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Comparative Analysis of the Chemical Composition of Various Brands of Portland Cement Available in South- Western Parts of Nigeria

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***Abstract*- This study compares the chemical properties of different brands of Ordinary Portland Cement (OPC) available in South- West part of Nigeria. The amounts of chemical constituents like SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, Insoluble Residue (IR), freelime and Loss On Ignition (LOI) were determined in accordance with British Standard (BS) Specifications. Four brands of cement considered are Dangote, Diamond, Elephant and Purechem Portland cement. This is to examine if these brands of cement meet the minimum and maximum standards as stipulated by British Standard Institute. It also helps to determine the appropriate brands of cement to be used for different types of construction work. Chemical analysis plays an important role in the categorization of cements, allowing manufacturers to predict the way that the material will react to its environment when mixed. The result showed that most of the compositions of these constituents were within the range of the standard values. Except for some variation in chemical compositions of one or two brand of the cements and the possible reasons for these variation in their chemical compositions and their consequences were discussed.**

Keywords: Ordinary Portland Cement; Chemical Composition; Quality Verification; Artificial Cement

I. INTRODUCTION

Cement is a binder which mainly consists of compounds of calcium, silicium, aluminum, iron and small amounts of other materials. The cements used in concrete production are called hydraulic cements which set and harden after being combined with water. In the earliest of the 19th century, Joseph Aspdin, a bricklayer, first made a hydraulic cement called Portland cement whose name was given since the hardened cement resembles the color and quality of Portland stone [1]. Portland cement is made by heating, in a kiln a homogeneous mixture of raw materials to a constant temperature of about 1450^0C for modern cement. The aluminium oxide and iron oxide are present as a flux and contribute little to the strength. For special cement, such as Low Heat cement (LH) and Sulphate Resistance (SR) types, the amount of tricalcium aluminate ($3CaO\text{-}ALO_3$) formed are limited [2]. The major raw materials for the clinker-making comprises of limestone ($CaCO_3$) mixed with a second material containing clay as source of alumino-silicate, an impure limestone which contains clay or silicon oxide (SiO_2) is used. The calcium carbonate ($CaCO_3$) content of the limestone can be as low as 80% secondary raw materials (material in the raw- mix other than limestone) depending on the purity of the lime stone. The four major clinker phases present in Portland cement are tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF).

However, in Nigeria, there are various brands of Portland cement in the market which are used in construction industries. Poor quality construction materials are one of the reasons for so many collapsed building incidents since the cement is an important constituent of concrete which serves as binder [3]. The quality of cement also plays an important role in preventing these concrete failures. Therefore, there is a necessity to check the chemical properties of these cement brands which affect the physical properties of the cement. Also, there are other few cases where the construction personnel will be in doubt of which of the brand of Portland cements available will perfectly meet the instant need like a little delay in setting time or early setting time as the case may be. The aim of this study is to compare the chemical properties of various brands of Ordinary Portland cement (O.P.C) available in south-western part of Nigeria through direct performance test and and to investigate its effect on the performance of concrete. The result of this study will serves as a guide for selection of appropriate cement for different types of construction work.

II.CHEMICAL COMPOSITION OF PORTLAND CEMENT

Composition of Portland cement distinguishes one type of cement from another. The effect of cement on cement concrete properties is shown in table 1. [4] present the standard chemical requirement for each type. Compositions phase in Portland cement is denoted by ASTM as tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF). It is noted that this composition occurs at a phase equilibrium of all component in the mix and do not reflect effects of burn temperatures, quenching, oxygen available and other real-world kiln conditions. The actual components are often complex chemical crystalline and amorphous structures, denoted by cement chemists as "elite" (C_3A), "belite" (C_2S) and various forms of aluminates. Early hydration of cement is principally controlled by the amount and activity of C_3A, balanced by the amount and type of sulphate interground with the cement. C_3A hydrates very rapidly and influence early bonding characteristics. Abnormal hydration on (C_3A) and poor control of this hydration by sulphate leads to problem such as flash set, false set, slump loss and cement-admixture incompatibility [5],[6].

Development of the internal structure of the hydrated cement (referred by many researchers as the microstructure) occurs after the cement concrete has set and continues for months (and even years) after placement. The microstructure of the cement hydrates determines the mechanical behavior and durability of the cement concrete. Test result presented by [7], shows that alkali and C_3A contents influence the required admixture to achieve the required mix.

