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# COMPARATIVE STUDY OF CHEMICAL COMPOSITION OF CLINKER FOR CEMENT PRODUCTION

**Sanusi Nuhu, Musa Umar, Abdullahi Muhammad Illela Nasiru and Muhammad Sani**
Umaru Ali Shinkafi Polytechnic Sokoto
sanusin48@gmail.com and mubazz2000@gmail.com

***ABSTRACT***
*The chemical composition of the clinker directly influences the quality of cement produced. The clinker is the key intermediate product in cement production, and it is created by heating a mixture of raw materials to high temperatures in a kiln. The precise chemical composition of the clinker is critical for achieving the desired strength, setting time, and other properties of the final cement product. The objectives of this research were to obtain the chemical composition of cement clinker sample data after the x-ray diffraction (XRD) analysis from the quality control department of the two plants, to study the variation and its effect on cement modulus such as lime saturation factor (LSF), silica modulus (SM) and alumina modulus (AM) on cement performance to correlate the cement modulus and clinker minerals using plot chats. The data were obtained from the quality control department of BUA Sokoto Cement and Dangote Cement. Lime saturation factor, Silica modulus and Alumina modulus were also used for data analysis. The study showed similarities and differences between the two clinker samples considered in this study. It also highlighted that the constituents of clinker affect its properties and performance. Using plotted graphs, The study also showed the correlation between cement modulus and clinker minerals. The lime saturation factor range (97.20-102.65) % average Silica modulus of 2.21 % and average Alumina modulus of 1.53 % for BUA Sokoto cement. Compared to the lime saturation factor range (96.46-98.81) %, average Silica modulus of 2.19 % and average Alumina modulus of 1.63 % for Dangote cement, it explains the variation in energy consumption, setting time and strength of the clinker. It was also concluded that there is a relationship between cement modulus and clinker minerals. Also, the differences in chemical composition between the clinker samples may be attributed to variations in the raw materials used in the production process.*

**Keywords:** Cement, Clinker, Constituent, Composition, Modulus

## INTRODUCTION

Cement is a hydraulic binding material forming paste when mixed with water. It is the most used construction material in the world. Cement has three fundamental stages in production: preparation of the raw materials, production of clinker and preparation of cement. Clinker is a well-finned raw material that undergoes a chemical transformation at 1450 C inside the kiln to form a new compound called clinker (Isa & Nuhu, 2019). Clinker is 75% cement; the clinker, gypsum and limestone would be ground to form cement.

Cement production is a significant industrial activity vital to the construction industry. Cement production uses various raw materials, including limestone, clay, and shale, which are heated at high temperatures to form cement clinker. The quality of cement clinker has a significant impact on the quality of the final cement product. Therefore, a comparative study of the chemical composition of cement clinker for cement production is essential for understanding the factors that affect cement quality.

Several researchers have conducted comparative studies on the chemical composition of cement clinker. For instance, Liu *et al*. (2021) investigated the chemical composition and mineral phase characteristics of clinker from different cement plants in China. They found significant variations in the chemical composition of the clinker, which could affect the quality of the final cement product. Similarly, Ahmad *et al*. (2020) conducted a comparative study of the chemical composition of clinker produced by different cement plants in Pakistan. Their findings indicated that the chemical composition of clinker significantly affects the compressive strength of cement. Therefore, this comparative study of the chemical composition of clinker for cement production aims to contribute to the existing knowledge on cement production and improve the quality of cement products. The study will analyze and compare the chemical composition of clinker from different cement plants and identify the factors that affect the quality of the final cement product.

**Research Problem Statement**

Cement is a fundamental building material used in construction activities globally. It is used in various forms, such as concrete, mortar, and grout, and is produced by combining clinker, gypsum, and other additives. Clinker, the primary ingredient in cement production, is manufactured by heating limestone and clay in a kiln at high temperatures. The chemical composition of clinker significantly affects the quality of cement and its final properties. Therefore, it is crucial to understand the variations in the chemical composition of clinker obtained from different sources and their impact on cement production.

