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NIGERIAN MINING JOURNAL

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Agbalajobi, S. A. & Durojaiye, A .G. (2014) Nigerian Mining Journal, 12(1) 1 - 7

Comparative analysis of drilling and blasting techniques in selected quarries in Kwara State, Nigeria

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Abstract

A comparative study of blasting techniques was carried out in four selected granite quarries in Kwara State, Nigeria, they are Ibro Salam, Yassat Integrated, Harbin Engineering and Gbose Quarries. Some blasting parameters (burden and spacing, depth of hole drilled, bottom and column charge, pattern of drilling) and blasting method were examined. The result obtained indicated that performance of blast is more efficient and effective in Gbose Quarry Limited than the other three quarries; this may be due to the variation in burden and spacing, bottom charge length and quantity of explosive used in the quarry. It is therefore necessary for the three quarries to introduce new blast design which will encourage improved blast performance.

Keywords: Techniques, Drilling, Blasting, Burden, Spacing, Charging, Pattern and Performance

Introduction

Rock blasting plays an important role in determining the efficiency and economics of the whole surface mining operations (Harries and Mercer, 1975). Improving the blasting efficiency means lowering the rejected percent of the product. This portion is defined by the size of fines and/or oversize according to the type of the product and end-user requirements. Blasting is generally inevitable for hard rock excavation activities not only in mining and quarrying, but also in tunnel, subway, highways and dam construction. As these infrastructure activities are often close to residential areas, environmental problems unfortunately occur by the ground vibrations and air blast induced by blasting. Tunnel construction with blasting in urban areas creates annoying ground vibrations and also may inflict structural damage when excess quantity of explosives is used. Only about 20–30% of the energy during the blasting is utilized to fragment the rock (Kuzu, 2008).

The primary purpose of drilling and blasting is to fracture rocks and prepare the material for excavation and subsequent transport. The end purpose of rock blasting is to produce input material for a crusher. This is the case in most mining and construction rock blasting operations. Fragments produced by blasting should then not only be small enough for the loading equipment, but they should also be small enough to pass easily into the crusher opening. Blasting efficiency can be evaluated by different design methods. The definition of efficient blasting is based on the idea that increased energy expenditure is required in blasting to obtain better fragmentation, but better blasting lowers the cost of loading, hauling, crushing and protecting newly opened slope faces thus assisting the next drilling and blasting operation. After (Sunu*et al.,*2008), the design methods which are available for assessing the performance of blasting and fragmentation in a rock mass can be categorized as physical and observational methods, empirical methods, and analytical methods.

Physical methods or reduced scale blasting in the laboratory or in the field provide experience in fragmentation assessment and results that could be used to optimize the expensive full-scale field tests. However, at reduced scale, rock structures such as bedding and jointing are exaggerated and can have an unrealistic effect, (Sunu*et al.,*2008 and Stagg, 2007).

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Blasting is still considered to be an art. Selection of optimum burden, or the powder factor, is still a matter of experience. Very often the design engineer or "blaster in-charge" prefers to use simple empirical formulae for their blast designs (Paul and Gershon, 1989).

Analytical methods include, finite element, finite difference, boundary element and distinct element codes, are used to simulate blasting and the effect of different rock parameters on fragmentation. Many investigations were limited to two dimensional analyses, where some difficulties were observed in simulating the effect of structural geological discontinuities on blasting which occur in a rock mass three dimensionally.When selecting the proper system and techniques, one should consider both blast design and safety, Peurifoy, *et al*., (1996). Electric systems are more sensitive to lightening than non-electric systems, but both are susceptible.

Drilling and blasting combination is still an economical and viable method for rock excavation and displacement in mining as well as in civil construction works. The ill effects of blasting, i.e. ground vibrations, air blasts, fly rocks, back breaks, noises, etc. are unavoidable and cannot be completely eliminated but certainly minimize up to permissible level to avoid damage to the surrounding environment with the existing structures (Singh *et al*., 1994). Among all the ill effects, ground vibration is ofmajor concern to the planners, designers and environmentalists (Hagan, 1973). A number of researchers have suggested various methods to minimize the ground vibration level during the blasting. Ground vibration is directly related to the quantity of explosive used and distance between blast face to monitoring point as well as geological and geotechnical conditions of the rock units in excavation area.Geological and geotechnical conditions and distance between blast face to monitoring point cannot be altered but the only factor, i.e. quantity of explosive can be estimated based on certain empirical formulae proposed by the different researchers (Duvall and Fogleson 1992) to make ground vibrations in a permissible limit. An appropriate and rock friendly blasting can be only alternative for smooth progress of the rock removal process.

Method and Materials

Description of the Study Area

The study area covered four selected granite quarries within Kwara State, they are Ibro Salam, Yassat Integrated Resources Limited, Harbin Engineering Nigeria, Limited and Gbose Quarries Limited,(Figure 1 and Table 1).

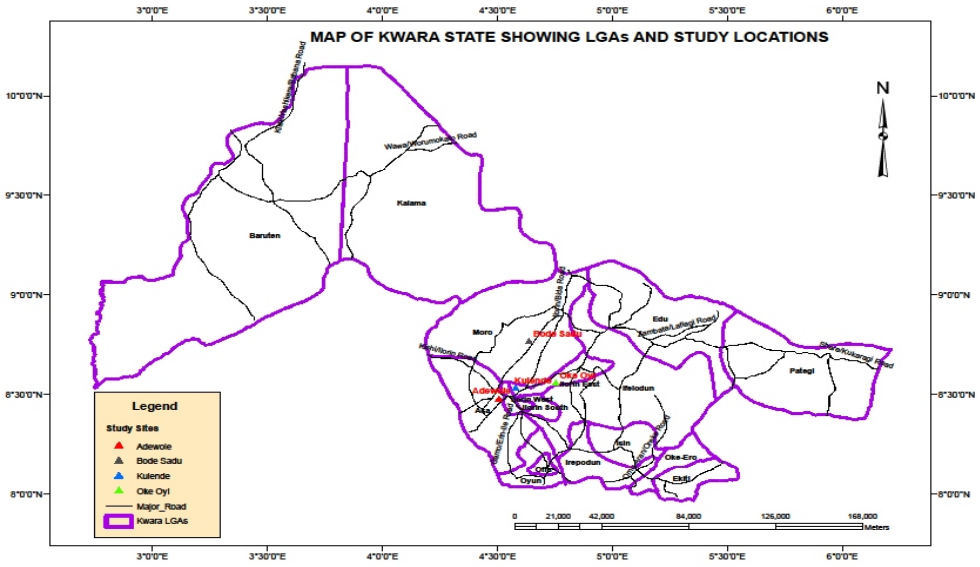

Figure 1: The Map of Kwara State Showing Location of the Study Area

Table 1: Location of the Study Area

Quarry Name	Sample Type	L.G.A	Co-ordinates of Location	
			Latitude	Longitude
Ibro Salam	Granite	Ilorin	06º 49'N	008º 32'E
YassatIntegrated	Granite	Ilorin	06º 21'N	008º 49'E
Harbin Engineering	Granite	Ilorin	06º 24'N	008º 45'E
Gbose	Granite	Ilorin	08º 09'N	004º 08'E

Primary data were collected from various quarries so as to reveal vital information, concerning drilling and blast operation in the respective quarries. These data were collected from competent and qualified personnel who are mining engineers, blaster and quarry supervisor and they were analyzed critically so that reasonable and reliable conclusion can be drawn with good recommendations.

Results and Discussions

Table 2 shows that the workforce of the quarries varies from 15 to 35. It is also observed that the establishment year of the quarries were different with Ibro Salam being youngest and Gbose being the oldest.

