Original Research Article

Comparative Study of the Chemical Analysis of Different Brands of Cements Used in Ghana

ABSTRACT

In Ghana, however, ordinary Portland-limestone cement in recent times continues to remain the alternative construction material compared to other brands. With the rising trend of infrastructural development in the country undertaken by individuals and real estates companies, there have been categories of different brands of cement alongside the existing brands being produced in Ghana**.** The usage of low quality cement resulting in poor bonding of construction materials has led to the investigation of some selected brands. In this study six different brands of Portland - limestone cement generally used in the construction industry in Ghana, namely; CIMAF cement, Dangote cement, Diamond cement, Ghacem cement, Sol cement and Supacem cement were investigated. The chemical compositions were analyzed using X-Ray Fluorescence (XRF) spectrometer equipment because of its accuracy and simplicity it has over other technologies. The amount of chemical constituents like A_2O_3, S_iO_2, Fe_2O_3, CaO, MgO, SO_3, Na_2O and K_2O were determined in accordance with ASTM C114-18.The results indicated that the properties of the six brands of cement are comparable and are all of good quality.

Keywords: Brands of cements used in Ghana, Chemical compositions, Chemical analysis

1. INTRODUCTION

Cement is one of the building materials which is non-metallic substance in nature with hydraulic binding properties and usually applied as a bonding agent in building materials such as concrete and other masonry works in the execution of structures in infrastructural development globally and used in the construction industry over many decades [1]. It consists essentially of mixture of calcium silicates and smaller amounts of other minerals that reacts with water and causes it to set uniformly. It is highly versatile building material as its provides a variety of benefits in the area of compressive strength, fire resistant, mouldability, impermeability and durability [2]. cement is used widely in building and civil engineering works for the construction of houses, dams, bridges, railways, airports facilities, hospitals, schools, supermarkets, factories among other applications in infrastructural development. The raw materials used for the manufacture of cement consist mainly of calcium, silica, alumina and iron oxide. Portland cements are manufactured through heating process, in a kiln by combining the raw materials with additives and grinding them to ensure a fine homogeneous mixture at a constant temperature of 1400-1500 ^{o}C. The oxides interact with one another in the kiln at high temperature to form more complex compounds [3]. The relative proportions of the oxide compositions are responsible for influencing the various properties of cement including rate of cooling and fineness of grinding of the matrix**.** The chemical bonds of the raw materials are broken down and then recombined into new compounds called clinker, which are rounded nodules between 1mm and 25mm [4]. The clinker is however grounded to a fine powder in a cement mill and mixed with gypsum to regulate the setting time.

Moreover, the identification of the major compounds of cement is largely based on Bogue's equations[5] . Again, in addition to the four major compounds present in Portland cement such as tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF), there are many minor compounds formed in the kiln during the cement manufacturing process [5]. In general, major oxides such as CaO, SiO_2, Al_2O_3, and Fe_2O_3 including the minor oxides (MgO, SO_3) as well as some alkalis (K_2O, Na_2O) in cement are of some importance and basically react with di-calcium and tri-calcium silicates in the aggregate enabling the cement to gain its full strength[6]. The percentage of MgO in cement represent about (0.5-4.0) % and 5 % maximum content usually control the expansion from hydration of the oxide in hard concrete [7]. Major compounds have been found to possess dominant effect on the cements which influence concrete strength. For instance, the tricalcium silicate and dicalcium silicate are the most important compounds responsible for strength and constitute about 70 to 80 % of cement whilst tricalcium aluminate and tetracalcium alumino ferrite contribute slowly to the strength development of the cement.

In analysing the performance of cement in modern construction, it is also essential to do empirical studies about the materials used in producing it. The reliability and quality of the material can be judged only on the basis of the materials used in producing the cement [8]. It is estimated that, the strength of concrete is normally determined using compressive strength value, although the flexural strength is the index used in rigid pavement work [9]. In view of this, many researchers have carried out studies in the area of cement technology to improve on the quality of cement. As an example, a study on the effects of polymer fiber on the properties of concrete was done [10]. It was observed that polymer fiber which usually served as a superplasticizer admixture resulted in concrete's lower rate of water absorption, high-rate water reducer, greater strength and excellence in elasticity. [11] evaluated and confirmed the feasibility of using both hemp hives and fiber in hempcrete (HC) to determine an optimal mix of the different binding agents and to investigate the performance of cement binder to the improvement of the mechanical strength of the material. Cement continues to remain as one of the quality materials used in construction of many projects of the world including Africa. In Ghana, however, ordinary Portland - limestone cement in recent times continues to remain the alternative construction material compared to other brands [12]. The authors observed that the decline in the production of cement will leave construction industries no chance to survive since huge tonnage of concrete is utilized annually. Again, with the rising trend of infrastructural development in the country undertaken by individuals and real estates companies, cement production has attracted expansion of existing manufacturers in Ghana alongside foreign ones and new brands are being produced alongside since the demand for cement has been increased tremendously in the country in recent times[13]. this challenge has been exacerbated by unsubstantiated manufacturers' statements of brand's superiority above others. In recent times, since the early years of 2000's, all the manufacturing companies have been adding extra limestone as additives to ordinary Portland cement clinker and branded it Portland - Limestone cement for the Ghanaian and West African markets. This study therefore aimed to establish the underlying basis for comparison among the different cement brands.

