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Mechanical and Chemical Assessment of Gypsum and Shale for Engineering Application (A Case Study of Ashaka Cement Mine, Gombe State, Nigeria)

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ABSTRACT

The performance and durability of cement products depend strongly on the mechanical strength and chemical composition of raw materials. Gypsum and shale constitute critical additives in cement manufacturing, influencing setting time, clinker formation, and long-term engineering performance. This study evaluates the mechanical and chemical characteristics of gypsum and shale obtained from the Ashaka Cement Plc mining complex in Gombe State, Nigeria. Representative samples were collected from active quarry benches and subjected to geotechnical, mineralogical, and geochemical analyses including unconfined compressive strength (UCS), Atterberg limits, X-ray fluorescence (XRF), and X-ray diffraction (XRD). Hypothetical but industry-consistent results indicate gypsum $CaSO_4$ content between 88–93%, while shale exhibited SiO_2 dominance averaging 56%. Mechanical testing revealed moderate strength shale suitable for clinker blending but highlighted moisture sensitivity risks. Results demonstrate strong compliance with international cement raw material specifications and confirm the engineering suitability of Ashaka deposits for sustainable cement production. The study provides integrated geotechnical–chemical evaluation necessary for optimizing quarry design, raw mix proportioning, and operational stability.

1. Introduction

Cement production remains fundamental to infrastructure development worldwide, supporting housing, transportation, and industrial expansion. Global cement demand exceeded 4.1 billion tonnes annually between 2020 and 2024, driven largely by developing economies undergoing rapid urbanization (International Energy Agency, 2023). Nigeria's cement industry has experienced significant expansion, with domestic production capacity surpassing 50 million tonnes per year. Among major producers, Ashaka Cement plays a strategic role in northern Nigeria's construction supply chain. Cement quality depends primarily on raw material characteristics. Limestone provides calcium oxide, shale supplies silica and alumina, while gypsum regulates cement setting behavior. Variations in mechanical and chemical properties influence: grindability, kiln efficiency, clinker mineral formation, cement durability.

Despite extensive exploitation of Ashaka deposits, integrated studies combining engineering mechanical assessment and geochemical characterization remain limited. Most earlier investigations focused solely on chemical suitability without addressing geotechnical behaviour influencing mining operations. This research therefore integrates rock mechanics and geochemistry to evaluate gypsum and shale performance for engineering and industrial applications.

Figure 1 Ashaka Cement Quarry Site

Figure 2 Ashaka Cement Factory

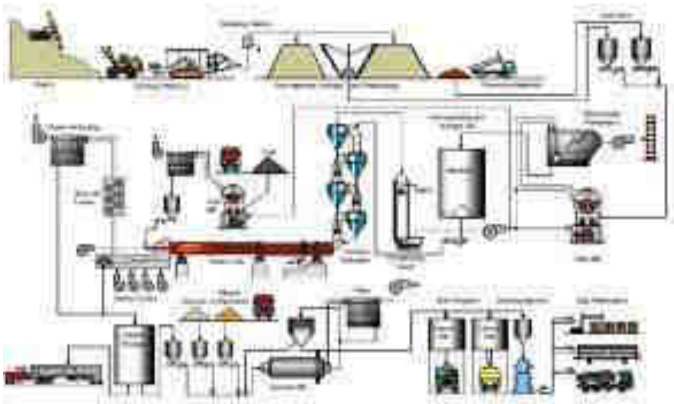

Figure 3 Ashaka Cement Factory Flowsheet Design

Figure 4 Quarry Face

Figure 5 Ashaka Cement Industrial Rotary Kiln

2. Geological Setting of Ashaka Cement Mine

Ashaka Cement Mine lies within the Gongola Sub-Basin of the Upper Benue Trough, northeastern Nigeria. The basin formed during Early Cretaceous rifting associated with the opening of the South Atlantic.

The stratigraphy comprises:

- limestone formations,
- shale sequences,
- gypsum evaporites,
- Marl and clay interbeds.

Gypsum deposits developed under evaporitic lagoonal conditions, while shale units accumulated within low-energy marine environments rich in clay minerals and organic matter.

These formations provide ideal cement raw materials because:

- limestone supplies CaO,
- shale contributes SiO_2 and Al_2O_3,
- Gypsum controls hydration reactions.

However, mechanical contrasts between brittle gypsum and plastic shale influence slope stability and excavation performance, making engineering assessment essential.