The difference in the number of workforce in the quarries can be traced to the present economic situation, type of equipment and the number of equipment that are present in each quarry and a way of minimizing cost of working capital. Based on the interviews conducted in these quarries, the granite products are sold to construction companies, within and outside the state.

Table 2: Information about the Selected Quarries

Quarry	Location	Year of Establishment	Work Force	Rock Produce
Ibro Salam	Agbele Village, Bode-Saadu, Jebba, Road, Ilorin	2009	18	Granite
Yassat Integrated	OkeOse, Old Jebba, Road, Ilorin	2008	15	Granite
Harbin Engineering	Kulende, Sango Area, Ilorin	2007	25	Granite
Gbose	Km 3, Omu-Aran, Oko Road	2004	35	Granite

Different bench heights were noticed in the quarries,(Table 3 and Figure 2). The vertical height from the toe to the crest shows the highest bench height which is that of Harbin Engineering and that of Yassat Integrated is the lowest. Also, burden and spacing only varies with little difference in the three quarries. Burden and spacing are important parameters to be considered while dealing with drilling pattern of a deposit and the size of the run-of mine to be produced will also depend on burden and spacing.

Table 3: Drilling Parameters

Quarry	Bench height (m)	Burden (m)	Spacing (m)	Drill hole diameter (mm)	Drill
Ibro Salam	16	1.0	1.5	65	Bottom bit
Yassat Integrated	9	1.0	2.0	50	Tungsten carbide
Harbin Engineering	20	1.1	1.3	65	Bottom bit
Gbose	15	1.7	1.8	80	Bottom bit

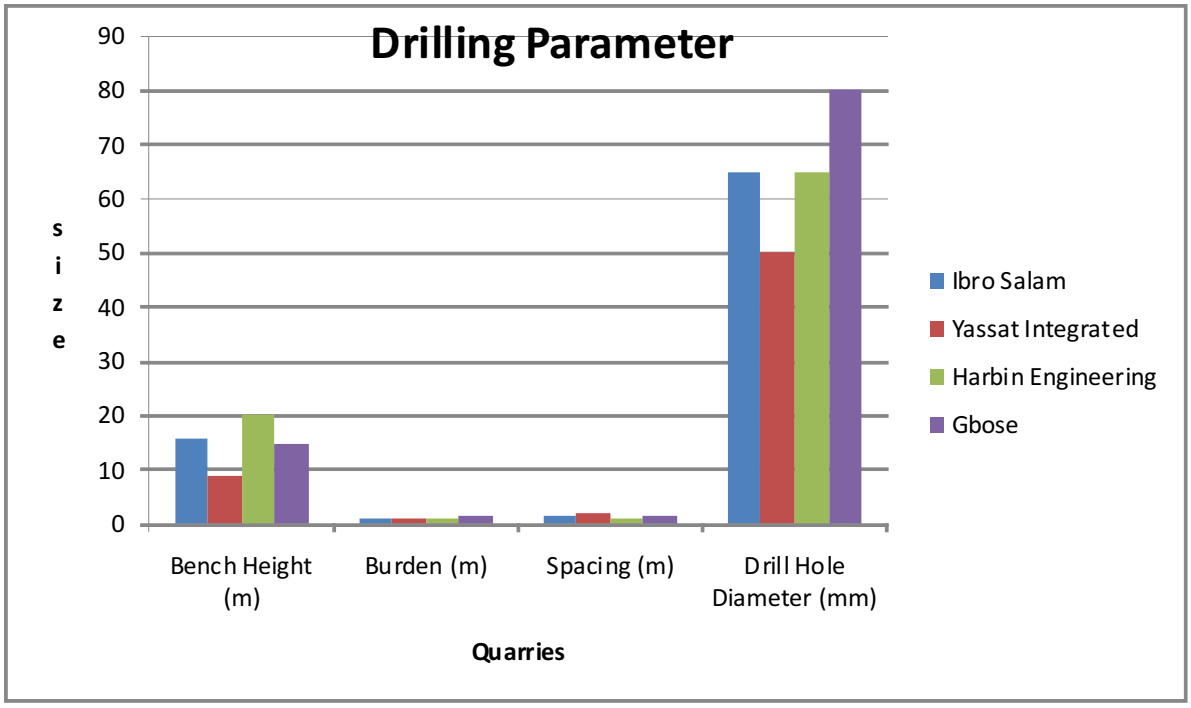

Fig. 2: Drilling Parameter

Table 4 shows information about blasting e.g. drilling pattern, construction pattern type of blasting accessories and type of explosives used in the quarries. The common drilling patterns used were staggered and rectangular. The connection pattern is the same for all the quarries. The type of explosive used by Gbose Quarries is high explosive as they are classified according to their strength. Its usage depends on the rock hardness and strength.

Table4: Blasting Parameters and Explosive Used

Quarry	Drilling Pattern	Connection Pattern	Explosive used	Blasting accessories	Blasting method	Hole depth (m)
Ibro Salam	Staggered	Parallel series	Special gel and ANFO	Safety fuse, Detonating cord blasting cap delay relay	Electric and Non Electric	1.52
Yassat Integrated	Rectangular	Parallel series	Nitroglycerin, Dynamite, ANFO	Safety fuse, detonating cord blasting cap	Electric and nonelectric	1.9
Harbin Engineering	Rectangular	Series parallel	Super 90, Nonel and ANFO	Safety fuse, detonating cord, delay, relay, blasting cap	Electric	4
Gbose	Rectangular	Series parallel	High Explosive, ANFO, Cordtex	Safety fuse, detonating cord, delay, relay, blasting cap	Electric	3

Figure 3 shows the result of a particular blasting in each quarry. The distance of fly rocks from the blasting face were taken and numbers of boulders were also recorded. There were many under size including dust. The length of stemming in each quarry is 30cm.

