigerian Government agency responsible for quality control (Standards Organisation of Nigeria) to ensure all brands of cement available in Nigeria are suitable.

(ii) A further test, which could be carried out on the tested brands of cement, is the assessment of their progressive loss of activity with storage. This would further bring out some salient characteristics of these brands of Ordinary Portland Cement.

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