2. MATERIALS AND METHODS

2.1.1 Experimental

Preparation of the samples

Materials used in the laboratory investigation are six selected brands of cements chosen from the Ghanaian markets namely: CIMAF cement, Dangote cement, Diamond cement, Sol cement, Ghacem cement and Supacem cement. However, Ghacem cement, Dangote Cement, Diamond Cement, Sol Cement and Supacem are produced in different classes, namely, Class 32.5R, Class 42.5R and Class 42.5N, whereas CIMAF cements are produced as Class 32.5R, Class 42.5R Ultimate Plus and Class 42.5R Smart Superior brands. In this research Ghacem 42.5N and Diamond 42.5R were not used due to their immediate unavailability in the Ghanaian markets at the period this research was undertaken and only their 32.5R brand was investigated. . CIMA, Supacem and Sol cements came in two variants, that is classes 32.5R and 42.5R brands of cement were used in the study. Diamond and Dangote cements both had classes of 32.5R and 42.5R respectively.

Chemical analysis was done on the cement sample to determine the percentage of chemical components or ingredients that are within the cement sample. The method used was the Rigaku NEX CG XRF fundamental parameters double determination approach. A mechanical device known as the Rigaku NEX CG XRF equipment was used to determine the percentage content of the following components: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, Na_2O and K_2O. Four grams (4g) of the cement powder sample on a powder paper was weighed on an electric scale. The sample cup was placed on another powder paper to avoid contamination from the analysis window. The samples for the analysis were measured and loaded into assigned changer positions in the XRF machine individually where an FP application for the samples to be analyzed was created. The XRF test carried out was in accordance with the ASTM C114-18 (Kirby and Kanare, 1988)

3. RESULTS AND DISCUSSION

3.1 Test Results

The results of the chemical analysis of the various brands of cements tested at the XRF laboratory at the Department of Earth Science of the University of Ghana has been presented in this research. A comparative analysis of the chemical compositions indicated significant variations existing among each cement brand. Summary of results of chemical analysis of 32.5R and 42.5R Brands of cements.

The results of the chemical analysis of the various 32.5R brands of cements from the XRF tests have been presented for discussion. Table 1 and Figures 1 to 5 show results of the chemical analysis of the various 32.5R brands of cement manufactured by five different companies. The chemical compounds and their percentage proportions contained in class 42.5R cements of six different manufacturers are illustrated in Table 2 and figures 7 to 12 The total percentages of of various chemical compounds in the different brands of cements that are involved in the hydration of cement with water and contribute to the physical and mechanical properties of concrete and other masonry products are summarized and presented in Tables 3 and 4 for 32.5R and 42.5R cements respectively.

Table 1: Chemical Compounds of 32.5R Brands of Cements

Chemical Compounds	Percentage (%)				
	Ghacem 32.5R	Diamond 32.5R	CIMAF 32.5R	Supacem 32.5R	Sol 32.5R
S_iO_2	22.90	23.70	32.80	28.90	26.60
Fe_2O_3	4.55	2.34	4.45	4.52	7.68
CaO	58.00	56.40	47.20	51.10	48.50
Al_2O_3	5.80	6.99	7.92	7.49	7.45
MgO	3.34	5.90	2.07	2.94	2.85
SO_3	3.46	2.52	2.77	2.63	4.09
Na_2O	0.00	0.00	0.00	0.00	0.00
K_2O	0.61	0.584	1.52	1.12	0.899

Table 2: Chemical compounds of 42.5R Brands of Cements

Chemical Compounds	Percentage (%)					
	CIMAF Smart Superior 42.5R	CIMAF Ultimate Plus 42.5R	Dangote 42.5R	Ghacem 42.5R	Sol 42.5R	Supacem 42.5R
S_iO_2	22.90	24.40	15.70	22.10	22.10	21.50
Fe_2O_3	3.59	3.77	3.49	4.04	5.18	4.17
CaO	60.90	59.20	70.10	5.20	59.80	61.50
Al_2O_3	5.09	5.38	3.78	3.25	5.18	5.36
MgO	2.05	2.37	1.08	2.51	1.78	3.22
SO_3	3.43	2.85	4.13	0.00	3.47	2.39
Na_2O	0.00	0.00	0.00	0.68	0.00	0.00
K_2O	1.04	0.85	0.773	61.10	0.889	0.766

Table 3: Combined Chemical Compounds of 32.5 Brands of Cements

Chemical Compounds	Percentage (%)				
	Ghacem 32.5R	Diamond 32.5R	CIMAF 32.5R	Supacem 32.5R	Sol 32.5R

$CaO + S_iO_2 + Fe_2O_{3+}$ Al_2O_3	91.25	89.43	92.42	92.0	90.26
$CaO + S_iO_{2\,+} + Al_2O_{3\,+}$	86.7	86.99	82.76	87.49	82.55
$CaO +$ SiO_2	80.9	80.1	80.0	80.0	75.1

Table 4: Combined Chemical analysis of 42.5R Brands of Cements

Chemical Compounds	Percentage (%)					
	CIMAF Smart Superior 42.5R	CIMAF Ultimate Plus 42.5R	Dangote 42.5R	Ghacem 42.5R	Sol 42.5R	Supacem 42.5R
$CaO + S_iO_{2\,+} Fe_2O_3 +$ Al_2O_3	92.48	92.75	93.07	92.44	92.26	92.53
$CaO + S_iO_{2\,+}$ Al_2O_3	88.89	88.98	89.58	88.40	87.08	88.36
$CaO +$ SiO_2	83.8	83.6	85.8	83.2	81.9	83.0