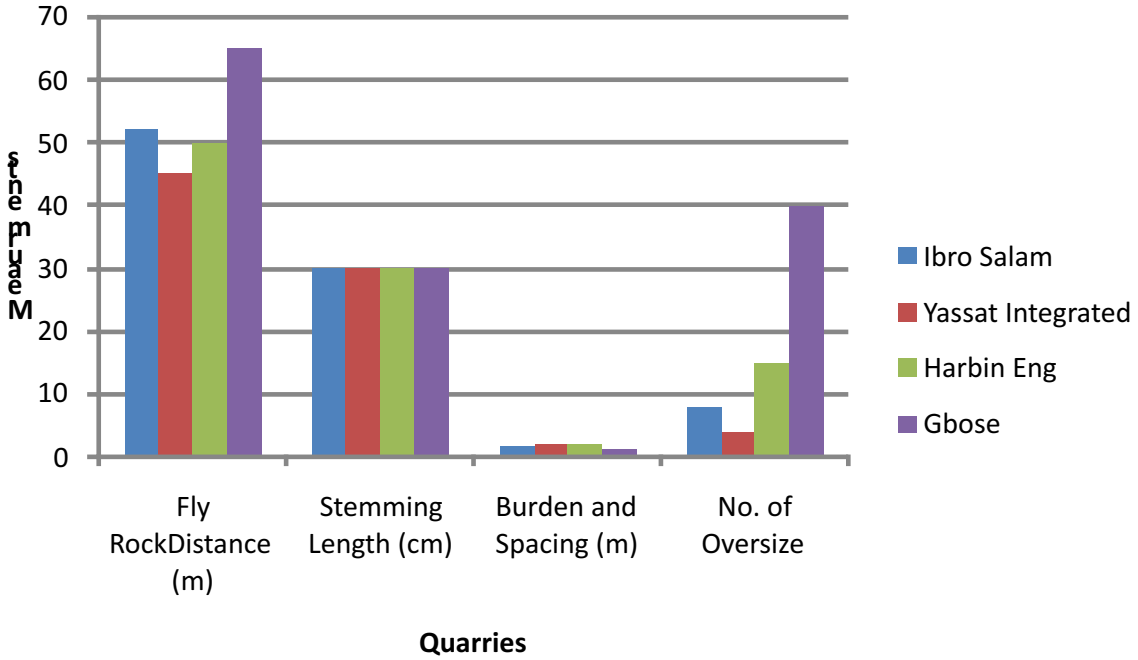

Fig. 3: Comparison of blasting parameter for selected Quarrying

Table 5 and Figure 4depict the productivity of the quarries per day (2007 to date). The major important factors that determine the production rate is the type of equipment used and their capacities. It was discovered that Gbose produces more than what the rest of the quarries produce per day. This means their efficiency is higher than the remaining three quarries. The four quarries operate the same shifting system i.e. 8am – 6pm. almost the same type of drilling equipment is used by all the four quarries but they are different in term of operation and efficiency.

Table 5: Equipment and Productivity

Quarry	No of shift	Output per day	Output from 2009 to date	Drilling machine and capacity
Ibro Salam	One shift 8am-6pm	100 tons per day	115,200 tons	Wagon drill rock 10m/hour compressor 825 psi
Yassat Integrated	One shift (8am– 6pm)	85 tons	97,920 tons	Wagon drill 22m/hr full capacity
Harbin Engineering	One shift (8am-6pm)	150 tons	172,800 tons	Wagon drill compressor 850 psi jackhammer
Gbose	One shift (8am-6pm)	600 tons	691,200 tons	Wagon drill compressor 850 psi, Drilling rig, jackhammer etc

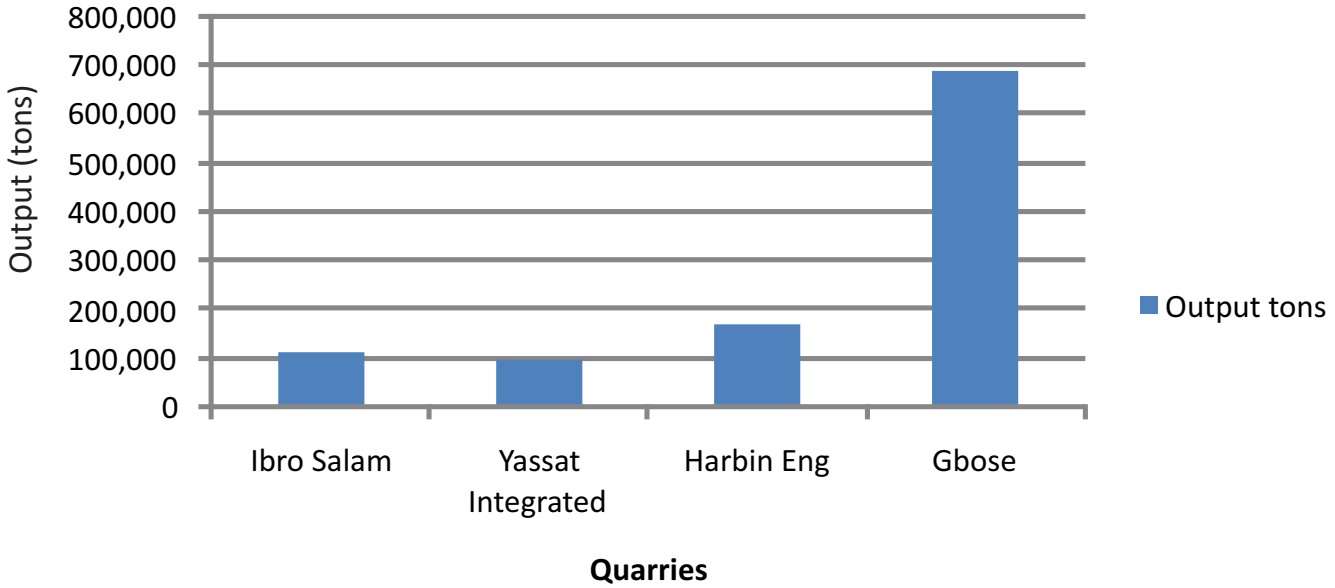

Fig. 4: Output of the Quarries from 2009 to Date

Conclusions

The conclusions made from this work are that, irrespective of the drilling and blasting designs used in all the quarries, they were able to realize their required specific objective which is to produce granite aggregates for engineering applications. The Gbose and Harbin Engineering produced more oversize than other three quarries because they needed low fragmentation. The equipment used in Gbose is of high capacity which made the production higher than the other three quarries. The analysis carried out on the quarries indicates that the techniques and drilling equipment used determined the total output/tonnage values.

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Olaoye, J. O., Olaleye, B .M. & Saliu, M. A.. (2014) Nigerian Mining Journal, 12(1) 8 - 14

Development of Geotech Software Version 1.0 for prediction of slope stability in selected laterite deposit in South West, Nigeria

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Abstract

The paper investigates the slope stability of lateritic soil in seasonal weather condition sat six different locations in south western Nigeria with the development of application package "GeoTech Software version 1.0" using Visual Basic 6.0 programming language for the model to predict their slope stability. The input values for the prediction of factor of safety are cohesion, unit weight, bench height, and friction angle. The output value is factor of safety with respective detail of possible slope failure. The software developed was a user-friendly computer programme for factor of safety calculations and ensures that computational time is kept minimal. The programme written in Visual Basic was tested using regression model generated via Statistical Package for Social Sciences (SPSS). This is for prediction of factor of safety for the selected lateritic deposits. The safety prediction application is recommended for operators handling burrow pit. A situation where possible slope failure is eminent, such operations like extraction and loading should be carried out with minimum bench height.

Keywords: Laterite Exploitation, Slope Circular failure, Factor of safety, Regression and Software Development.

Introduction

Laterite has been defined in various forms according to its physical (particle size distribution, and state of hardening) and chemical properties. In petrology, laterite is defined as a red or brown, superficial deposit of clay or earth which gathers on the surface of rocks and have been produced by their decomposition. For engineering purposes they can be generalized as highly weathered residual soil material resulting from the leaching of bases and silica but rich in concretions of secondary oxides, hydroxides of iron, aluminium and possessing little organic matter though slightly acidic. They can also be conventionally thought of as hard red sandy gravelly clays, as nearly all laterite are rusty red; because of the presence of iron oxides. The remarkable thing about laterite is the effect of its coarse particles on its strength, which is obtained from tests like compaction test, California Bearing Ratio test (CBR), Unconfined Compressive Strength (UCS). (ISRM,1989). Like everything in life that has different composition, laterite exhibits different laboratory and field characteristics which makes it unique.

Lateritic soils are unconsolidated rock fragment on the surface or subsurface of the earth that has been subjected toand shows effects of genetic and environmental factors of climate (including water and temperature effects) and macro and micro-organisms, conditioned by relief, acting on parent material over a period of time. It differs from the material from which is derived in many physical, chemical, and morphological properties and characteristics, (Wiktionary, 2013). In lateritic soil exploitation, particular attention should be paid to its potential slope failure which is a function of the laterite internal friction, cohesion, degree of water saturation and unit weight amongst others.

The work focused on developmentof software application package to predict factor of safety of laterite deposit excavation using the following predictor variables: cohesion, unit weight, bench

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height, and friction angle. These parameters were used for development of a regression model. Since factor of safety is a key to safe and economic exploitation of a mineral deposit, the outcome of the investigation will be useful for laterite quarrying operators and other stakeholders in the mining industry.