**Research Aim and Objectives**

This research aims to conduct a comparative study of the chemical composition of clinker for cement production using BUA Sokoto Cement Plant (Cement Company, Sokoto) and Dangote Cement Plant Obajana, Kogi State, as a case study. The objectives are: To obtain the chemical composition of cement clinker after the lab analysis from the quality control department of the two plants, study the variation and its effect on cement modulus such as lime saturation factor (LSF): silica modulus (SM) and alumina modulus (AM) on cement performance: correlate the cement modulus and clinker minerals using plot chats.

**Clinker and its Importance in Cement Production**

Cement clinker is a dark grey nodular material made by heating ground limestone and other materials, such as clay or shale, in a kiln at high temperatures, typically ranging from 1,450 to 1,500°C (2,642 to 2,732°F) (Friedman, 2003). The process of heating the raw materials to produce cement clinker is known as clinker. Clinker is then ground with a small amount of gypsum to produce cement. The production of cement clinker is a highly energy-intensive process and is responsible for a significant amount of greenhouse gas emissions. According to the International Energy Agency (IEA), the cement industry accounts for approximately 7% of global carbon dioxide emissions (IEA, 2020). As a result, there is ongoing research into developing more sustainable and energy-efficient methods of cement production.

Cement clinker plays a crucial role in cement production as it is the primary raw material used to produce cement. The material is ground with a small amount of gypsum to produce the final cement product. The quality and properties of the cement clinker have a significant impact on the quality of the final cement product (Nuhu et al., 2020)

**Brief Overview of the Chemical Composition of Cement Clinker**

Cement clinker is primarily composed of four main chemical compounds: tricalcium silicate ($Ca_3SiO_5$), dicalcium silicate ($Ca_2SiO4$), tricalcium aluminate ($Ca_3Al2O_6$), and tetra calcium aluminoferrite ($Ca_4AlFeO_7$). These compounds are formed during the high-temperature process of calcination, which involves heating a mixture of raw materials such as limestone, clay, and iron ore in a kiln. They play essential roles in the setting and hardening of cement, as well as its resistance to chemical and sulfate attacks.

**Factors Affecting Clinker Formation**

Clinker formation is a complex phenomenon that occurs during cement production. The formation of clinker is affected by several factors, which can be broadly classified into three categories;

a) The chemical composition of raw materials used for cement production plays a significant role in clinker formation. The presence of impurities, such as sulfur, alkali, and chlorine, in the raw materials can affect clinker formation by increasing the melting point of the clinker and slowing down the reactions that lead to its formation (Javed, 2021). Moreover, the raw materials' fineness and homogeneity can affect the clinker formation rate (Ghosh, 2020).

b) Several process parameters can affect the formation of clinker. The most critical are temperature, residence time, and oxygen content. The kiln's temperature should be maintained within a specific range, usually between 1350 and 1450°C, for clinker formation (Javed, 2021). The residence time of the materials in the kiln also plays a crucial role in clinker formation. If the residence time is too short, the raw materials may not be adequately heated, resulting in incomplete reactions and insufficient clinker formation. Similarly, if the residence time is too long, the materials may be overcooked, forming excessive amounts of clinker (Ghosh, 2020). Finally, the oxygen content in the kiln atmosphere must be carefully controlled, as an excess of oxygen can lead to the oxidation of raw materials and the formation of unwanted compounds (Javed, 2021).

c) Several environmental conditions can affect clinker formation, including ambient temperature and humidity. High ambient temperatures can increase the rate of clinker formation, while high humidity levels can slow down the process (Ghosh, 2020). Moreover, dust and other particulate matter in the kiln can affect clinker formation by interfering with heat transfer and chemical reactions (Javed, 2021).

## METHODOLOGY

### Data collection

Chemical composition data from different cement clinker plants were collected for analysis and comparative study.