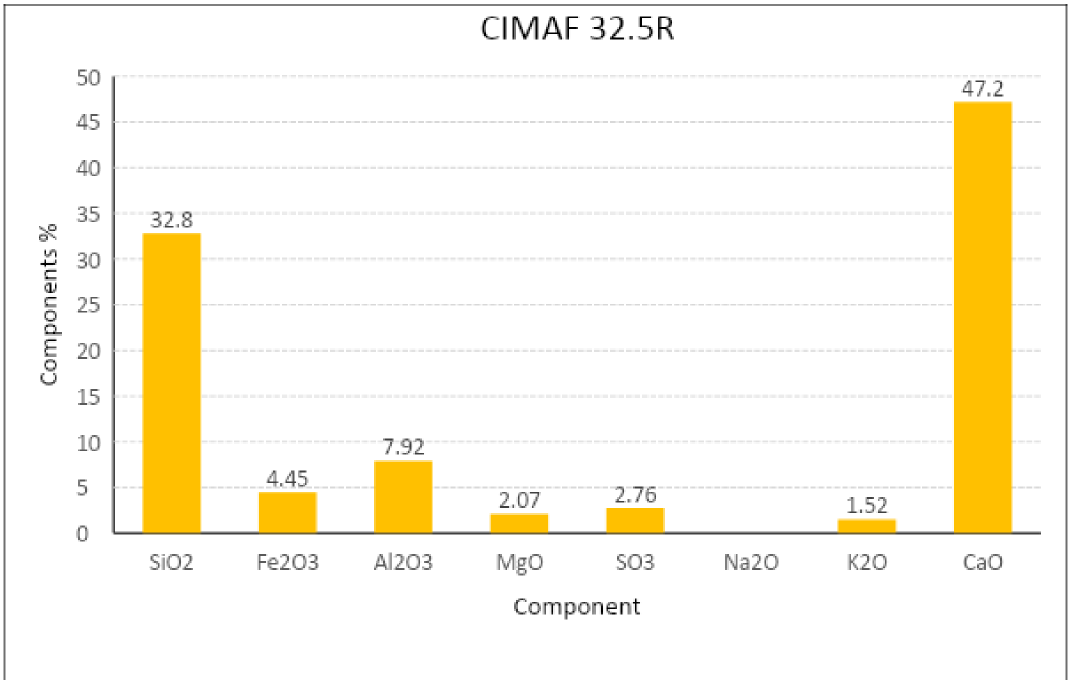

Fig.1. Chemical composition of CIMAF 32.5R

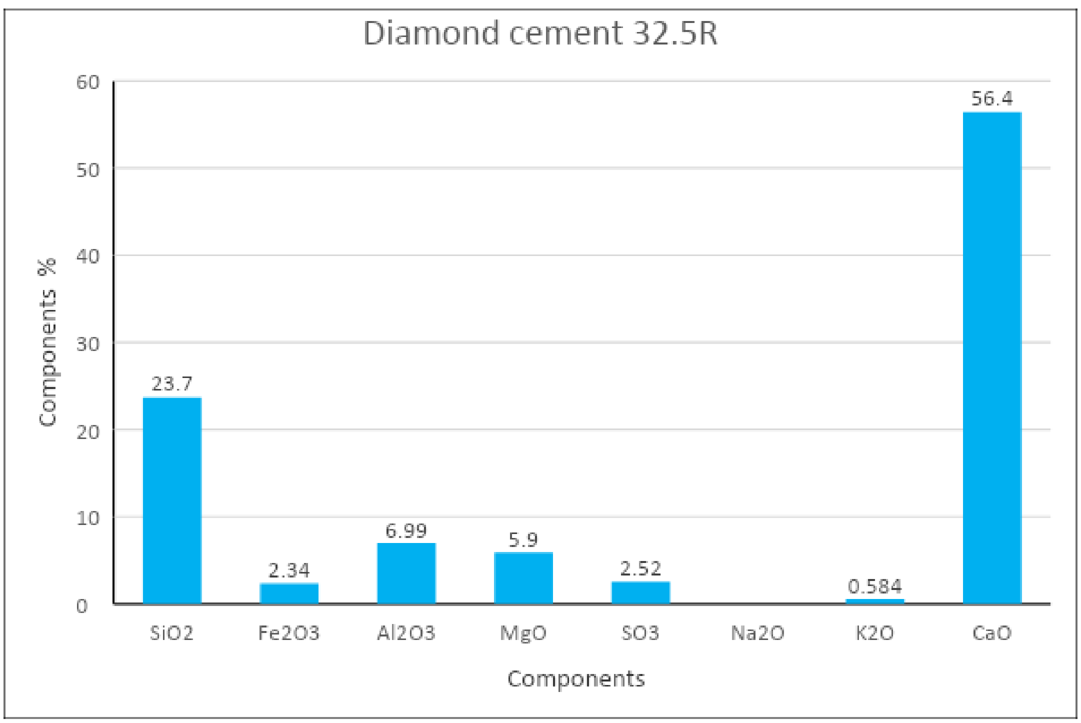

Fig. 2. Chemical composition of Diamond 32.5R

UNDER PEER REVIEW

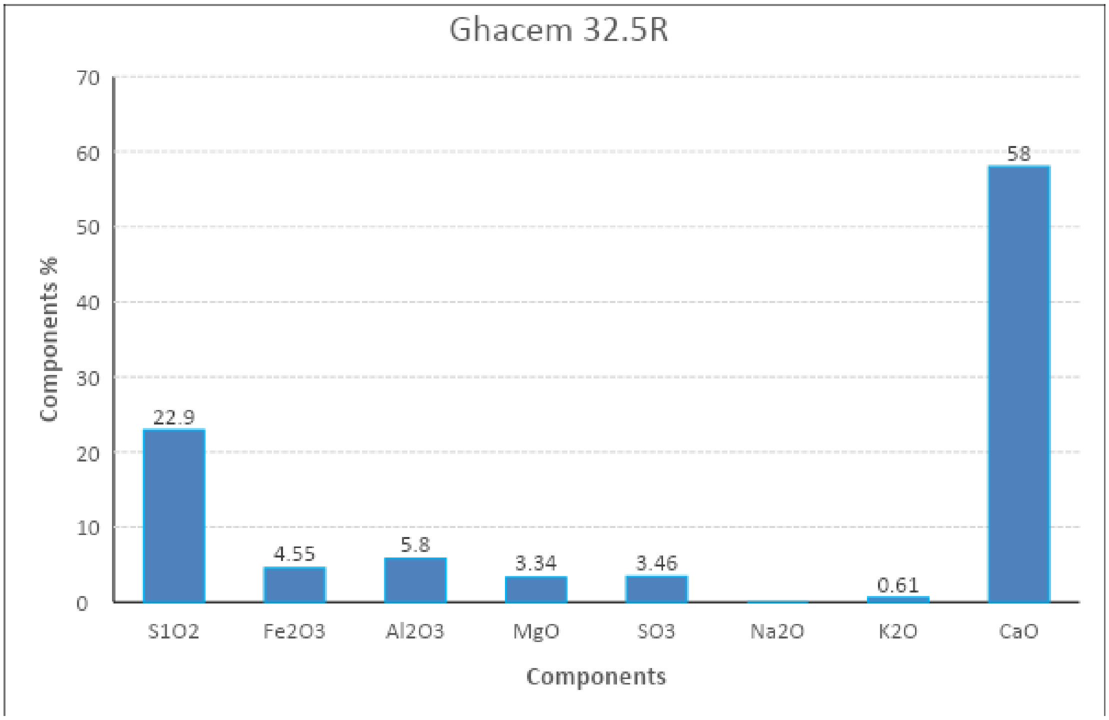

Fig. 3. Chemical composition of Ghacem 32.5R

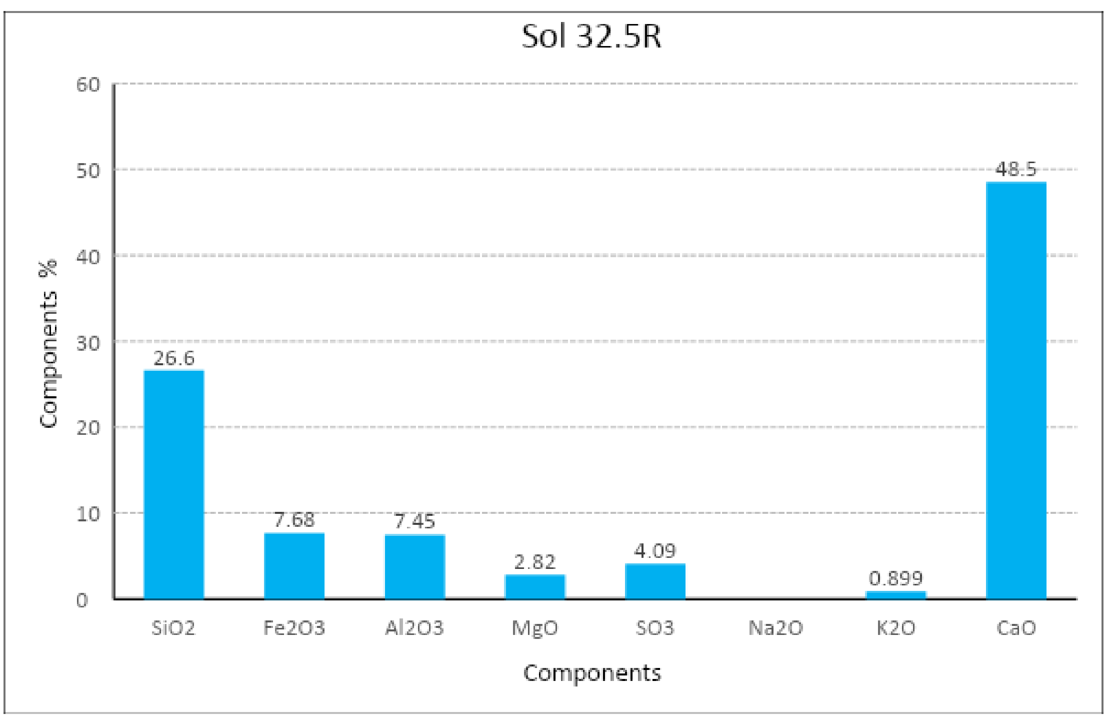

Fig. 4. Chemical composition of Sol 32.5R

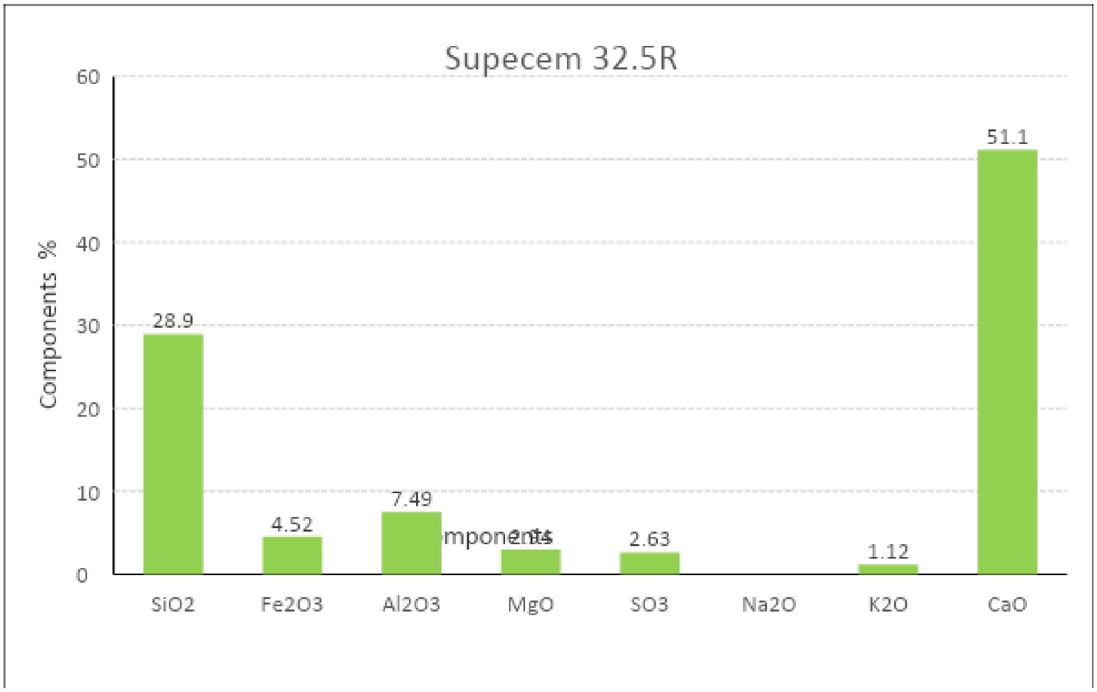

Fig. 5. Chemical composition of Supacem 32.5R

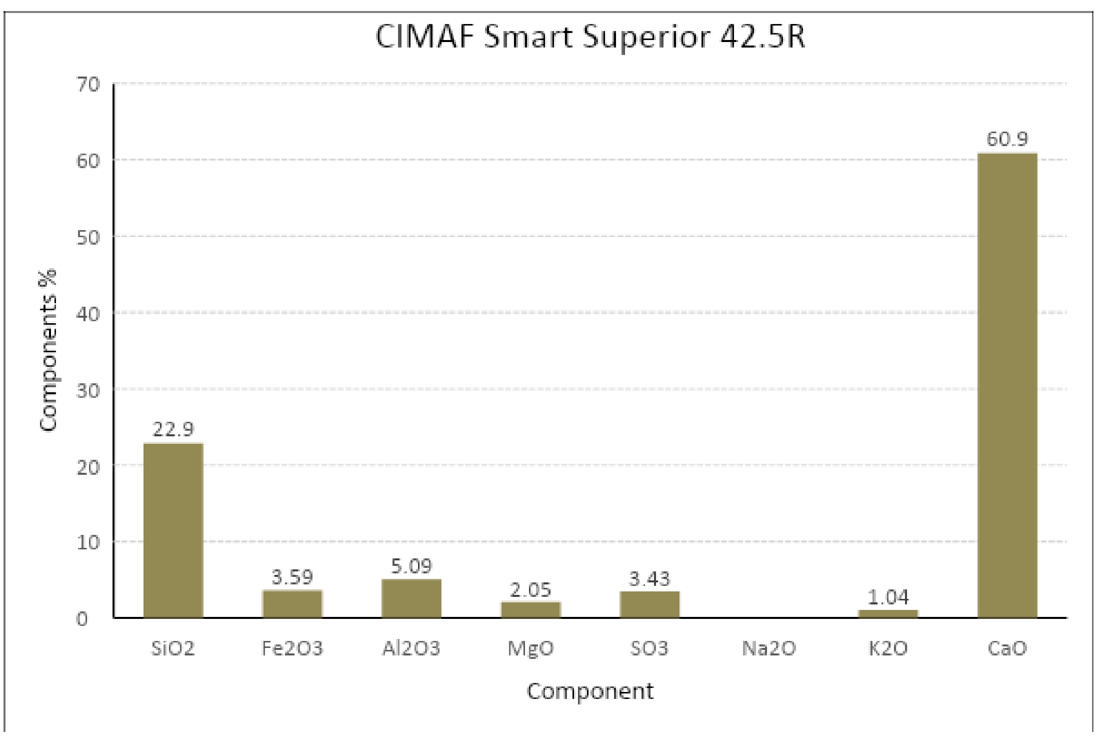

Fig. 6. Chemical composition of CIMAF Smart Superior 42.5R

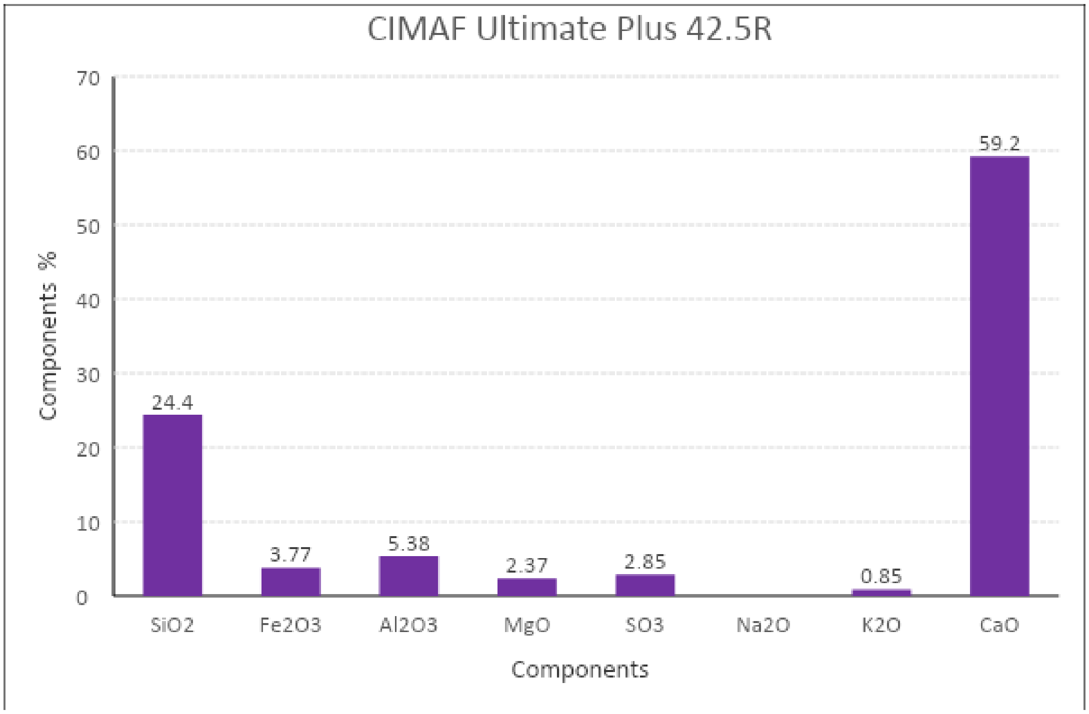

Fig. 7. Chemical composition of CIMAF Ultimate Plus 42.5R

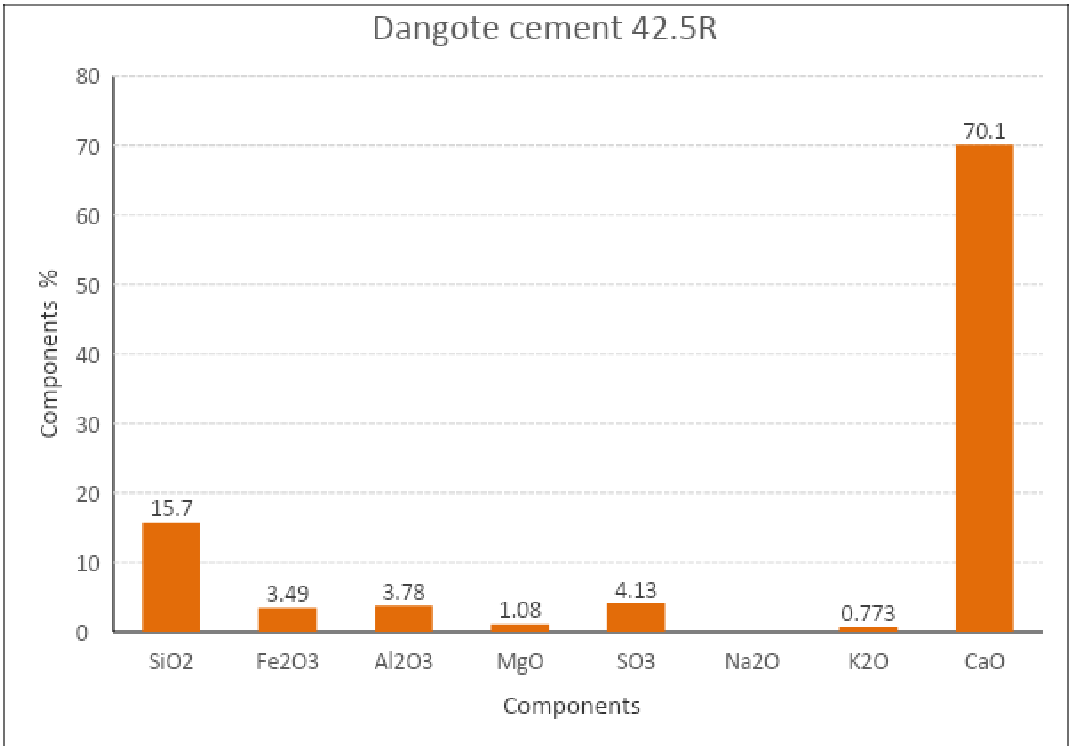

Fig. 8. Chemical composition of Dangote 42.5R

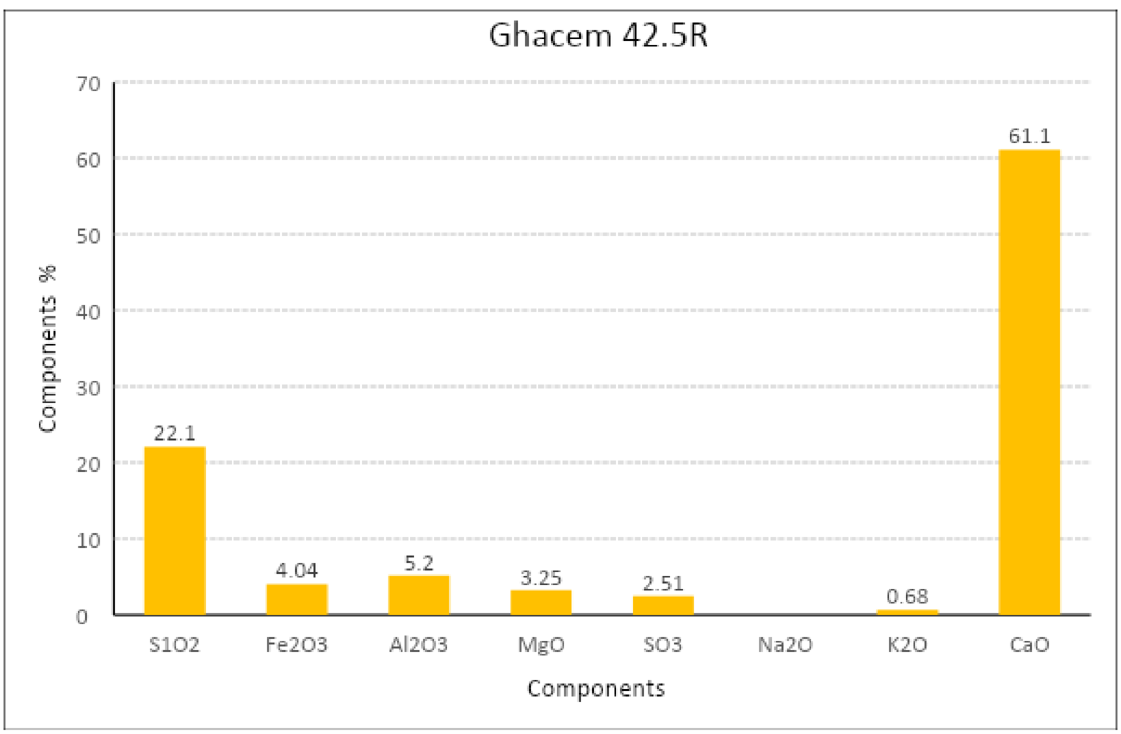

Fig. 9. Chemical composition of Ghacem 42.5R

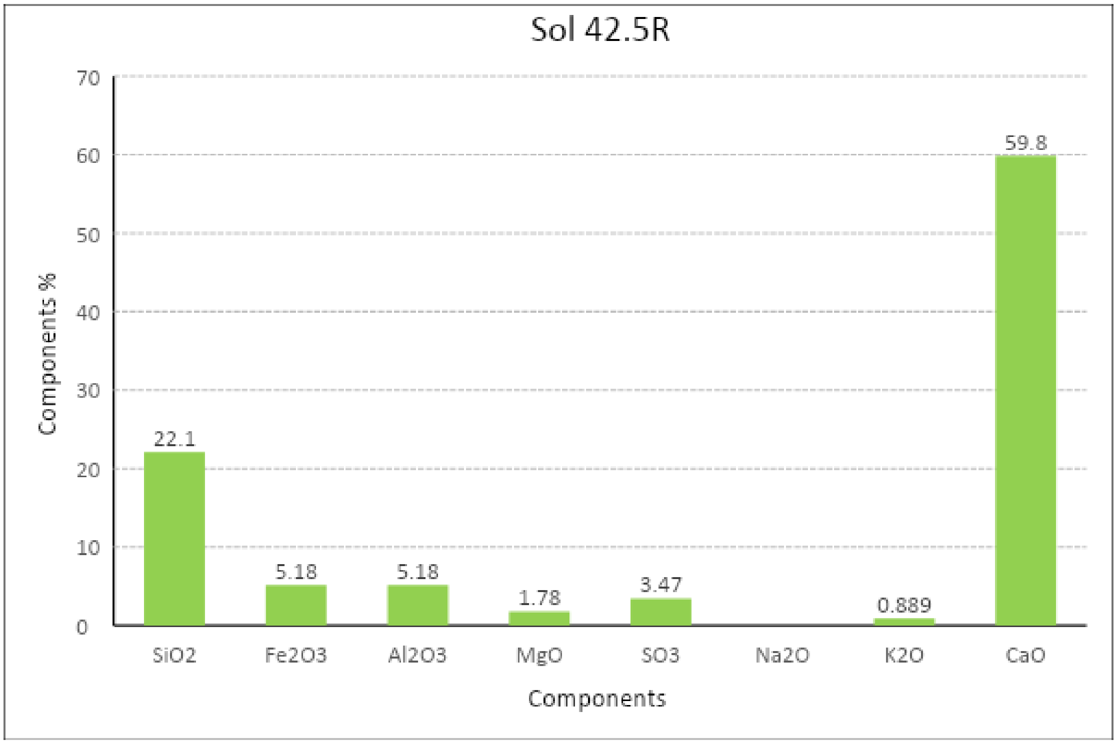

Fig. 10. Chemical composition of Sol 42.5R

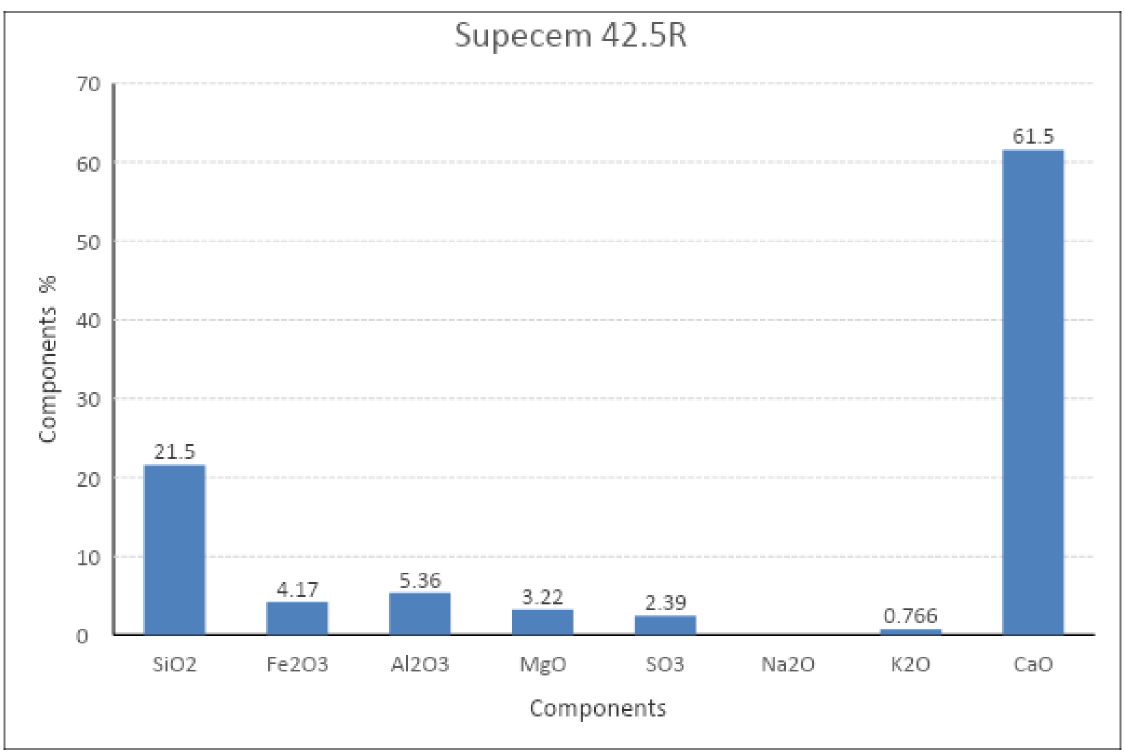

Fig. 11. Chemical composition of Supacem 42.5R

3.2 DISCUSSION