Study Area

The study areas cover laterite deposit (borrow-pit) in Ogun, Ondo, and Oyo States all within south-western Nigerian Basement Complex terrain(Fig.1).The coordinates of locations in Ondo State are: Oda (07° 12' 10" N and 005° 12' 52" E) and Oke-Odu (07° 18' 43" N and 005°09' 36" E). The Ogun State location coordinates are: Iperu Remo (06° 53' 16" N and 003° 40'11" E) and Ewekoro (06° 56' 43" N and 003° 12' 09" E). The Oyo State locations coordinates are: Odo - Ona Elewe (07° 19' 23" N and 003° 52' 24" E) and Toll gate (07° 19' 11" N and 003° 52' 31" E). Fig. 1 presents Geological Map of Nigeria showing study areas.

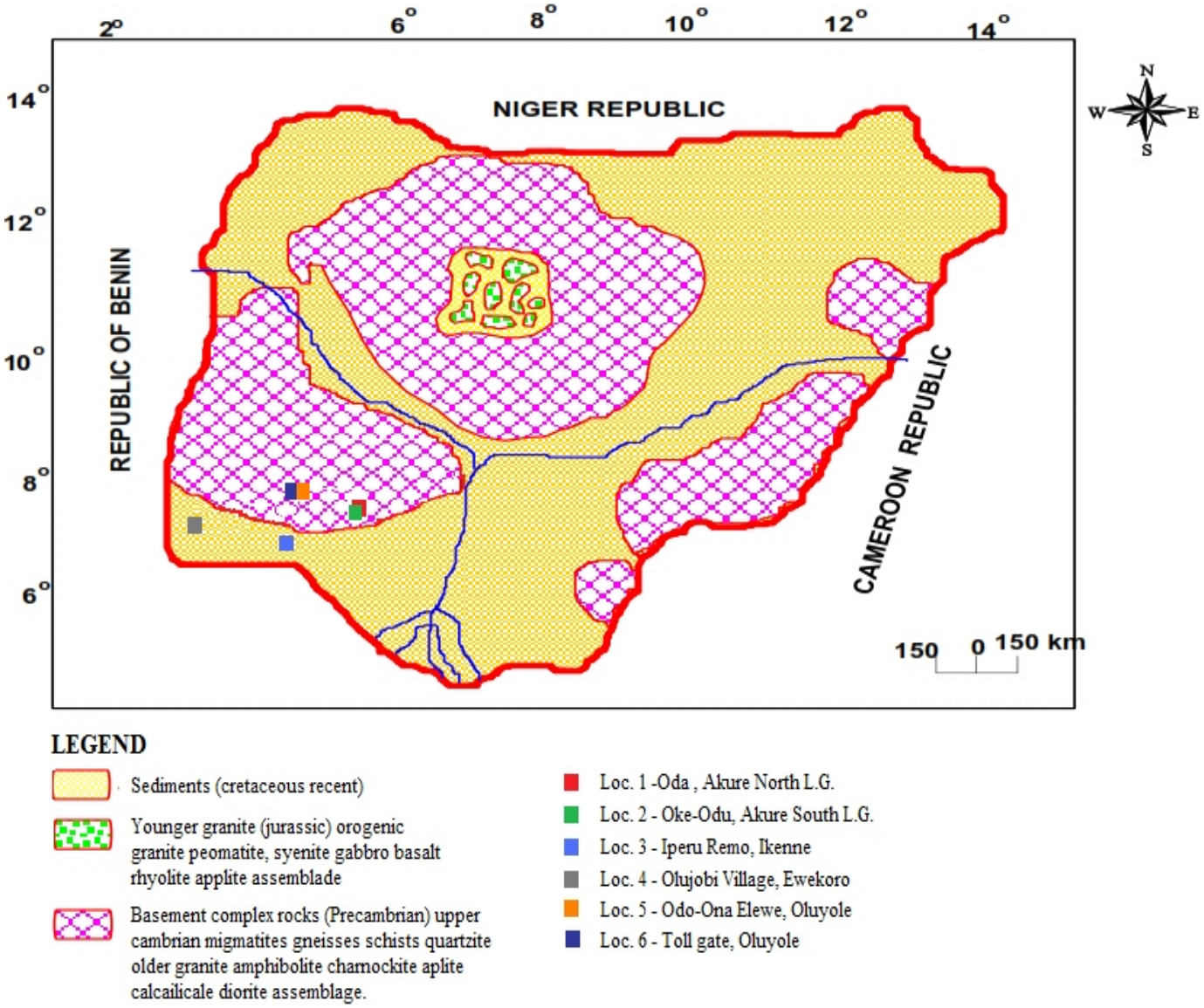


Fig.1. Geological Map of Nigeria showing Study Areas (Source: Adapted from Jegede and Olaleye, 2013).

Research Methodology

Geotechnical Properties of Laterite Soil (Triaxial Compression Test)

The test method covered determination of the strength and stress-strain relationships of a cylindrical specimen of remolded cohesive lateritic soil. The molded specimen was prepared in accordance with ASTM (2003).

The axial strain, ε (expressed as a decimal), for a given applied axial load was calculated using Equation 1;

$$\varepsilon = \frac{\Delta H}{H_0} \quad ...1$$

Where: ΔH is change in height of specimen as read from deformation indicator (m); and H_0 is the height of test specimen minus any change in length prior to loading (m).

The average cross-sectional area, A, for a given applied axial load is calculated using Equation 2;

$$A = \frac{A_0}{(1-\varepsilon)} \quad ...2$$

Where A_0 is the initial average cross-sectional area of the specimen (m); andε is the axial strain for the given axial load (expressed as a decimal), (%).

The principal stress difference (deviator stress), $\sigma_1 - \sigma_3$, for a given applied axial load is calculated using Equation 3;

$$\sigma_1 - \sigma_3 = \frac{P}{A} \quad ...3$$

Where P is the measured applied axial load (corrected for uplift and piston friction, if required), (kPa); and A is the corresponding average cross-sectional area (m).

Correction for rubber membrane assuming units are consistent was computed using Equations 4 and used to correct the principal stress difference or deviator stress for the effect of the rubber membrane.

$$(\sigma_1 - \sigma_3) = \frac{4E_m t_m \varepsilon_1}{D} \quad ...4$$

Where $\Delta(\sigma_1 - \sigma_3)$ is the correction to be subtracted from the measured principal stress difference (kPa); $D\sqrt{\frac{4A}{\pi}}$ is the diameter of specimen (m); E_m is the Young's modulus for the membrane material; t_m is the thickness of the membrane (m); andε_1 is the axial strain (%).

The Young's modulus of the membrane material was determined hanging a 10.0 mm wide strip of membrane over a thin rod, placing another rod along the bottom of the hanging membrane, and measuring the force per unit strain obtained by stretching the membrane. The modulus value was computed using Equation 5;

$$E_m = \frac{FL}{A_m \Delta L} \quad ...5$$

Where E_m is the Young's modulus for the membrane material; F is the force applied to stretch the membrane; A_m is twice the initial thickness of the membrane multiplied by the width of the membrane strip; L is the un-stretched length of the membrane; and ΔL is the change in length of the membrane due to application of F.

$$FS = \frac{(c + \sigma \tan\phi)}{\tau} \quad ...6$$

Where: c is the cohesion (kPa); τ is the total shear (kPa); ϕ is the friction angle; and σ is the total shear stress.