### Results

**Table 1: Chemical composition of clinker samples from BUA cement plant**

| XRD (QUANTITATIVE) ANALYSIS RESULTS OF CLINKER SAMPLES FROM BUA SOKOTO CEMENT PLANT | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S/NO | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | SM | AM | LSF | C3S | C2S | $C_3A$ | $C_4AF$ | Lt.wt | F.CaO |
| 1 | 20.90 | 5.60 | 3.79 | 66.79 | 2.16 | 2.20 | 1.47 | 99.33 | 59.73 | 15.03 | 9.81 | 11.52 | 1279 | 3.79 |
| 2 | 20.50 | 5.60 | 3.90 | 66.80 | 2.10 | 2.20 | 1.47 | 100.52 | 63.07 | 11.14 | 9.71 | 11.85 | 1270 | 3.90 |
| 3 | 20.50 | 5.54 | 4.20 | 66.60 | 2.05 | 2.15 | 1.48 | 99.88 | 54.21 | 17.82 | 9.33 | 12.76 | 1267 | 4.20 |
| 4 | 20.30 | 5.64 | 4.21 | 66.10 | 2.12 | 2.10 | 1.32 | 99.50 | 60.22 | 12.92 | 9.47 | 12.79 | 1257 | 4.21 |
| 5 | 20.50 | 5.48 | 3.98 | 66.79 | 2.06 | 2.06 | 1.34 | 100.33 | 63.06 | 11.29 | 9.56 | 11.07 | 1269 | 3.98 |
| 6 | 20.50 | 5.63 | 3.77 | 66.40 | 2.07 | 2.16 | 1.37 | 99.65 | 60.68 | 13.11 | 9.52 | 12.09 | 1257 | 3.77 |
| 7 | 20.50 | 5.56 | 3.74 | 66.30 | 2.13 | 2.18 | 1.50 | 99.72 | 59.64 | 13.81 | 9.45 | 11.46 | 12580 | 3.74 |
| 8 | 20.20 | 5.50 | 3.36 | 66.96 | 2.10 | 2.20 | 1.48 | 102.65 | 60.90 | 11.94 | 9.55 | 11.37 | 1255 | 3.36 |
| 9 | 20.90 | 5.84 | 3.22 | 66.72 | 2.19 | 2.27 | 1.63 | 98.56 | 59.01 | 15.55 | 9.80 | 10.21 | 1253 | 3.22 |
| 10 | 21.00 | 6.74 | 3.21 | 65.89 | 2.20 | 2.30 | 1.81 | 97.20 | 63.17 | 25.85 | 9.75 | 9.78 | 1257 | 3.21 |
| 11 | 20.50 | 6.55 | 3.23 | 66.86 | 2.14 | 2.34 | 1.78 | 101.01 | 58.70 | 11.21 | 9.81 | 9.81 | 1251 | 3.23 |
| 12 | 20.70 | 6.63 | 3.27 | 66.12 | 2.13 | 2.30 | 1.72 | 99.01 | 59.53 | 15.00 | 9.36 | 9.85 | 1252 | 3.27 |

