

Classification of Three Nigerian Cements Using the Chemical and Physical Properties of the Cements

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Abstract—The aim of the study was to analyse and classify three major Portland cement products manufactured in Ashaka (ASK), Sokoto (SKO) and WAPCO (WPC) cements companies into different cements types using the international standard method of classification (ASTM). The method involve the use of chemical analysis to determine the chemical constituents of each cement sample from where the major mineral compounds (C_3S , C_2S , C_3A and C_4AF) were calculated using Bogue's mathematical equation. The mineral compositions form the basis for the classification of the cements into different cement types. The results show that ASK cement has the characteristics of cement type II. WPC cement nearly fits cement type III and SKO cement also has the characteristics of cement type II.

Key words: Portland cement, compressive strength, cementitious compounds, ettringite

1 INTRODUCTION

Cement is derived from a Latin Word "Cementum", which means stone chippings, such as the type used in the Roman mortar and not the binding material itself. This definition has been broadly modified recently to mean a material with adhesive and cohesive properties, which makes it capable of binding mineral fragments into a compact whole [15].

There are different types of cements used widely for various applications, but the most common type is the Portland cement. Portland cement may be defined as a product obtained by intimately mixing together calcareous and argillaceous, or other silica, alumina and oxide of iron bearing materials, and burning them at a clinkering temperature and grinding the resulting clinker into cement powder [13].

Portland cement itself is further sub-divided into various classes based on their chemical composition and specific uses. These include the ordinary Portland cement, the rapid hardening cement, the low heat Portland cement and the sulphate resistant cement. Other types of Portland cements are the Portland blast furnace cement, super sulphate Portland, pozzolana cements and pozzolanas and white Portland cement [15]. All of these cements are produced specifically for various applications in the construction industry

There are many locally operating cement companies in Nigeria which are all producing Ordinary Portland Cement (OPC) using either the dry process or the wet process. Some of the companies are Ukpila, Yandev, Nkalagu, Shagamu, Ewekoro, Sokoto, Obajana, Ibese, Edo, Benue and Ashaka cement companies. Unfortunately, some of projects executed with these

cements sometimes suffer from the problem of building collapse. Apart from such factors as cement aggregate ratio and cement water ratio, the poor qualities of these structures could be due to the intrinsic chemical composition of the cement used [9].

Various scholar, scientist and researchers have attempted to conduct various investigations in the area of chemical and physical analysis of Nigerian cements. The major goal of the investigations is to analyse the chemical as well as the physical compositions of Nigerian cements with a view to comparing the results with the international standard specifications, so that the quality of the cements can be established

Although some of the previous physico-chemical analyses carried out have indicated that there are minor variations in the compositions of cements *vis-a-vis* the major cement oxides (CaO , Al_2O_3 , SiO_2 , Fe_2O_3 , etc.) between the cements and between the cements and the standard specifications, on the overall, the scholars have unanimously observed that the compositions of Nigerian cements are within the acceptable international standards limits [16], [21].

Likewise, on the physical parameters (compressive strength, fineness, soundness, etc.) the compressive strength is one of the major parameter that is used to determine the quality of cements. Earlier studies have equally shown that the compressive strength of cements is a factor of their chemical composition and the analyses carried on the effect of composition on compressive strength, where some portion of cement sample was replaced with other pozzolanic materials, have shown that the compressive strengths of cements reduces in proportion to the quantity of pozzolana material added [1], [17], [20].

Although the composition of the cement is a major factor in the compressive strength of cements the quality of the limestone, as the raw material in the production of Portland cement, has been found to play an important role in determining the compressive strength of cements [12].

Since most of the studies conducted before have largely concentrated on the physico-chemical studies as a way of analysing the composition of cements without classification of the product, which is important for its applications. Therefore, the main objective of this study is to conduct a comprehensive physico-chemical analysis of some selected Nigerian Portland cements and to classify the cements into different cement types based on international standard of classification. In this current work the physico-chemical results of the compositions of the cement will be adopted as the bases of classification of the cements into different cement types using the international standard classification charts [15].

It is believed that the classification of Nigerian cements into various cement types is important to the construction industry and it will enable future projects to be executed using the correct cement that satisfies the specific construction requirement instead of using any type of cement as general purpose cement.

2 MATERIALS AND METHODS

Cement samples were collected directly from the factory of three cement companies at Sokoto, Gombe and Shagamu and coded SKO, ASK and WPC respectively. The analysis was conducted in the laboratory of Cement Company of Northern Nigeria (CCNN), Sokoto in accordance with the procedure stated in the quality control manual of the Company.