The dimensionless ratio was determined using Equation 7 guided by steps on circular failure chart. (Wyllie and Mah, 2004)

$$FS = \frac{c}{(\gamma H \tan\phi)} \quad]\quad ...7$$

Where FS is the factor of safety; γ is the unit weight (kN/m^3); H is the bench height (m);and

c is the cohesion (kPa).

The corresponding values on both vertical and horizontal axes were used to determine factor of safety as presented in Equation 8 – 9;

$$Dimensionless \quad ratio = \frac{\tan\phi}{FS} \quad ...8$$

and

$$Dimensionless \quad ratio = \frac{c}{\lambda HFS} \quad ...9$$

Design of the software model

The software was compiled using object-oriented programming techniques of Visual Basic 6.0, Microsoft Incorporated (David, 1999). Also, relevant geotechnical parameters equation of the laterite soil was considered. The model was developed to predict the factor of safety which is presented as follows:

The prediction of factor of safety is expressed in Equation 10 as:

$$FS = 2.485 + 0.003c + 0.001UW - 0.053BH + 1.028FA \quad ...10$$

Where *Dependent variable;* FS is the factor of safety; and *Predictor variables:* c is the cohesion (kN/m^3), UW is the unit weight (kN/m^3), BH is the bench height (m), and FA is the friction angle.

Results and Discussion

UndrainedTriaxial Compression Test

The quick undrained triaxial test results carried out on disturbed laterite soil type were presented in Table 1.

Table 1. Quick Undrained Triaxial Test Results

Measurement	Loc. 1	Loc. 2	Loc. 3	Loc. 4	Loc. 5	Loc. 6
Cohesion, kPa	96	82.1	80.3	86.1	95.3	52.3
Angle of friction, deg.	17.5	20.2	17.3	19.4	20.1	14.6
Bulk density, kg/m^3	1587.8	1549.7	1826.8	1691.7	1515.0	2031.2
Unit weight, kN/m^3	15.7	19.9	15.2	17.9	16.6	14.9
Moisture content, %	25.1	26.2	18.2	22.1	27.2	12.3
Max. deviator stress $\sigma_1 - \sigma_3$ kPa (at cell pressure ??, 100 kPa)	358.2	206.7	358.2	312.3	358.2	394.9
Max. deviator stress $\sigma_1 - \sigma_3$ kPa (at cell pressure σ_3, 200 kPa)	450.4	268.3	474.4	397.7	445.6	498.3
Max. deviator stress $\sigma_1 - \sigma_3$, kPa (at cell pressure σ_3, 300 kPa)	542.3	346.9	591.2	493.5	576.5	625.4

The test samples were partially saturated / compacted where the degree of saturation is less than 100 %, consolidation may occur when the confining pressure is applied and during shear, even though drainage is not permitted. Therefore, if several partially saturated laterite soil samples of the same material are tested at different confining stresses, they will not have the same undrained shear strength. Thus, the Mohr failure envelope for unconsolidated undrained triaxial tests on partially saturated soils was usually curved. The unconsolidated undrained triaxial compression test was performed at cell pressures of 100 kPa, 200 kPa, and 300 kPa under standard proctor test according to guideline proposed by Proctor (1933). The cohesiveness of the laterite soil samples was a result of low water absorption during soaking processes thereby reduced the void ratio. The void between laterite soil particles was filled with little moisture and increased the particle bonds. Consequently, the soil was in a firm condition and results in high values of shear parameters. The corresponding water content obtained was lower than the derived optimum water content.

Correlation Model (Slope Stability –Circular Failure)

The Relationship between Factor of Safety and Bench Height

The basic parameters required for the derivation of factor of safety using circular failure charts as well as GeoTech Softwareare presented in Table 2 and Table 3 respectively.

Table 2. Factor of safety (using Circular Failure Charts)

Location	Cohesion, kPa	Unit weight, kN/m^3	Bench height, m	Friction angle, (tanθ)	Factor of safety
Loc. 1	96.0	15.7	15.2	0.3153	2.30
Loc. 2	82.1	15.2	12.0	0.3679	2.47
Loc. 3	80.3	17.9	10.0	0.3115	2.49
Loc. 4	86.1	16.6	12.0	0.3522	2.50
Loc. 5	95.3	14.9	20.5	0.3659	2.03
Loc. 6	52.3	19.9	42.0	0.2605	0.68

Table 3. Computed Factor of Safety (using GeoTech Software)

Location	Cohesion, kPa	Unit weight, kN/m^3	Bench height, m	Friction angle, (tanθ)	Factor of safety
Loc. 1	96.0	15.7	15.2	0.3153	2.31
Loc. 2	82.1	15.2	12.0	0.3679	2.49
Loc. 3	80.3	17.9	10.0	0.3115	2.53
Loc. 4	86.1	16.6	12.0	0.3522	2.49
Loc. 5	95.3	14.9	20.5	0.3659	2.08
Loc. 6	52.3	19.9	42.0	0.2605	0.70

Model Implementation

The implementation of the empirical application model consists of the design of the system, the procedure (input and output) and analysis of the system. In this research, the "GeoTech Software version 1.0" developed was implemented using Microsoft Visual Basic 6.0 application language as the front end as an event – driven programming language which has evolved as a result of Graphical User Interface (GUI) provided by the windows operating system. The programme flow chart is presented in Fig. 2.

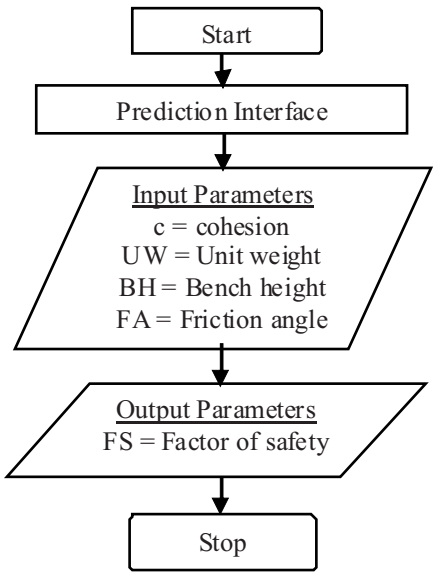


Fig. 2. Flow Chart for the GeoTech Software program

Input

The user enters required input values, the analysis carried out, in order to achieve the desired result.

Analysis

This section handles successive entered data by analysing the raw data to achieve desired result, comprehensive codes have been written for the program. The program computes less than 2 seconds depending on the speed of the system processor.

Output

The software is designed such that the geotechnical parameters are outputted

numerically and factor of safety description details inclusive.

Examples to illustration of the use of the software (GeoTech Software)

To illustrate the effectiveness of the software package, the following numerical examples were considered.

Example:

The following parameters are:cohesion, unit weight, bench height and friction angle were considered. The laterite sample cohesion is 52.3 kPa with friction angle of 14.6^0(0.2605). The unit weight value 19.9 kN/m^3 while the bench height is 42.0 m. Prediction of the laterite deposit factor of safety was deduced thus.

Solution:

The given input values are:

Cohesion = 52.3 kPa, unit weight = 19.9 kN/m^3, bench height = 42.0 m, and friction angle = 14.6^0(0.2605). Factor of safety =?