**Table 2: Chemical composition of clinker sample at Dangote Cement Plant**

| XRD (QUANTITATIVE) ANALYSIS RESULTS OF CLINKER SAMPLES FROM DANGOTE CEMENT | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S/NO | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | SM | AM | LSF | C3S | C2S | $C_3A$ | $C_4AF$ | Lt.wt | F.CaO |
| 1 | 20.02 | 5.84 | 3.66 | 67.84 | 1.94 | 2.17 | 1.65 | 98.81 | 60.42 | 14.73 | 9.81 | 11.12 | 1279 | 0.48 |
| 2 | 20.23 | 5.83 | 3.71 | 67.92 | 1.80 | 2.18 | 1.63 | 98.23 | 59.46 | 16.03 | 9.71 | 11.28 | 1270 | 0.53 |
| 3 | 20.22 | 5.93 | 3.78 | 66.14 | 1.88 | 2.19 | 1.57 | 98.10 | 56.89 | 17.94 | 9.33 | 11.49 | 1267 | 0.55 |
| 4 | 20.22 | 5.94 | 3.78 | 66.28 | 1.76 | 2.20 | 1.60 | 97.85 | 57.46 | 17.51 | 9.47 | 11.28 | 1257 | 1.20 |
| 5 | 21.21 | 5.93 | 69.00 | 65.40 | 5.22 | 2.22 | 1.63 | 97.63 | 61.97 | 14.10 | 9.56 | 11.07 | 1269 | 1.22 |
| 6 | 21.10 | 5.90 | 3.82 | 65.58 | 1.84 | 2.22 | 1.63 | 97.15 | 59.99 | 15.28 | 9.52 | 11.00 | 1257 | 1.22 |
| 7 | 20.98 | 5.94 | 3.82 | 64.98 | 3.98 | 2.17 | 1.60 | 97.05 | 61.87 | 13.50 | 9.45 | 11.31 | 1258 | 1.54 |
| 8 | 20.78 | 5.92 | 3.85 | 64.00 | 1.99 | 2.18 | 1.63 | 96.92 | 63.57 | 11.64 | 9.55 | 11.04 | 1255 | 2.10 |
| 9 | 21.67 | 5.99 | 3.82 | 63.84 | 1.84 | 2.16 | 1.67 | 96.76 | 63.27 | 11.57 | 9.80 | 10.92 | 1253 | 2.14 |
| 10 | 21.67 | 6.03 | 3.80 | 63.91 | 1.98 | 2.14 | 1.66 | 96.64 | 63.41 | 11.47 | 9.81 | 11.07 | 1257 | 2.18 |
| 11 | 21.82 | 6.45 | 3.87 | 62.49 | 2.30 | 2.21 | 1.68 | 96.64 | 60.41 | 14.68 | 9.78 | 10.76 | 1251 | 2.18 |
| 12 | 21.85 | 6.89 | 3.87 | 62.15 | 4.38 | 2.18 | 1.59 | 96.46 | 62.05 | 13.04 | 9.36 | 11.25 | 1252 | 2.23 |

**Variation and Effect of Cement Modulus (Lime Saturation Factor (LSF), Silica Modulus (SM) and Alumina Modulus (AM)) On Cement Performance**.

**BUA Sokoto Cement**

Lime saturation factor range; 97.20−102.65 %

The lime saturation factor of clinker lies in the range of 92−98 %. BUA Sokoto Cement has a higher range and yields better quality clinker due to the high $C_3S$ content, but there would be difficulty in linearization and high energy consumption.

Silica modulus range; 2.06−2.34 %

The average value is 2.21 %

The presence of a higher silica modulus in BUA Sokoto cement increases the strength of the cement but also prolongs the setting time. Also, the workability of concrete decreases

Alumina modulus range; 1.32−1.81 %

The average value is 1.53 %

Low Alumina Modulus in (BUA) Sokoto cement makes the clinker darker with the slow setting of cement.

**Dangote Cement**

Lime saturation factor range; 96.46−98.81 %

Dangote cement has a lower range and yields less good quality clinker due to the low $C_3S$ content, but there would be easy linearization and low energy consumption.

Silica modulus range; 2.14−2.22 %

The average value is 2.19 %

The presence of a lower silica modulus in Dangote cement decreases the strength of the cement but also shortens the setting time.

Alumina modulus range; 1.57−1.68 %

The average value is 1.63 %

High Alumina Modulus in Dangote cement makes the clinker lighter with the fast setting of cement. To delay the setting time, more gypsum is required. Higher Alumina modulus results in the hard burning of clinker, which causes high fuel consumption (Jasim et al., 2019).