In a comparative analysis regarding the results produced from the XRF tests, each cement brand indicated variations in the chemical compositions existing among them in this research. However, the predominant oxide compositions were found to be CaO, S_iO_2, Al_2O_3, Fe_2O_3, K_2O, MgO and SO_3. The compositions of the various major Chemical compounds in the cements used in Ghana are shown in Tables 1 to 4 and Figures 1 to 11 .It is known that during cement hydration oxides such as CaO, S_iO_2, Al_2O_3, and Fe_2O_3 lead to hardening of the cements due to the formation of di-calcium silicates, tri-calcium silicates, calcium aluminosilicates and tetra calcium aluminoferrite hydrate. High presence of MgO may adversely lead to poor soundness of cement which may not be ideal to be used for civil or structural works. There were significant differences noticed among the chemical compositions of each cement brands. The variation in chemical composition may be attributed to the differences in the proportioning of raw materials and the process of manufacturing of the cements by their respective companies. The analysis shows that the presence of CaO content was more compared to the other chemical components. Again, there was no significant difference among the rest of the chemical components except that gradual increase was noticed in S_iO_2 as plotted.

Class 32.5R cements

The different chemical compounds in ordinary Portland cement play different roles to influence the physical and mechanical properties of concrete and other masonry products during and after hydration of the binding cement. In Figure 3 the total proportions of the main compounds in the class 32.5R of the various cement brands that are involved in hydration of cement have been presented for comparison. These chemical compounds comprise the combination Calcium Oxide (CaO), Silica (SiO_2), Iron Oxide (Fe_2O_3) and Aluminium Oxide (Al_2O_3). These compounds contribute immensely to the physical properties of hydrated cement products such as density, porosity and permeability. The total percentage of these combined chemical compounds in the 32.5R cement was found to be approximately the same in the cements from the different manufacturers although the figures varied slightly from between a minimum of 89.43 percent for Diamond cement and a maximum of 92.42 percent for CIMAF cement.