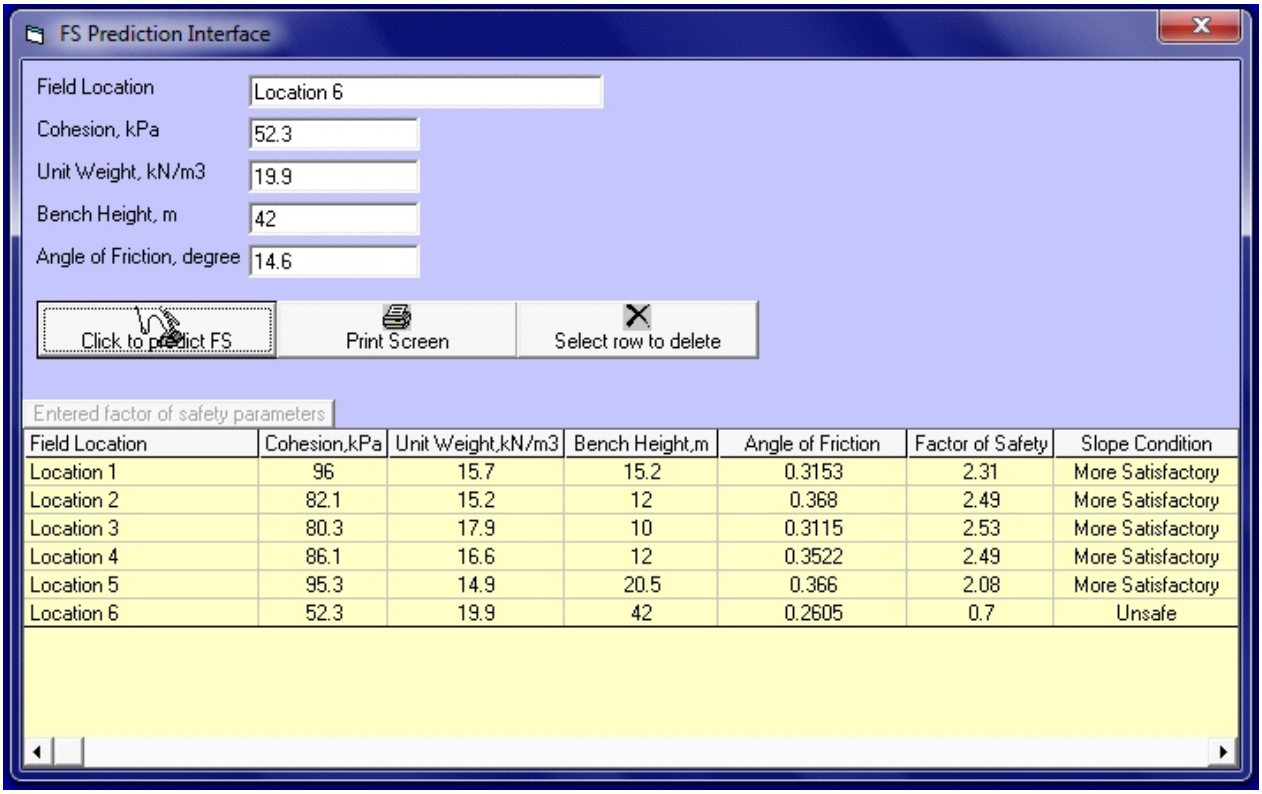
The output from the software for this analysis is:

Factor of safety = 0.70

The software also presents respective slope condition details:

Slope condition: “Unsafe”

The display of the solutions for the iterations is shown in Fig.3.



Field Location	Cohesion,kPa	Unit Weight,kN/m3	Bench Height,m	Angle of Friction	Factor of Safety	Slope Condition
Location 1	96	15.7	15.2	0.3153	2.31	More Satisfactory
Location 2	82.1	15.2	12	0.368	2.49	More Satisfactory
Location 3	80.3	17.9	10	0.3115	2.53	More Satisfactory
Location 4	86.1	16.6	12	0.3522	2.49	More Satisfactory
Location 5	95.3	14.9	20.5	0.366	2.08	More Satisfactory
Location 6	52.3	19.9	42	0.2605	0.7	Unsafe

Fig. 3.Factor of Safety Prediction Model using GeoTech Software

The GeoTech software has a user-friendly interface and interactive for prediction of factor of safety when appropriate input parameters are supplied. The modelling approach was based on linear regression analysis. The software was designed in such a way that errors are detected if data was wrongly entered.

Conclusions

The study conducted on the stability of lateritic soil (borrow-pit) in seasonal weather conditions brought to focus the need to perform an effective stress analysis. The factor of safety relationship with bench height indicates that the higher the bench height, the higher the possibility of slope failure of the lateritic soil (borrow pit).The model could be useful in determination of a workable bench height for the extraction and loading operations in Laterite excavation. The prediction model provides database on factors that affects stability of the lateritic

deposit with projection of essential area of possible slope failure.

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Thomas D. G., Yaro S. A., Oyeladun O. A. W. & Salawu O. A. (2014) Nigerian Mining Journal, 12(1) 15 - 24

Metallization of some Nigerian iron ores: Toto-Muro, Itakpe and Koton-Karfe iron concentrates using Obi and Okaba coals

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Abstract
The metallization of beneficiated Toto Muro, Itakpe and Koton Karfe iron concentrates using Okaba and Obi coal samples was investigated. The Toto Muro, Itakpe and Koton Karfe iron ores samples were obtained from the iron ore deposits in Toto, Itakpe and Koton Karfe Local Government Areas of Nasarawa and Kogi States respectively. The iron ore samples in lump sizes were crushed, pulverized and analyzed to obtain their chemical compositions using XRD. The analyses revealed that the head sample of Toto Muro iron ore has 33.5% Fe, 54.14%SiO_2, Itakpe iron ore has 36.88%Fe, 44.80SiO_2 and Koton Karfe iron ore has 43.40%Fe, 10.14%SiO_2 respectively. The pulverized various samples were sieved and concentrated using their established liberation sieves particle sizes fractions and their most suitable adoptable methods of separations. The various concentrates obtained from the various established separation methods established for the respective iron ores samples were assayed for their iron and silica contents respectively. Toto Muro iron concentrate has 57.19% Fe , 8.26% SiO_2 , Itakpe iron concentrate has 64.0%Fe, 31.0%SiO_2 and Koton Karfe iron concentrate has 69.10%Fe, 0.41%SiO_2 respectively. The various concentrates were metalized using up-graded Okaba and Obi coals samples at 1200°C for 2 hours in a muffle electric heating furnace with temperature range of 0-1300°C. The degrees of metallization of the various specimens produced using the various iron concentrates were calculated and found to be 98.79, 70.63 and 62.66% for Toto-Muro, Itakpe and Koton-Karfe using upgraded Okaba, and 88.23, 89.85 and 91.17% on the averages for Toto-Muro, Itakpe and Koton Karfe using as-recieved Obi coking coals samples respectively. The values obtained for the degrees of metallization of the respective iron concentrates using upgraded Okaba and as-received Obi coking coals samples respectively meets the requirements for iron making using direct process route as cited in the literature.

Key words: metallization, iron concentrates Obi and Okaba coals.

Significance of the Research Work: the technology for metallization route for the production of spongy iron from Toto Muro, Itakpe and Koton Karfe iron concentrates will be developed and the utilization of Okaba and Obi coal deposits will be enhanced and through such, job opportunities will be created for the increasing teeming population and also conservation of foreign exchange for the importation of coke will be reduced.

Introduction
Iron and steel industries are the basic foundation for the technological development of any country. A country that neglects iron and steel will ever remain undeveloped and technologically backward in its national development plan. As a result of the realization of the importance of the iron and steel industries and with the intention of laying a formidable foundation for technological take-off of the country, the Government of the Federation in 1971 established the Aladja and Ajaokuta iron and steel projects. Although, the establishment of these projects was laudable, inadequate attention was given to the development of the raw materials to feed the plants even though Nigeria is endowed with large reserves of proven and unproven iron-ore, coal and other raw materials required for the production of iron and steel scattered all over the country (Uwadiale, 1989). As a result, for example the Aladja iron and steel plant on commissioning in early eighties had to depend on foreign sources of iron

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concentrates and coke. Not until recently, with the efforts of the National Ore Mining Project Itakpe, National Metallurgical Development Centre, Jos and individual researchers that a process flow sheet has been developed for the beneficiation of the Itakpe iron ore deposit, estimated at 200 million tonnes to be upgraded and used as feedstock in Ajaokuta and Aladja iron and steel plants (Uwadiale, 1989).