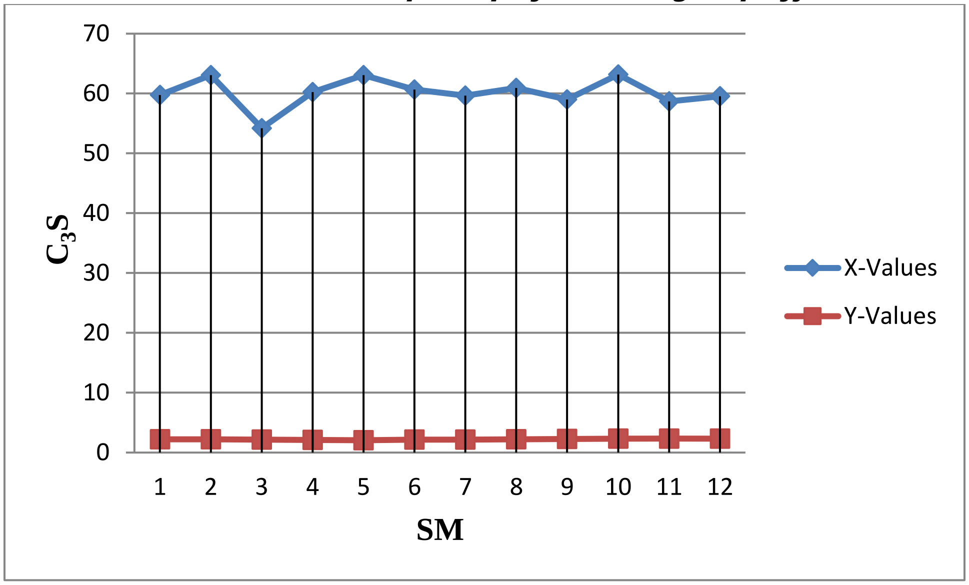


**Figure 1: A graph of Alite $C_3S$ against Silica modulus**

The chat of silica modulus (SM) against the elite ($C_3S$) shows a positive correlation; this is the fact that has already been stated from the literature review that when the silica increases in the clinker sample, it decreases the elite ($C_3S$), and hence will lead to decrease the liquid formation in the burning zone inside the kiln and of the final product (cement).

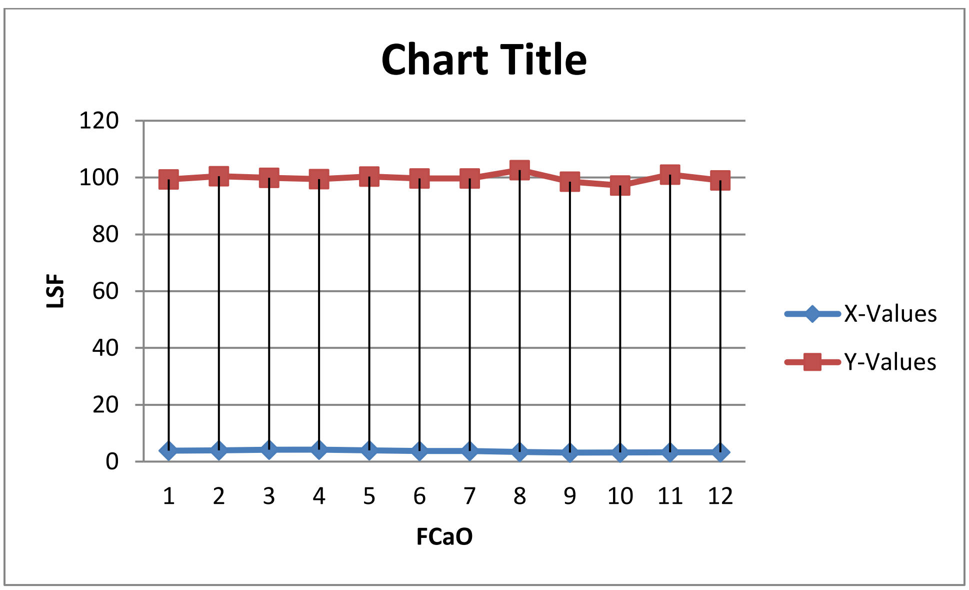


**Figure 2: A graph of Lime saturation factor against FCaO**

This chat also indicated a positive correlation. As the Lime saturation factor (LSF) increases, the Free lime (FCaO) increases. From the data collected, it has indicated that there is fluctuation of LSF above 100 %, which has influenced the presence of free lime. Hence this would reduce the cement strength, as stated in the literature review.