TABLE 1. EFFECT OF CEMENT ON CEMENT CONCRETE PROPERTIES.

Cement properties	Cement effect
Placeability	Cement amount, fineness, setting characteristics
Strength	Cement composition (C_3S,C_2S andC_3A), fineness
Drying shrinkage	SO_3content, cement composition
Permeability	Cement composition, fineness
Resistance to sulphate	C_3A content
Alkali silica reactivity	Alkali content
Corrosion of embedded steel	Cement composition (esp. C_3A content)

It is a Portland cement chemical property that determines its physical properties and how it cures. A basic understanding of Portland cement chemistry helps to understand how and why it behaves as it does. Chemical properties according to [4] are;

- Tricalcium silicate $3CaO.SiO_2$ (C_3S)
- Tricalcium aliminate $3CaO.AL_2O_3$ (C_3A)
- Dicalcium silicate $2CaO.SiO_2$ (C_2S)
- Tetracalcium aluminoferrite $4CaO.AL_2O_3.Fe_2O_3$ (C_3AF)

Tricalcium Silicate (C_3S): Tricalcium silicate hydrates and hardens rapidly and largely responsible for initial set and early strength. Portland cement with higher percentages of C_3S will exhibit higher early strength. C_3S is the most abundant and important cement minerals in Portland cements contributing most of the early strength development. The hydration of C_3S can be written as

$$C_3S + (1.3+X)\ H \longrightarrow C_{1.7}SH_X + 1.3CH \qquad (1)$$

Where $1.7C\text{-}S\text{-}H_X$ is the calcium silicate hydrate (C-S-H) gel phase and CH is calcium hydroxide, which has the mineral name portlandite. The variable x in equation (i) represent the amount of water associated with C-S-H gel, which varies from 1.4 to 4 depending on the relative humidity inside the past and amount of water that associated with the C-S-H is considered to be part of its actual composition. The kinetics of hydration of C_3S is substantially similar to those of Portland cement as a whole. Much of the reaction occurs during the first few days, leading to substantial strength gains and reaction in a capillary porosity.

Tricalcium Aluminate (C_3A):Tricalcium aluminate hydrates and hardens quickly. It liberates a large amount of heat immediately and contributes to early strength. Gypsum is added to Portland cement to retard C_3A hydration and without gypsum, C_3A hydration will cause Portland cement to set immediately after adding water.

Dicalcium Silicate (C_2S): Dicalcium silicate hydrates and hardens slowly and is largely responsible for strength increase within one week. The calcium silicate phase C_2S react according to

$$C_2S + (0.3+X)\ H \longrightarrow C_{1.7}SH + 0.3CH \qquad (2)$$

The hydration products are the same as those of C_3S, but the relative amount of CH formed is less. C_2S is much less soluble than C_3S, so the rate of hydration is much slower. C_2S hydration contributes little to the early strength of cement, but makes substantial contributions to the strength of mature cement paste and concrete.

Tetracalcium Aluminoferrite (C_4AF): Tetracalcium aluminoferrite hydrates rapidly but contribute very little to strength. It allows lower kiln temperatures in Portland cement manufacturing. Most Portland cement color effects are due to C_4AF.

III. MATERIALS AND METHOD

A. Materials

The ordinary Portland cement (O.P.C) made available for analysis are Elephant Portland cement, Dangote

Portland cement, Purchem Portland cement and Diamond Portland cement. The Elephant Portland cement and Dangote Portland cement were procured at main depot in Iree, Osun State. The Diamond Portland cement was procured at main depot in Ede, Osun State, and the Purchem Portland cement was procured at main depot in Lagos State, Nigeria. The chemical composition test was determined in Chemistry laboratory of Osun State Polytechnic Iree, Osun-State.

B. Method

The testing procedures based on British Standards [8] have been followed for chemical analysis of Portland cement. Amount of total SiO_2, Al_2O_3, Fe_2O_3, lime content, MgO, SO_3, IR, free lime and LOI were determined [9],[1].

IV. RESULTS ANALYSIS AND DISCUSSION

Table 2. shows the results of the chemical analysis of the composition of the major constituents of four brand of Ordinary Portland Cement available at the South West part of Nigeria.