Individuals and other research Institutions have also worked on other locally available iron ore deposits for example Aladja iron ore deposit (Uwadiale, 1989). This is the largest iron ore deposit in the country estimated at over 1 billion tonnes and has been established to possess extremely fine-grained texture and hence has to be ground to -5m in order to achieve substantial degree of liberation. At such extremely fine size, most conventional beneficiation techniques such as froth flotation, magnetic and gravity concentration processes cannot be used to separate the iron oxides from the gangue minerals. Comminuting the ore to that extremely fine particle size, most especially iron ore will be uneconomical because of its market value (Thomas, 2002). In addition, it has a very high phosphorous content, which has discouraged its utilization to date. Attempt has also been made on the beneficiation Agbodo Okudo iron ore deposit (Uwadiale, 1989). The investigation revealed that the ore could be upgraded to a standard concentrate using a combination of gravity and magnetic concentration techniques. The liberation sizes, sieves sizes fractions and most suitable adoptable concentration techniques used in beneficiating the Itakpe, Toto-Muro and Koton –Karfe iron ores samples used for this research work were on the basis of the results findings published by Thomas and Yaro, 2007 in some journals.

Furthermore, with these vast deposits of iron ores, the country could not verily ascertain whether or not her vast coal deposits could be used as reducing agent in the metallization of the country potential iron ores deposits for iron and steel making. Hence, for Nigeria to succeed, in its efforts to develop the indigenous iron and steel industries and hence attain technological development and economic self-reliance, it has thus become necessary to investigate the utilization of some Nigerian coal deposits for iron making.

Currently, new technology for iron making that utilizes coal only as the reducing agent beside the blast furnace route are on the increase and example of these technologies in use are the SL (Stelco-Lurgi process using Rotary Kiln without recycle scrap charge), FASTMELT and HYL (Hojalata Y Lamina) are exploited to produce iron metal. On the basis of the above, prompted this research work with the hope of producing metalized (spongy) iron for steel making.

Metallization is a form of direct reduction applies to processes in which reduction and the resulting metalized spongy iron occurs below melting temperature and the product is in a solid form. This characterized direct reduction from other processes such as a blast furnace route in which melting temperatures are attained and the products are molten pig iron and molten slag usually called hot metal. Metallization of metal is measured by the degree of metallization of the metal, expresses in percentage and defined as the percentage of metal or reduced iron to the total iron content in the concentrate (Obaje and Abba, 2002).

Furthermore, metallization is the science of the production of metals from their concentrates by application of the principles of pyrometallurgy, hydrometallurgy or electrometallurgy. Pyrometallurgy which has found application in the metallization of iron ore concentrates is to be used for the purpose of this research work. It involves the use of heat energy where coke, charcoal or hydro carbon are used as the sources of heat energy and at the same time reducing agents required for metallization process prior to steel making direct method of iron making. Before then, the ore mineral and the reducing agents have to be beneficiated in order to reduce the gangues associated with them.

In metallization process of iron concentrates, iron concentrates or nodules (40-60% Fe_T) is charged with coke, lime,

limestone or dolomite, sometimes scraps and blast air into the furnace where the iron concentrates are reduced to spongy or metallic iron(Maigini, 2008).

Metallization reactions using coal (Carbon)

$$3Fe_2O_{3(s)} + C_{(s)} \longrightarrow 2Fe_3O_{4(s)} + CO_{(g)}\uparrow \quad \ldots 1.0$$

$$Fe_3O_{4(s)} + C_{(s)} \longrightarrow 3FeO_{(s)} + CO_{(g)}\uparrow \quad \ldots 1.1$$

$$FeO_{(s)} + C_{(s)} \longrightarrow Fe_{(s)} + CO_{(g)}\uparrow \quad \ldots 1.2$$

(Thomas, 2002)

$$\text{Degree of metallization} = \frac{\%\ \text{assay of metallized iron}}{\%\ \text{Assay of concentrate}} \quad \ldots 1.3$$

Directly reduced iron metal is a remarkable new iron source for steel making, there are two main groups of processes for direct reduced iron productions: (i) a gas based process using natural gas as a reducing agent, for example, the MIDREX and the HYL (Hojalata Y Lamina) processes. (ii) a coal-based process which uses coal as a reductant, for example the SL/RN (Stelco-Lurgi process using Rotary Kiln without recycle scrap charge). The gas-based process is already a well-known process, but it is necessary to have easy access to natural gas which for now is difficult to attain. The direct reduced iron process, where carbon composition and iron concentrate pellets are heated rapidly in a rotary hearth furnace, for example the FASTMELT process (Rotary Hearth or Electric Melter) is much better than the process using natural gas or the process operated in a rotary kiln. The advantages of this process seems to be that location of plant is less limited due to the use of coal as reductant and plant investment is low. Hence, make the production of steel economical from the adoption of the latter process as an option (Maigini, 2008).

The country is blessed with up to 3 billion tonnes of iron ores deposits that cut across the Niger and Benue troughs of the country, some investigated fully, while others are partially investigated. Table 2.1 gives the various iron ores deposits in the country and Table 2.2 gives the chemical composition of some major Nigerian iron ore deposits (RMRDC, 2000).

Nigerian coal available data shows that coal (are mainly sub-bituminous seam coals, except for the Lafia-Obi that is a bituminous coking coal) occurrences in Nigeria have been indicated in more than 22 coal fields spread over 13 states of the Federation. The proven coal reserves so far in Nigeria total about 661 million metric tons while the inferred reserves sum up to 2.75 billion metric tons (Damisa, 2001).

There are five economically important seams of sub-bituminous coal so far recognized in Nigeria of which most are located in the south – east and middle belt of the country. Table 2.3 gives the summary of coal deposits in Nigeria and shows that Nigeria has over 2.5 billion metric tonnes of coal with proven reserves of about 661 million metric tonnes out of which about 25million metric tonnes have been mined.

Metallurgical Requirement for Coke/Coal as Metallization Agent

Coke is a solid carbonaceous residue derived from low ash, low sulphur bituminous coal from which the volatile constituents are driven off by baking in an oven without oxygen at temperatures as high as 1,000^{0}C (1,832^{0}F) so that the fixed carbon and residual ash are fused together. Metallurgical coke is used as a fuel and as a reducing agent in smelting iron ore in blast furnace. Coke from coal is grey, hard and porous and has a heating value of 24.8million btu/ton (29.6mj/kg) (Tastsch, 1980 in Damisa, 2001).

The primary essential in the selection of coking coals is its chemical analysis composition. It is required at frequent intervals in order to ensure maintenance of quality ones the coal has been selected. In the American standard for testing and measurements (ASTM) classification, the ranks of most coking coals are defined by their proximate analysis and the heating value determination. A proximate analysis including moisture, ash, sulphur and sometimes phosphorus also shows the grade of a coal (see Tables 2.4 and 2.5). A good coking coal or blend must possess the correct combination of swelling, coking and plastic properties so that during heating

would cause the coal particles to fuse together to form a strong coherent mass, which fractures a long planes of weakness to leave a preponderance of pieces in the 20mm size range on cooling (Damisa, 2001).