With regard to the major chemical compounds, namely Calcium Oxide (Ca O) and Silica (SiO_2) that produce the silicates (that is, tricalcium silicate and dicalcium silicate) during hydration of cement, the total percentages in proportion of the combined Calcium Oxide and Silica varied from a minimum of 75.1 percent for SOL cement to a maximum of 80.9 percent. The Silicates in hydrated cement are the most stable compounds and contribute most to the physical properties of concrete. Together the C_2S and C_3S constitute 70 to 80 percent of the constituent cement [11]. From Table 3, all the cement brands from the different manufacturers in Ghana met the proportional requirements of the main compounds that are expected to develop the dicalcium silicate (Ca_2S) and tricalcium silicvate (Ca_3S).

Class 42.5 R cement

In the case of the 42.5 R cement brands, as Figure 4 illustrates, the total percentage of all the combined major chemical compounds (SiO_2 + Al_2O_3 + CaO + Fe_2O_3) ranged from a minimum of 92.26 for SOL cement to a maximum of 93.07 for DANGOTE cement albeit a slight variation in their values that indicate that the different cements are expected to developsimilar physical, chemical and mechanical properties As regards the chemical compounds that mainly develop the silicates during cement hydration, namely Calcium Oxide and Silica, their combined percentages varied from a minimum of 81.9 for SOL cement to a maximum of 85.8 for DANGOTE cement.All these values of silicate-producing chemical compounds exceed the minimum required percentage of 70 to 80 for chemical stability and strength development in concrete.

It is clear from Figures 3 and 4 that the different manufacturers' Class 42.5 R cements contain higher percentages of combined major chemical compounds that are necessarily required to develop the mechanical, physical and chemical properties of ordinary Portland cement concrete. The Class 42.5 R cement brands are therefore expected to be superior to the Class 32.5R cement branmds.

4. CONCLUSION

The chemical investigation of the various brands of cements used in Ghana was carried out using X-Ray Florescence Spectrometer. The results from the laboratory investigations showed that the major chemical compounds of the different brands of cement are comparable and all meet standard specifications These chemical compounds will therefore expectedly provide the physical, chemical and mechanical properties that satisfy the design requirements of users of the cement. The chemical constituents enable the appropriate brands of cement to be used for different types of construction work in the country. . The application of XRF equipment to conduct experimental investigations of chemical composition of cements should be carried out by cement manufacturing companies in Ghana fo quality control purposes on chemical composition.This will allow manufacturers to determine the way that the material will react to its environment when mixed and used for construction work in the infrastructure development of the country.

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