TABLE 2: THE COMPOSITION OF MAJOR CONSTITUENTS OF FOUR BRANDS OF ORDINARY PORTLAND CEMENT.

Cement	Dangote	Diamond	Elephant	Purechem	Bs for OPC
CaO (%)	64.0	66.3	62.0	67.1	65.0
iO_2 (%)	22.0	18.0	16.0	24.0	21.0
Fe_2O_3 (%)	5.2	3.4	3.2	3.0	3.5
AL_2O_3 (%)	5.6	4.4	5.2	5.8	6.0

The British standards specified that amount of CaO should be within the range 63% to 67%. All five brands of cement contain CaO within the specified limit that can be observed from Fig. 1. The proper lime content is limited due to the lower early strength produced when lime content of Ordinary Portland Cement is too low, and unsoundness when it is too high [10],[2]. High lime content is associated with early strength whereas, slightly lower content of lime favours ultimate strength which develops gradually over a long period of time [10], In order to increase the strength it is necessary to raise the lime content, or grind finer, or both But higher

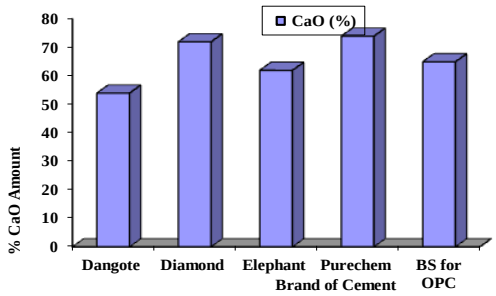

Fig. 1. Comparison of Calcium oxide (CaO) in different brands of cements with British standard.

British standards specify amounts of SiO_2 in Portland cement within the range 21% to 22%. The result in Fig.2. shows that only Dangote cement conformed within specified limit with 22% and Purechem cement slightly higher with 24%. All other brands of cement are below the specified limit.

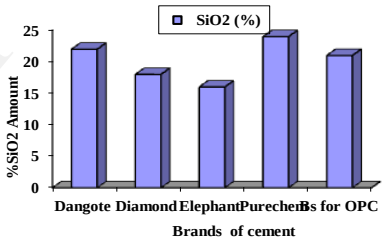

Fig. 2. Comparison of SiO_2 in different brands of cements with British standard

It was found as shown in Fig. 3.that all the brands of cement were within the specified limit of 3.5% for Fe_2O_3 except Dangote cement which has a higher amount of 5.2%. However, all the brands of cement were found within the specified range of 6% for Al_2O_3.Purechem cement has the highest value of 5.8% for Al_2O_3, Dangote has 5.6% and 3.4%, 3.2% Al_2O_3 for Diamond and Elephant cement respectively. A Variations of Al_2O_3 is shown in fig. 4. If the lime content is fixed, and the silica becomes too high, which may be accompanied by a decrease in alumina and ferric oxide, the temperature of burning will be raised and the special influence of the high lime will be lost. If the lime content is too low, which means an increase in the alumina and ferric oxide; the cement may become quick-setting and contain a larger amount of alumina compounds, which appear to be of little value for their cementing qualities. Rapid setting is undesirable, and is not permitted by the standard specifications, because the cement sets up so rapidly that it cannot properly be worked in the forms before stiffening occurs [10],[2].

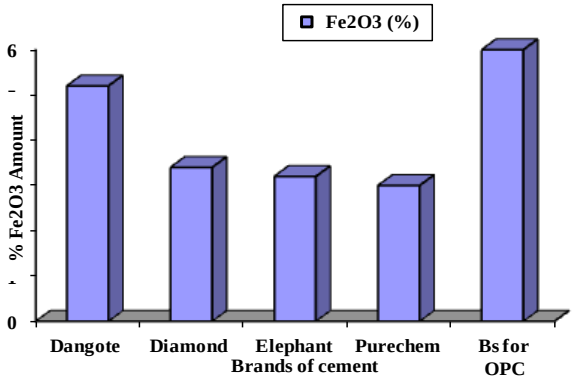

Fig. 3. Comparison of Fe_2O_3 in different brands of cements with British standard

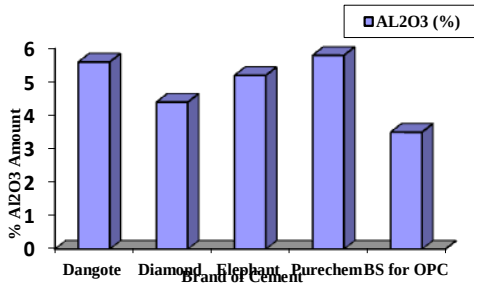

Fig. 4. Comparison of Al_2O_3 in different brands of cements with British standard

TABLE 3.: THE COMPOSITION OF MINOR CONSTITUENTS OF FOUR BRANDS OF ORDINARY PORTLAND CEMENT.