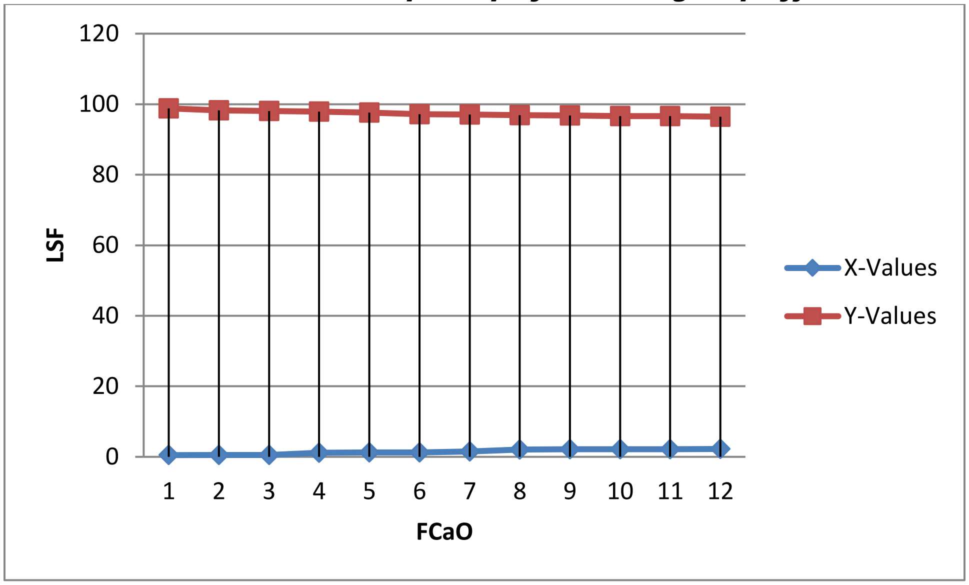


**Figure 3: A graph of Lime saturation factor against FCaO**

Figure 3 indicates a positive correlation. As the Lime saturation factor (LSF) increases, the Free lime (FCaO) increases, as the literature states. The data collected indicated that the LSF is within the target range compared to the BUA cement plant, which has influenced the free lime to be within the range value. Hence this would increase the strength of cement.

## CONCLUSION

The research is a comparative study of the chemical components of cement clinker for cement production. To achieve this aim mentioned above, the study further assessed the chemical components of cement clinker for BUA Sokoto cement and the chemical components of cement clinker for Dangote cement, obtained the constituent of clinker, and also called clinker minerals, and determined similarities and differences between these two cement samples from different plants. Data was collected from the quality control department of the BUA Sokoto cement plant and the Dangote cement plant with plant analysis of cement clinker from the x-ray machine (XRD). A descriptive statistical technique was used to analyze the data of this study.

From the analysis, the two Clinker samples have significantly different chemical compositions, particularly in their silica and alumina contents. The differences in chemical composition between the clinker samples may be attributed to variations in the raw materials used in the production process. BUA Sokoto cement has a higher Lime saturation factor range, higher silica modulus and lower alumina modulus. Dangote cement has a lower Lime saturation factor range, lower silica modulus and higher alumina modulus. By comparing the two plants, BUA Sokoto Cement has a higher range and yields better quality clinker due to the high $C_3S$ content. However, there would be difficulty in linearization and high energy consumption. However, the presence of a higher silica modulus in BUA Sokoto cement increases the strength of the cement but also prolongs the setting time. Also, the workability of the concrete decreases.

Moreover, low alumina in BUA Cement Plant makes the clinker darker with low setting time than the Dangote Cement Plant.

Furthermore, the research pointed out factors and properties of cement contained in the two samples that increase performance and effectiveness. These properties include the setting time, energy consumption, strength of cement and resistance to environmental factors and optimization.

## RECOMMENDATION

We are evaluating the impact of the differences in chemical composition on cement quality and adjusting the production process as necessary.

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