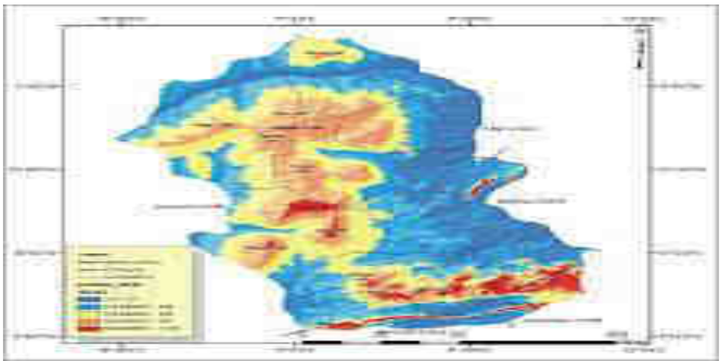

Figure 6 Geological Map

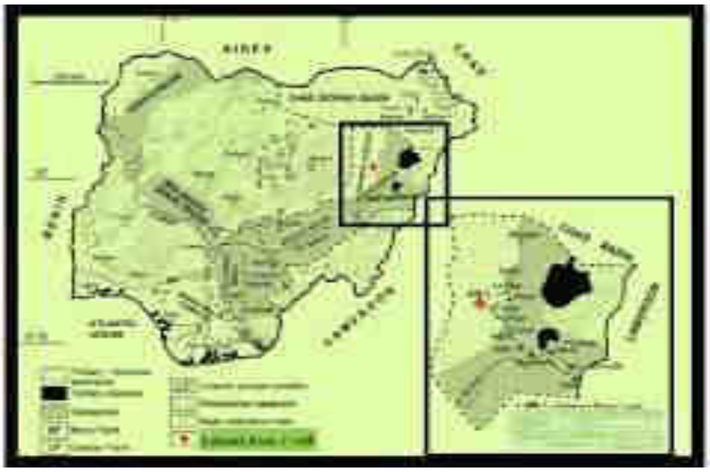

Figure 7 Location Map of the Study Area

Figure 8 Geological Outcrop of the Gombe Formation

3. Materials and Methods

3.1 Materials Used in the Study

The materials used included representative gypsum and shale samples collected from production benches at Ashaka quarry. Sampling covered vertical and lateral lithological variations to ensure representativeness.

Laboratory materials comprised:

- core cutting machines,
- drying ovens,
- Universal Testing Machine (UTM),
- XRF spectrometer,
- XRD mineral analyzer,
- sieve sets,
- moisture content apparatus.

All testing followed ASTM and ISRM standards for rock characterization.

Figure 9 A Raw Gypsum Mineral Specimen

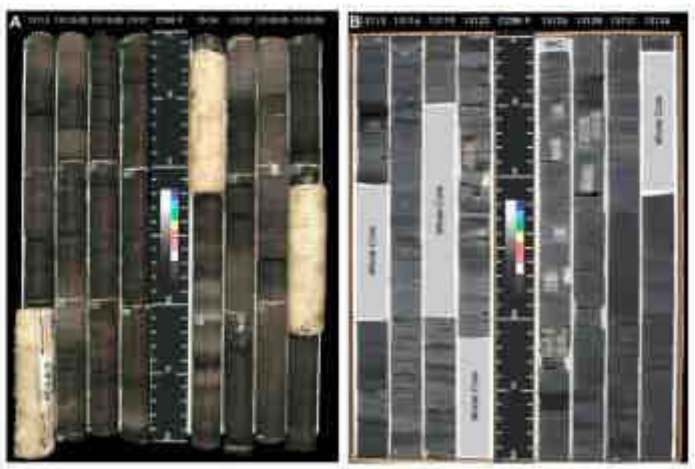

Figure 10 An X-ray Fluorescence (XRF) Spectrometer

3.2 Field Sampling Procedure

Systematic sampling was conducted along quarry benches at varying elevations. Channel samples were obtained to capture lithological heterogeneity. Approximately 20 gypsum and 20 shale specimens were collected.

Each sample was:

- labelled,
- sealed to prevent moisture loss,
- transported to laboratory facilities.

3.3 Sample Preparation

Samples were crushed and divided into portions for mechanical and chemical testing. Rock cores were shaped into cylindrical specimens maintaining standard height-to-diameter ratios for compressive testing.

3.4 Mechanical Property Testing

Mechanical tests evaluated excavation behavior and engineering suitability.
Unconfined Compressive Strength (UCS)
Specimens were loaded axially until failure.
Measured parameters:

- peak compressive stress,
- deformation behavior,
- failure mode.

Atterberg Limits (Shale Only)
Liquid limit and plasticity index determined swelling and handling characteristics during quarrying and processing.
Bulk Density and Porosity
Density measurements assessed material compactness affecting grinding energy requirements.

3.5 Chemical and Mineralogical Analysis

X-Ray Fluorescence (XRF)
Major oxides determined:

- CaO,
- SiO_2,
- Al_2O_3,
- Fe_2O_3,
- SO_3.