% Element	Dangote	Diamond	Elephant	Purechem	BS for OPC
LOI (%)	2.49	1.22	1.49	2.04	4.0
IR (%)	2.5	2.1	2.6	1.9	1.5
FREECaO (%)	2.36	2.03	2.01	1.91	2.0
SO_3 (%)	1.59	1.89	1.34	2.27	1.5
MgO (%)	0.58	2.14	1.48	2.38	2.0

Table 3. shows the composition of minor constituent of the four brands of OPC. The result shows that all the cement samples were found to be satisfactory with regard to maximum LOI limit of 4.0% as specified by the British Standard with Dangote cement having the highest percentage of 2.49% and Diamond cement 1.22% as the lowest amount of LOI. A high LOI indicates pre-hydration and carbonation, which may be caused by improper and prolonged storage or adulteration of OPC during transport or transfer. This is shown in Fig. 5.

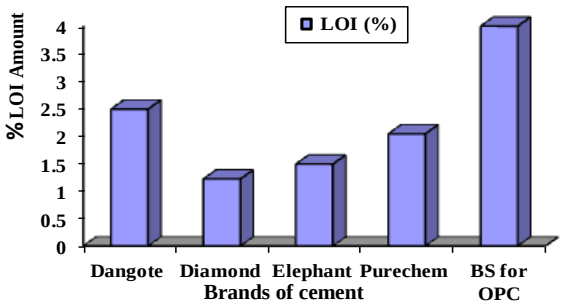

Fig. 5. Comparison of LOI in different brands of cements with British standard

Table 3. shows that Insoluble Residue (IR) of all the cement samples were not within the maximum limit of 1.5% stipulated by the British standard.IR is a non-cementing material in Portland cement and this affects the properties of cement, especially its compressive strength. Purechem cement has 1.9% IR and Elephant cement has the highest amount of 2.6%. Fig. 6. shows that all the cement samples were not within this limit. Addition of the IR in Portland cement affect the compressive strength of cement mortar during the early age, but it is reduced as the cement mortar gets older.

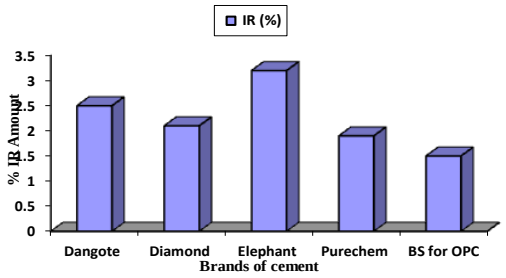

Fig. 6. Comparison of IR in different brands of cements with British standard

Fig. 7 shows the amount of free lime found in different brands of cement that were sampled. The amount ranges from 1.91% to 2.36%. There is no advantage in adding extra lime unless it is brought into combination with other constituents. If appreciable lime is left uncombined, it may cause expansion and cracking of the mortar or concrete [10],[2]. Amount of free lime were found to be very high among the different brands of cements except Purechem cement with 1.91%.

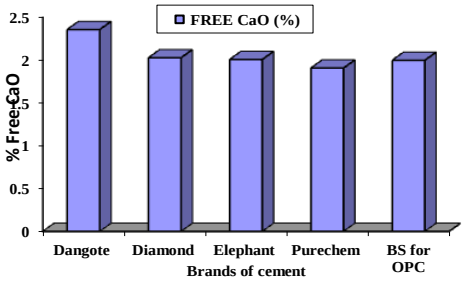

Fig. 7. Comparison of Free CaO in different brands of cements with British standard

The maximum amounts of SO_3 in Portland cement as specified by BS is 1.5 -2.5%. Four brands of cement were found to be within the limit specified with Elephant cement lower with 1.34%. Purechem has the highest amount with 2.27% .This is shown in figure 8. A minimum amount of Calcium sulphate is needed to control the setting time of cement effectively. It is mostly in form of gypsum added to the clinker [11],[10],[2].