2.1 Aggregate Material

The sand aggregate used for this analysis is the standard laboratory sand which is in conformity with the international standard specification.

2.2 Chemical Analysis of Cement Samples

The chemical analyses for the determination of the constituents of the cement samples were conducted using the standard titrimetric method of analysis contained in the laboratory quality control operational manual of Sokoto cement. This method involves the use of a complexometric reagent ethylene diaminetetraacetic acid (EDTA) to form soluble octahedral complexes with the metal ions. This is selectively achieved through control of

pH, by masking the interfering element using appropriate reagents [13].

2.2.1 Treatment of Cement Samples

The sample (1.00g) was mixed with 1g of solid ammonium chloride (NH₄Cl) in a 150 cm³ beaker. Then 10 cm³ of concentrated HCl was added. The contents were mixed and the beaker covered with watch glass. The mixture was heated on a sand bath for 20 minutes. During this time the content was stirred repeatedly with a clean glass rod. The solution was diluted to 80cm³ with hot distilled water and left on the sand bath for another five minutes. The mixture was then filtered into a 500cm³ Erlenmeyer flask. The residue on the filter paper was washed several times with the hot distilled water. The beaker was cleaned with a 'policeman' and all the washing were transferred onto the filter paper. The filtrate in the flask was cooled to room temperature. It was then used to carry out the analysis.

2.2.2 Analysis of Oxides

For these analyses, the tests samples were obtained from the filtrate prepared in section 2.1.1 and used to determine the weight percentage of CaO, MgO, Al₂O₃, FeO₃, SiO₂, SO₃ and free CaO expected from the three cement samples. The tests methods employed are those contained in the laboratory manual as described elsewhere [6] and are based on the international standard method of analysis for Portland cement.

2.2.3 Determination of alkalis (Na₂O and K₂O)

These compounds occur in cement in minute proportions of about 0.2-1.0 percent [15]. They are determined by flame photometry. The instrument used was Corning EEL Model 100 Flame Photometer, set at air pressure of 101b/in² (690kN/m²).

2.2.4 Determination of Potassium and Sodium

Exactly 1.9070g of analytical grade pre-dried KCl was dissolved in deionised water and diluted to 1dm³. The solution contains 1g of K⁺ per dm³ i.e. 1000ppm. The solution was appropriately diluted to get a series of standard solutions (CCNN Operational Manual, 1984). The galvanometer reading was adjusted to zero with deionised water. It was adjusted to full scale with standard solution containing 20ppm (highest concentration). The other standard solutions were subsequently aspirated and their galvanometer deflections were noted. The galvanometer reading for each sample was taken and matched with calibration curve (Figure 1) in order to determine the potassium concentration in the sample [3].

Table 1: Galvanometer deflection/solution concentration for Potassium

Galvanometer Deflection	Concentration (Mg/dm ³)
100	20
79	15
55	10
29	5
0	0

Table 2: Galvanometer deflection/solution concentration for Sodium

Galvanometer Deflection	Concentration (Mg/dm ³)
100	20
80	15
56	10
31	5
0	0

2.2.5 Determination of Lime (CaO)

From the filtrate obtained above, 50cm³ was taken into 300ml beaker. It was diluted to 200cm³ with distilled water. The beaker containing the solution and stirrer was placed on a magnetic plate. 25% of potassium hydroxide (KOH) solution was added drop by drop from a dropping bottle until the pH paper in the solution indicated a colour which corresponded to the pH of 5. The 10cm³ of triethanol amine was added and 20cm³ of conc. potassium hydroxide was added. Now a spatula full of calcon indicator was added. Then the ethylene diamine tetraacetate (EDTA) solution was applied by automatic burette for titration from red to violet to clear blue. The end point of titration was reached when one drop did not result in a sensible colour change. The addition of triethanol amine ensures the masking of any heavy metals present [9].

The percentage composition of CaO was calculated using the relation below:

$$\%CaO = V_1 \times F_1$$

V₁ = consumption of EDTA solution

F₁ = the constant factor from standardisation of EDTA for CaO.

2.2.6 Determination of Magnesium Oxide (MgO)

From the same sample filtrate as obtained above, 50 cm³ was taken into 300ml beaker. It was diluted with distilled water to 200cm mark. The beaker containing the solution and stirrer was placed on a magnetic plate. Now, (1:1) ammonium hydroxide (NH₄OH) was added drop by drop from a dropping bottle until the P^H paper in the solution changed to a colour corresponding to a p^H of 5. Then, 10cm³ of triethanol amine was added and 10cm³ of conc. NH₄OH was also added. A spatula full of mixed indicator was added. Then the (0.05m) EDTA solution was applied by automatic burette for titration from violet to colourless and by the addition of triethanol amine heavy metals were masked [5].