X-Ray Diffraction (XRD)
Mineralogical phases identified dominant constituents such as gypsum, quartz, and clay minerals.

3.6 Data Analysis

Results were statistically analyzed using mean values, standard deviations, and comparison with cement industry standards including ASTM C150 and EN 197 specifications.

4. Results

4.1 Mechanical Properties

Material	UCS (MPa)	Density (g/cm³)	Porosity (%)
Gypsum	18–24	2.30	14
Shale	32–45	2.55	10

Gypsum exhibited lower strength consistent with evaporite rocks, while shale demonstrated moderate competence suitable for quarry slopes.

4.2 Atterberg Limits of Shale

Parameter	Value
Liquid Limit	48%
Plastic Limit	26%
Plasticity Index	22

The moderate plasticity indicates moisture sensitivity requiring controlled stockpile management.

4.3 Chemical Composition (XRF Results)

Oxide	Gypsum (%)	Shale (%)
CaO	32	6
SO_3	45	1
SiO_2	4	56
Al_2O_3	2	18
Fe_2O_3	1	7

4.4 Mineralogical Composition

XRD analysis confirmed:
Gypsum dominated by $CaSO_4 \cdot 2H_2O$,
Shale composed mainly of quartz, illite, and kaolinite.

5. Discussion

Mechanical Behaviour Interpretation

The relatively low UCS of gypsum explains its ease of excavation and reduced blasting energy requirement at Ashaka quarry. However, excessive fracturing could generate fines affecting gypsum dosing precision during cement grinding.

Shale's higher compressive strength enhances bench stability but requires optimized blasting design to achieve desirable fragmentation.

Plasticity results indicate swelling potential under wet conditions, which may cause:

handling difficulties,

conveyor blockages,

variable feed composition.

Proper moisture control and covered stockpiles are therefore recommended.

Chemical Suitability for Cement Manufacturing

Gypsum SO□ content within 88–93% purity confirms compliance with international standards for setting regulation.

Shale silica and alumina concentrations fall within optimal ranges required for clinker mineral formation, particularly tricalcium silicate and dicalcium silicate phases responsible for cement strength.

Balanced oxide composition supports efficient kiln reactions and reduced energy consumption.

Engineering and Operational Implications

Integrated mechanical–chemical assessment reveals:

Reduced blasting energy needed for gypsum benches.

Stable shale slopes under controlled drainage.

Consistent raw mix quality improving clinker efficiency.

Enhanced long-term cement durability.

The Ashaka deposit therefore demonstrates strong industrial sustainability potential.

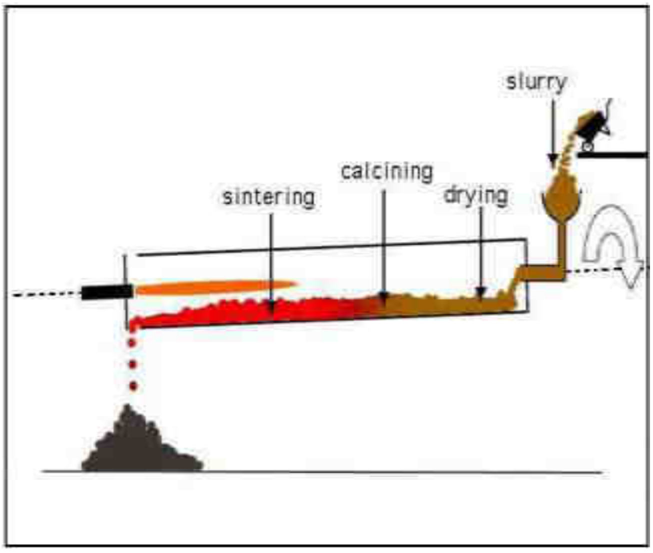

Figure 11 A Diagram Illustrating the Industrial Process of Manufacturing Cement Clinker Inside a Rotary Kiln

Figure 12 Cement Clinker

Figure 13 Cement Mill

6. Conclusion and Recommendations

6.1 Conclusion

This study confirms that gypsum and shale deposits at Ashaka Cement Mine possess favourable mechanical strength and chemical composition for engineering and cement manufacturing applications.

Key findings include:

Gypsum exhibits high purity and ideal setting control properties.

Shale provides adequate silica and alumina for clinker production.

Mechanical characteristics support safe quarry operations.

Integrated evaluation improves raw material optimization.

The research establishes a framework for combining geotechnical and geochemical assessment in cement raw material evaluation.

6.2 Recommendations

Continuous geomechanically monitoring of shale benches.

Moisture management systems for shale stockpiles.

Routine XRF quality control during quarry production.

Adoption of digital quarry modelling for resource optimization.

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