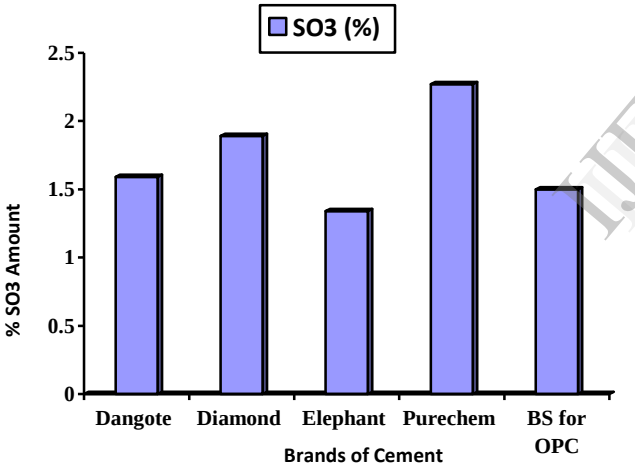

Fig. 8. Comparison of SO_3 in different brands of cements with British standard

Fig. 9. shows the graphical representation of the comparison of MgO. The result shows that Dangote cement and Elephant cement are not beyond the limit of 2%. Diamond cement is slightly higher with 2.14% while Purechem cement is with the highest percentage of 2.38% MgO. Amin, Ali and Shah, 2008 stated that higher magnesia contents may be detrimental to the soundness of the cement resulting in expansion cracks commonly known as magnesia expansion. This occur when magnesia content is beyond the limit of 2% The magnesia appears in the clinker as free MgO (periclase). This reacts with water to form Mg $(OH)_2$ the slowest reaction among all other hardening reactions. Since Mg $(OH)_2$ occupies a larger volume than the MgO and is formed on the same spot where the periclase particle is located, it can split apart the binding of the hardened cement paste [9],[10].

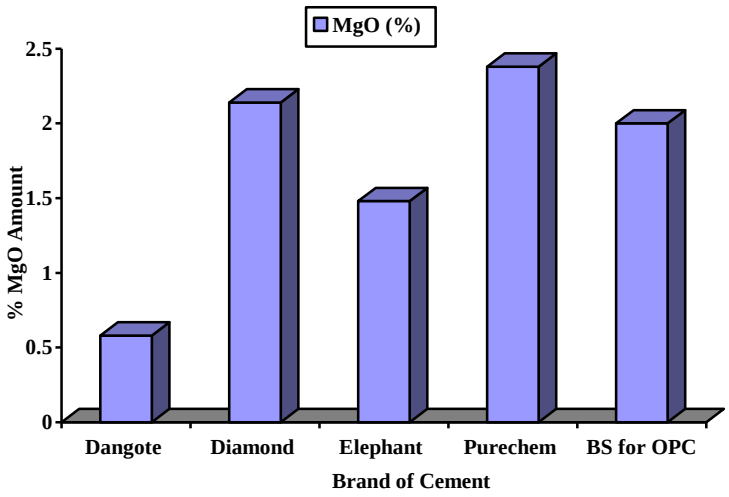

Fig. 9. Comparison of MgO in different brands of cements with British standard

V. CONCLUSION

Chemical analysis plays an important role in the chemical categorization of cements, allowing manufacturers to predict the way the material will react to its environment when mixed. From the obtained results it could be concluded that the chemical composition of the brands of cement available in the south western part of Nigeria conform with BS 12: part 2, 1992 with a slight variation in SiO_2 with Diamond and Elephant cement falling below the maximum limit with 18% and 16% respectively and in Fe_2O_3, Dangote is having higher value of 5.2%.While for minor constituents the cements met the required specification for LOI and SO_3 with variation in IR, FREE CaO and MgO. Any one of the brands available will optimally perform in construction industry.

VI. RECOMMENDATION:

All the cement brands can be recommended for large concrete pours with provision for expansion joint to prevent cracking, due to a compressive research and direct performance test carried out both on physical and chemical properties on four brands of cement. Since all the brands of cement tested have the required standards of BS 12 : part 2 (1992) in chemical requirements. They are hereby recommended to all Nigerian contractors for use in building construction and all other contracting jobs.

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