The percentage of MgO oxide in the samples was calculated using the formula below:

$$\%MgO = (V_2 - V_1) \times F_2$$

V₁ = consumption of weak EDTA

V₂ = consumption of Strong EDTA

F₂ = constant factor from EDTA standardisation for MgO.

2.2.7 Determination of Iron (III) Oxide Fe₂O₃

100cm³ of the filtrate was taken into 500ml Erlenmeyer flask. Then three drops of bromophenol blue indicator was added, the colour changed to yellow. Then, by addition of NH₄OH from droppings bottle, the colour changed from yellow to blue. Then 20cm³ of 0.1m HCl was added and the colour changed to yellow again and 15cm³ of buffer solution of zinc chloride was added. Now 20-25 drops of salicylic acid was added as an indicator and the colour changed to violet. The solution was

heated on a hot plate to 50°C and the hot solution was titrated with EDTA solution from the automatic burette [2].

The percentage of Fe₂O₃ oxide in the samples was calculated using the formula below:

$$\% \text{Fe}_2\text{O}_3 = V_1 \times F_3$$

V₁ = consumption of EDTA

F₃ = constant factor from standardisation of EDTA for Fe₂O₃.

2.2.8 Determination of Alumina (Al₂O₃)

After the determination of Fe₂O₃ the same solution was titrated for the determination of Al₂O₃. Ammonium acetate was added drop by drop until the colour changed from yellow to blue. Then, 5cm³ of acetic acid was added, which result in colour change from blue to yellow. Three drops of complexion and 5 drops of PAN indicator are added respectively. The Erlenmeyer flask containing the solution was boiled and the colour of indicator was intensive pink. The solution was titrated against 0.115m EDTA solution at a temperature near the boiling point until the colour changed from pink to clear yellow [5].

The percentage of Al₂O₃ oxide in the samples was calculated using the formula below:

$$\% \text{Al}_2\text{O}_3 = (V_2 - V_1) \times F_4$$

V₁ = consumption of weak EDTA for Fe₂O₃

V₂ = consumption of weak EDTA for Al₂O₃

F₄ = constant factor from standardisation of EDTA for Al₂O₃.

2.2.9 Determination of Free Lime

Cement sample could contain free lime if there is excess (un-reacted) lime, coarse raw meal or low burning temperature. When free lime combines with water it forms Ca(OH)₂, which results in volume increase and hence unsoundness [13].

Exactly 1.00g of the sample was taken in a wide-mouthed Erlenmeyer flask. 45 cm³ each of glycol and methanol solution were added. The Erlenmeyer flask containing the solution and stirrer was placed on a hot magnetic stirrer for about 30 minutes, After this time, the solution was filtered through a filter paper and the residue was sucked to dryness by means of an A/C compressor. Few drops of bromophenol blue were added to the filtrate and the resultant blue solution was titrated against 0.1 M HCl. The end point was reached when one drop did no longer result in sensible colour change.

The percentage composition of free limestone (Free CaO) in the cement samples was evaluated as follows:

$$\% \text{CaO} = 0.28 \times V_{\text{HCl}}$$

V_{HCl} = the titre value.

2.2.10 Determination of Sulphuric Anhydride (SO₃)

Exactly 1.00g of cement sample was taken into 250 cm³ beaker and 150 cm³ of distilled water was added. 15ml of conc. HCl was added and the mixture was stirred. The mixture was warmed so that all the lumps present were broken down and then the solution was heated gently to boiling. The content of the beaker was filtered through a filter paper and the beaker was rinsed out with hot distilled water.

The filtrate was then transferred to into the hot plate and allowed to boil. Then 20ml of 10% BaCl₂ solution was added. The content was then boiled for further 10 minutes and then set aside and left overnight and then passed through a dense double filter paper. The deposits on the filter paper were washed with hot distilled water to get rid of chloride ion. The residue together with the filter paper was transferred into a pre-weighed platinum crucible and burnt to char over a Bunsen burner.

The crucible together with the burned filter paper was transferred into a furnace at 1100°C and heated for 30 minutes. The crucible was then taken out and cooled in a desiccator to room temperature. The crucible was then weighed [5].

The percentage composition of SO₃ in the cement samples was determined as follows:

$$\% \text{SO}_3 = W \times 0.343$$

W = weight of the ash and 0.343 is the gravimetric factor for conversion of BaSO₄ to SO₃ i.e. SO₃/BaSO₄.

2.2.11 Determination of Insoluble Residue (IR)

Exactly 1.00g of the sample was weighed into 200ml beaker and stirred together with 45cm³ distil water. Then 5cm³ of conc. HCl was added and stirred. The mixture was warmed so that all the lumps present were broken down. And after that the content was boiled for 15 minutes. The content of the beaker was then filtered. The beaker was rinsed thoroughly several times with distilled water. The filter paper was washed with hot distilled water until the colour faded to colourless. The residue and the filter paper were transferred back into the same beaker and 100cm³ of 2M NaOH solution added.

The content of the beaker was boiled for another 15 minutes. 4 drops of methyl red indicator was added and then conc. HCl was added drop by drop until the colour changed to red. The content of the beaker was then filtered again and washed with hot 10% NH₄NO₃ solution until the red colour on the filter paper was decolourized. The filter paper was transferred into a pre-weighed platinum crucible. The crucible was put onto Bunsen burner flame till the content was charred and then transferred into a furnace at 1100° C. After 30 minutes heating inside the furnace, the crucible was taken out and

placed inside desiccator and cooled to room temperature. The weight of the crucible and ash was determined [9].

The percentage of insoluble residue contained in the cement samples was determined as follows:

$$\% \text{ I.R.} = \frac{\text{EL} - \text{AI} \times 100}{\text{E}}$$

EL = crucible weight + sample before heating

AI = crucible weight + sample after heating

E = weight of sample taken (g)

2.2.12 Determination of the Mineral Compounds

To determine the percentage of the main compounds, Bogue's equation was employed [13]:

$$\text{C}_3\text{S} = 4.07(\text{CaO}) - 7.60(\text{SiO}_2) - 6.72(\text{Al}_2\text{O}_3) - 1.43(\text{Fe}_2\text{O}_3) - 2.85(\text{SO}_3)$$

$$\text{C}_2\text{S} = 2.87(\text{SiO}_2) - 0.754(3\text{CaO} \cdot \text{SiO}_2)$$

$$\text{C}_3\text{A} = 2.65(\text{Al}_2\text{O}_3) - 1.69(\text{Fe}_2\text{O}_3)$$

$$\text{C}_4\text{AF} = 3.04(\text{Fe}_2\text{O}_3)$$

Where, the terms in the bracket represent the weight percent of the given oxide in the total weight of the cement [13]. Also, the factors were obtained from the ratios of the oxides molecular mass, as;

$$\frac{\text{CaO}}{\text{SO}_3} = 0.70, \frac{3\text{CaO} \cdot \text{Al}_2\text{O}_3}{\text{Al}_2\text{O}_3} = 2.65, \frac{\text{Al}_2\text{O}_3}{\text{Fe}_2\text{O}_3} = 0.64$$

$$\frac{3\text{CaO}}{\text{SiO}_2} = 1.87, \frac{3\text{CaO}}{\text{AlO}_3} = 1.65, \frac{4\text{CaO}}{\text{Fe}_2\text{O}_3} = 1.40$$

$$\frac{4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3}{\text{Fe}_2\text{O}_3} = 3.04, \frac{3\text{CaO} \cdot \text{SiO}_2}{\text{CaO}} = 4.07$$

2.3 Physical Analysis of the Cement Samples

This was devoted to the physical properties of the cement. These could be compared with the already acceptable specification, in order that the inferior materials may be detected in diversions from such standards [13]. The following tests were conducted; setting time, permeability test (Blaine), compressive strength and expansion (soundness).

2.3.1 Test for Compressive Strength

Exactly 185g of each cement sample and 555g of standard sand was mixed homogeneously. Then 74cm³ of distilled water was added and mixed for 4 minutes. The mortar was then compacted in the metal cube moulds on a vibrating machine for 2 minutes and levelled with a levelling knife. The resulting cubes were cured in the humid chamber of at relative humidity of 70-90% for 24 hours. The cubes were labelled and cured to mature in water. The maturity dates ranged from 3 days, 7 days and 28 days.

2.3.2 Test for Loss on Ignition

This is the loss of weight of concrete as a result of absorbed and adsorbed substances such as moisture and gases especially CO₂. The total loss on ignition should not exceed 3 percent (%) according to the standards specification [7].

1g of each sample was taken in a platinum crucible and put into a furnace at 1000°C. After 30 minutes, the platinum crucible with the sintered substance was removed from the furnace. After cooling in a desiccator down to room temperature, its weight was determined. The lost in weight was recorded in percentage [5].

2.3.3 Determination of Soundness

In this analysis the instrument used was the LeChatelier's apparatus. The expansion of cement determined by this method is not expected to exceed more than 10mm [13].

The 200g of each cement sample was taken and mixed with appropriate volume of water to form a cement paste of good consistency. This was then moulded into the LeChatelier's apparatus. Glass plates were placed on top and below the apparatus and held with rubber band. The apparatus was placed in water of about 29°C for 24 hours. The distance between the two pointers was measured and the content was removed, cooled and the difference between the two pointers was measured again as the expansion of the cement [13].

2.3.4 Determination of Setting Time

Setting time refers to the change of cement paste from a fluid to a rigid state. This should not be confused with hardening which refers to the gain of strength of a set of cement paste. Setting is caused by a selective hydration of cement compounds; the two first to react are C₃A and C₂S. The setting time of cement decreases with a rise in temperature but above 30°C a reverse effect may be observed [3].

400g of each cement sample was taken and mixed with quantity of about 120cm³ of distilled water within 4 minutes. It was then filled into cylindrical mould. The plunger position was then determined.

2.3.4.1 Initial Setting Time

For the determination of initial Setting time, the test paste confined in the mould was placed under the rod bearing the needle. This was then lowered gently into contact with the surface test paste and quickly released to allow the needle to sink in. This was repeated until the needle when brought into contact with the test paste and released does not penetrate beyond a point of approximately 5mm from the bottom mould. The period elapsing between the time when the water was added to the cement and the time at which the needle ceased to pierce the test paste beyond 5mm is known as the initial setting time of the cement paste [9].

2.3.4.2 Final Setting Time

For this determination the needle of the Vicat's apparatus was replaced by the needle with an annular attachment. The cement paste was considered as finally set when upon applying the needle gently to the surface of the test paste. Only the needle makes an impression, while the attachment fails to do so [5].

2.3.5 Determination of Fineness (Blaine)

3.01g of each cement sample was weighed and placed in a permeability cell Blaine apparatus. The lower part of the cell was lubricated and fixed to the upper part of the apparatus. The rubber bulb was pressed to allow air pass through the cement bed. Air movement was impeded by the liquid (baby oil) in the apparatus. The time taken for the liquid to drop between the two levels of the apparatus was recorded and the specific surface was calculated from the products of time taken for the liquid to fall and the factor [13].

The specific area of the cements is determined as follows:

$$\text{Specific surface} = \text{factor} \times \sqrt{T} \text{ (sec.)}$$

factor = 350 = calibration factor

$$\text{factor} = \frac{\text{Blaine of standard sample}}{\sqrt{T} \text{ (sec)}}$$

T = time in second for the liquid to drop between the two levels of the apparatus.

3.0 RESULTS AND DISCUSSION

3.1 Chemical Tests

3.1.1 Mineral Composition

Mineral contents of the cements include tricalcium silicate (C₃S), dicalciumsilicate (C₂S), tricalcium aluminate (C₃A) and the tetracalciumalumino ferrite (C₄AF). These compounds are regarded as the major constituents of cement.

Table 3: Mineral Composition

Cement Samples	Percentage Composition (%)			
	C ₃ S	C ₂ S	C ₃ A	C ₄ AF
ASK	62.15	7.08	10.73	9.0
WPC	67.27	2.98	8.36	10.9
SKO	60.06	12.06	7.74	12.0

C = CaO; S = SiO₂; A = Al₂O₃; F = Fe₂O₃

3.1.1.1 Tricalcium Sulphate (C₃S)

The results of the analysis (Table 3) show that the composition of C₃S for ASK and SKO samples are within the acceptable standard limits [16]. WPC sample shows composition higher than the acceptable limit. There are variations in the content of C₃S compound between the samples, with the WPC sample exhibiting higher composition compared to SKO and ASK samples. The compound C₃S is among the silicates primarily responsible for the strength of cement paste. It contributes most of the strength development during the first four weeks. The increase in C₃S content is accompanied by increase in strength and WPC cement with the highest C₃S content is expected to have the best strength characteristics.

3.1.1.2 Dicalcium Sulphate (C₂S)

Dicalciumsilicate (C₂S) is also responsible for the hydration of cement. Its effect is not so marked as that of tricalcium silicate. C₂S affects the medium term strength. These compounds together with tricalcium sulphate are called the cementitious compounds. The values obtained for C₂S compound in the three samples are in agreement

with the international standard limit of 40% maximum and as reported by [21]. The contribution of C₂S on gain in strength starts from 4 weeks onward. Its influence is positive up to between 5 and 10 years only. It has a negative influence there after [15].

3.1.1.3 Ticalcium Aluminate (C₃A)

The tricalcium aluminate content (C₃A) of all the samples show slight variations in composition across the three samples. ASK cement has the highest value of 10.73% followed by WPC with 8.36% and lastly SKO cement with the lowest value of 7.7%. The values obtained are within the standard specified limit [6].

The mineral tricalcium aluminate (C₃A) is responsible for setting time of cement. This is justifiable from table 5 where ASK and SKO because they have higher C₃A values recorded higher setting times. High increase in setting time is advantageous because of greater workability of cement that has higher setting time. However, higher value of C₃A content leads to lower early strength [15] as shown in table 5.

In addition, the compound tricalcium aluminate (C_3A) also prevents the attack of sulphate in concrete and for this process low C_3A proportion is desirable [10].

3.1.1.4 Tetracalcium Alumino-ferrite (C_4AF)

The effect of tetracalcium alumino-ferrite on cement is not well understood, although its magnitude should be kept

at a minimum because it lowers clinkering temperature [8].

3.1.2 Oxides Content

Table 4 below shows the results of the analysis for the chemical composition of the three cement samples of ASK., WPC and SKO cement companies.

Table 4: Oxides Composition

Parameter (wt %)	% Composition		
	ASK	WPC	SKO
CaO	62.80	63.70	63.47
MgO	2.10	1.45	1.61
Fe ₂ O ₃	2.96	3.58	1.95
Al ₂ O ₃	5.94	5.44	5.44
SiO ₂	18.92	18.73	20.00
SO ₃	1.96	2.80	1.28
K ₂ O	0.70	1.01	1.43
Na ₂ O	0.40	2.25	2.67
LOI	2.26	2.05	0.57
IR	1.14	1.05	4.08
Free CaO	2.27	2.49	2.10

3.1.2.1 Calcium Oxide (Lime)

From table 4 above it can be seen that the values of the CaO (lime) compositions for all the cements show slight variation between each others. The values are, however, within the standard allowable limits [8]. This indicates that the content of the lime needed to combine with other oxides to form the minerals is in the correct proportion. When the lime content exceeds the required limits, it could cause increased in CaCO₃ formation at early stage of production process, resulting in rapid hardening combination difficulty [14].

3.1.2.3 Magnesium Oxide (MgO)

The magnesium oxide contents of the three samples are within the Nigerian standard value of 0.1 – 5.5% (Chia, 1986). The amount of MgO in cement should be as low as possible, because it causes unsoundness in cement as the result of its hydration to form Mg (OH)₂; which is an expansive agent [15]. From the results there is an indication that ASK cement may have comparatively higher unsoundness properties than SKO and WPC cements. The latter may have the least expansion process as justified in Table 5.

3.1.2.4 Iron Oxide (Fe₂O₃)

Iron Oxides compositions of the samples show that they were within the standard specified value of 0.5% - 6.0% [7]. Fe₂O₃ combines with CaO to form 4CaO.Al₂O₃.Fe₂O₃ (tetracalcium aluminoferrite). Higher proportion of iron

Oxide in the cement could retard the process involved in setting and impart colour to the cement [4]. Table 4 shows that WPC cement has the highest value of Fe₂O₃, followed by ASK cement and SKO cement has the lowest content of Fe₂O₃. This could mean that WPC cement would have the lowest setting time.

3.1.2.5 Aluminium oxide (Al₂O₃)

The aluminium Oxide contents of the samples show that the values are 5.94% (ASK), 5.44% (WPC) and 5.44 (SKO). These values are within the standard limits [16], but slightly above the Nigerian standard specification of 3% - 5% [9]. The alumina in a combined state is an important oxide in cement. The oxide combines with lime to form the mineral tricalcium aluminate (C_3A). The determination of this compound in the analysis has shown that ASK cement contains the highest amount of aluminium oxide, justifying why it has the highest proportion of tricalcium aluminate (Table 3). Both SKO and WPC cements contains the same quantity of aluminium oxide.

3.1.2.6 Silicon dioxide (SiO₂)

The silica (SiO₂) contents (Table 4) in the cement samples are in conformity with the Nigerian standard specification of 17% - 25% (CCNN Operational Manual, 1984). SKO cement contains the highest proportion of silica. Silica contributes to the formation of the silicates of calcium (C_3S and C_2S), which are the main constituents of Portland cement. High content of silica adversely affect

the grindability of clinker thereby producing coarse cement [13]. SKO cement should be expected, according to this result, to produce coarse cement. This is shown in Table 3, which indicates least value of fineness (specific area) of 21cm²/g for SKO cement, hence the coarser cement. It should also have a harder clinker. Higher value of silica makes setting time easier to control [13].

3.1.2.7 Sulphur trioxide (SO₃)

The magnitude of sulphur trioxide in cement is recommended to be within the value of 1 -3% [3]. In Table 4 the values obtained fall within this range. While WPC cement has the highest content of SO₃ of 2.8%, SKO has the lowest content of 1.28%. ASK has SO₃ content 1.96%. Higher value of SO₃ in the presence of tricalcium aluminate (C₃A) reduces the formation of tricalcium silicate (C₃S). This is detrimental to the strength development [13]. But, low value of SO₃ content has some favourable effect on the formation of C₃S.

3.1.2.8 Loss on Ignition (LOI)

The loss on ignition determines the extent of carbonation and hydration of free lime and also free magnesia due to the environmental exposure of the cement (Neville, 1981). The recommended standard value is 2.5 – 3.0% at 1000°C. The values obtained in this analysis shows that ASK cement has the highest value of 2.26%, followed by WPC with 2.05% and the lowest value is that of SKO sample with 0.57%.

High loss on ignition value is desirable as the carbonation occurring in the presence of calcium compounds results in increased strength and reduced permeability [15]. In

addition, carbonation protects reinforced steel from corrosion due to the alkaline conditions of hydrated cement paste. ASK cement is expected to have greater advantage with regards to the above processes because of its highest L.O.I value.

3.1.2.9 Insoluble Residue (IR)

The maximum recommended value of insoluble residue is 0.75%. In this analysis, all the cement samples tested contains amount higher than the standard specification. SKO cement contains a much more divergent value of 4.08%, WPC has 1.05% and ASK sample has 1.14%. The highest value could be attributed to the poor quality of the gypsum used. Insoluble residue measures the amount of adulteration of cement caused largely from impurities in the gypsum [13].

3.2 Physical Tests

3.2.1 Fineness (Blaine)

The Specific Area is a test carried out to determine the fineness of the cement. It refers to the surface area of the cement that represents material available for hydration. From the analysis conducted it is clearly shown that ASK and WPC cements have the same values of fineness higher than that of SKO (Table 5). This indicates that building made from these cements should have lower strength than that from SKO cement. This is explained by the ability of paste with greater fineness proportion to entrails less air bubbles. These bubbles are needed by air-entrained concrete to resist frost attack. However, higher value of fineness reduces the rate of expansion and rapid strength development [13].

Table 5: Physical Properties of the Cement

Cement Samples	Specific Area (cm ² /g)	Setting Time (min)		Expansion/Soundness (mm)
		Initial	Final	
ASK	3200	125	200	2
WPC	3200	110	180	1
SKO	2100	180	250	1

3.2.2 Compressive Strength

Fig. 1 is the results of the compressive strength tests of the samples carried out for 3 days and 7 days respectively. The strength of concrete is a factor that is perhaps most obviously required from structural use. Compressive strength is the cohesion of the cement paste on its adhesion to the aggregate particles [13]. From the analysis carried out on the comprehensive strength of the three samples the results obtained show that the

compressive strength of SKO at three days is higher than the strength of ASK and WPC. However, at seven days the compressive strength of WPC, which is lowest at 3 days, is higher than that of the other two samples. Although the results for SKO are in the same range as those obtained by [16], on the overall the compressive strength of all the samples are above the standard acceptable limit [4].

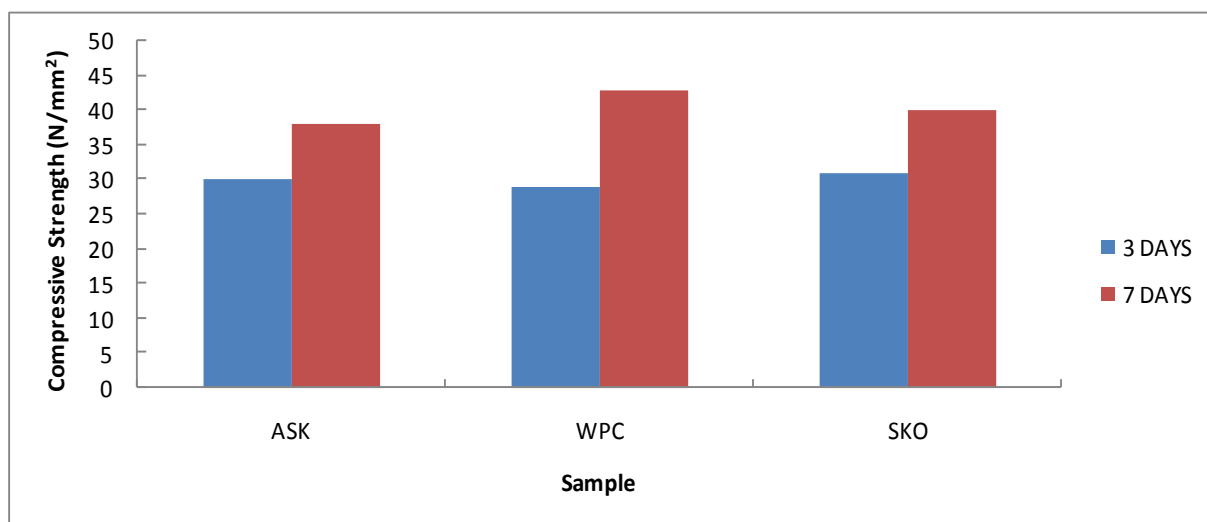


Fig. 1. Compressive Strength of the Cement Samples

3.2.3 Setting Time

The results of the setting time of the samples are contained in Table 6. The results show that the setting time of WPC is less than the setting time of SKO and ASK for both the initial and final setting times. SKO cement has the highest setting time of 3 hours for initial and 4 hours for final. The initial setting time could be defined as that time when the cement slurry starts to change from fluid to rigid form. The final setting time is when the cement becomes stiff [5].

The hardening procedures of cement could take a year to reach completion. Setting time could be attributed to the selective hydration of the cement minerals. The higher setting time of SKO cement is due to the cement being coarser than the other two as justified by Table 5. Fineness affects the rate of setting. This indicates also that Sokoto cement is more suited in temperate areas. WPC

and ASK cements when employed in this area are more prone to early crack development [11].

3.2.4 Expansion

The expansion tests conducted on the cements show that SKO cement and WPC samples have low values of expansion. The expansion value of ASK cement doubles the expansion of the other two samples. Expansion occurs as a result of the formation of calcium sulphoaluminate hydrate (ettringite) [3]. This compound is the agent of expansion. Ettringite is undesirable due to the tendency of the cement to form cracks. From the result obtained ASK cement may be prone to crack formation than the other two cements.

4.0 CLASSIFICATION OF CEMENTS

According to ASTM classification Portland cement is classified into for cement types (Table 6 below).

Table 6: Cement Types and their Uses

CEMENT TYPE	USES
Type I	General concrete construction when no special properties are specified
Type II	General concrete construction exposed to moderate sulphate action or where moderate heat of hydration is required
Type III	Used when a high early strength is required
Type IV	Used when a low heat of hydration is required

In order to classify the various cements analysed, analytical data was used to calculate the composition of the compounds of the cement samples in terms of C₃S, C₂S, C₃A and C₄AF.

Table 7 above is the typical values of compound compositions for different types of cements [13].

Table 7: Typical values of compound composition of Portland cement

Cement Type	Compound Composition	Loss on
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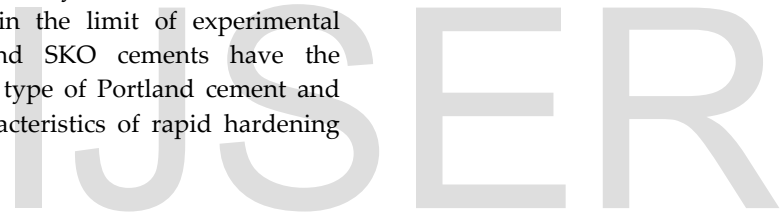
	C ₃ S	C ₂ S	C ₃ A	C ₄ AF	Free Cao	MgO	Ignition (LOI)
Type I	67	31	14	12	1.5	3.8	2.3
Type II	55	39	8	16	1.8	4.4	2.0
Type III	70	38	17	10	4.2	4.8	2.7
Type IV	44	57	7	18	0.7	4.1	1.9
Type V	54	49	5	15	0.6	2,3	1.2

Using the results of the analysis carried for ASK, WPC and SKO cements and the categorisation of cements according to types in Table 7 the cements can be classified according to the type to which they belong as follows:

ASK cement may be regarded as cement type II, which is suitable for use general concrete construction. WPC cement nearly fits into Portland cement type III, which is applied when a high early strength is desired and SKO cement may be regarded as cement type II, which is suitable for general concrete construction exposed to moderate sulphate action or where moderate heat of hydration is required.

5.0 CONCLUSION

Based on the experimental analysis carried out we can tentatively conclude, within the limit of experimental error, that both ASK and SKO cements have the characteristics of modified type of Portland cement and WPC cement has the characteristics of rapid hardening Portland cement.



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