Individually, the above coking data serve only to indicate the coals potential for coke manufacture. A confident prediction of coals performance in the coke oven can only be made after more extensive testing. Prime coking coals would exhibit properties in the upper part of the ranges mentioned. The best metallurgical coke would be found from gray king types G4 – G9. The coke pieces must be resistant to further abrasion and size degradation, be un-reactive and contain less than 10% ash, 1% sulphur and only traces of phosphorus or complete elimination of it. Coals outside this range can be blended with high range coking coal (Damisa, 2001).

Caking Power

The behaviour of coal on heating is of special importance and many methods have been suggested for its definition and measurement. One of these is the Gray king method. Coal (20g passing a 72 B.S. sieve) is carbonized under standard conditions to 600^{0}C. If the carbonized residue is porous with no sign of coherence, the term “non caking type A” is assigned. Coal which gives a hard, compact, non fissured coke of the same volume as the original coal is termed A, while the intermediate letters designated coals whose coke friability decreases within this range, coals of higher caking power are blended with 72 mesh carbon to give a coke corresponding to type a and termed A1 to G10 respectively, the subscript members indicating the corresponding to type G and termed G1 to G10 respectively, the subscript members indicating the number of grains of coke necessary in the 20g blend((Mathias, 2008, Damisa, 2001)).

Types of coke from Gray King Assay

A, B	Non-caking
C, D	Very weakly caking
E, F, G (G_1, G_2, G_3, G_4)	Medium caking
G_5 – G_8	strongly caking
G_9 and over	Very strongly caking

Gray King	A	B	C	D	E	F	G	G_1	G_2	G_3	G_4	G_5	G_6	G_7	G_8	G_9
Swelling Index	1	½	2			3	4	5		6	7	8		8	9	

Figure 1.0: Types of coke from Gray-King Assay (Damisa, 2001).

Materials and Method

Materials

The materials used are sodium carbonate, Obi and Okaba coals samples, Itakpe, Koton Karfe and Toto Muro iron concentrates.

Sample collection and Preparation

10 kg each of the sample of Toto Muro, Itakpe and Koton Karfi iron ores and coals samples were sourced from their various deposits located in Nasarawa and Kogi states respectively. The iron ore samples were pulverized, sieved to their required liberation size and beneficiated using their established published most suitable adoptable concentration techniques. The various iron concentrates obtained and the beneficiated various coals samples were assayed for iron and silica contents using XRF; fixed carbon, ash, moisture and volatile maters contents using proximate analysis respectively. The results are presented in Tables 2.8 and 2.9 of this paper.

Equipment

Electric heating furnace with control temperature ranges, platinum crucible, electrical weighing balance, Denver magnetic separation, Denver pulverizing machine, Denver laboratory shaking and XRF analytical machines.

Method

Metallization of Toto-Muro, Itakpe and Koton-Karfe Iron Concentrates using Okaba and Obi Coal Samples Respectively

2 grams of Toto-Muro iron concentrate was mixed with the upgraded Okaba coal and lime to form a paste (Table 2.11). The paste was placed into crucibles and inserted into an electric furnace. The electric furnace was switched on and allowed to reach the temperature of 1200°C after which the crucibles containing the paste were inserted into the electric furnace and heated for one hour. After one hour, the crucibles were removed from the furnace and cooled at room temperature. The molten paste specimens were taken for chemical analyses using XRF and the result of the degree of metallization was computed using equation 1.3. The same procedures were repeated for Itakpe and Koton Karfe iron concentrates respectively and also with Obi coal respectively. The results of the metallization tests are given in Table 2.10 of this paper.

Discussion of Results

The chemical analyses of Toto-Muro, Itakpe and Koton-Karfe iron ores samples.

The chemical analyses of Toto-Muro, Itakpe and Koton-Karfe iron ores samples are given in Table 2.9. The Toto-Muro iron ore has 33.60%Fe and 54.14%SiO_2, Itakpe has 36.88%Fe and 44.80%SiO_2 and Koton-Karfe has 43.40%Fe and 10.14%SiO_2 on the average. Comparing the chemical compositions of the head samples of the various iron ores used for this research work to other four (4) major iron ores given in Table 2.2 revealed that the percentage of phosphorous peroxide (P_2O_5) in Toto-Muro(0.3%), Itakpe (0.18%) and Katon-Karfe (2.14%) are less and moderately compared favourably with that of Agbado-Okudo (2.08%) and Bassa-Nge (1.45%) respectively. Also, the percentage of sulphur of the Toto-Muro, Itakpe and Koton-Karfe iron ore samples are moderately less and lies closely to that of the four (4) major iron ore deposits. The sulphur contents of Toto-Muro, Itakpe and Koton-Karfe iron ores are within the acceptable limit of 0.20% required for iron making. Also, the proportion of 54.14%SiO_2 of the Toto-Muro iron ore is high compared to that of Bassa-Nge (8.28%), Katon-Karfe (10.14%), Itakpe (44.80%) and Agbado Okudo (10.89%). The silica contents of the iron ores samples could be drastically reduced during beneficiation and slag formation (Wills, 1985; Kudrin, 1985). Therefore, the low and moderate phosphorus, low and high percentages of silica contents of some of the iron ore samples do not pose any threat to their utilization in iron and steel plants. The proportions of the chemical compounds in Toto Muro, Itakpe and Koton Karfe iron ores are within the acceptable limit required for iron and steel making (Kudrin, 1985).

Proximate analyses of the Okaba and Obi coals samples.

The tests of the qualities of the coals are given in Tables 2.7 and 2.8. The results compared favourably with the literature values cited in Tables 2.4 and 2.5. From results, the selectively leached and inoculated Okaba coal has high percentage of fixed carbon compared to that of Obi coal as indicated in Tables 2.7 and 2.8; this could be attributed to the absorption of the fossil fuels into the matrix of the Okaba coal during treatment before being used as a reducing agent. Hence, this action increased the proportion of the fixed carbon content in the Okaba coal sample compared to the untreated Obi coking coal sample used also in the metallization process. See also Table 2.10.

Metallization of Toto Muro Iron Concentrate using Okaba Coal.

The Koton-Karfe, Itakpe and Toto-Muro iron

concentrates were metalized using the beneficiated Okaba and Obi coals as reducing agents. Table 2.10 gives the % assays of the spongy (metalized) iron of the various specimens A, B, C, D and E and the corresponding degrees of their respective metallization of the various iron concentrates used in this research work. From the result, the % assays of iron in the metalized specimens E and F of the Toto-Muro iron concentrate sample was found to be 56.60% Fe with corresponding degrees of metallization of 98.79% on the average for the specimens E and F respectively using Okaba coal as the metalizing agent. 50.45%Fe was found as the assayed of iron on the average in the metalized specimens E and F with 88.23% on the average as the corresponding degree of metallization for the same iron concentrate using Obi coal sample as the metalizing agent respectively. The values obtained for using Okaba coal sample as a metalizing agent are higher compared to that of Obi coal and the metalized values of 90 to 91% cited in the literature. This phenomenon could be attributed to the improved properties of the Okaba coal by selective leaching and inoculation using fossil fuels (Kerosene and diesel oils as inoculants) to increase its carbon content before being used as a reducing agent. This action enhanced the prompt response of the Toto Muro iron concentrate to the reactive characteristic of the inoculated Okaba coal compared to that of Obi coal. Since carbon is the principal source of energy and the reducing agent that aid metallization in iron ore reduction. The higher the percentage of associated combustible carbon alongside fixed carbon in coal, the better its reducibility property as stated in the literature (Mathias, 2008). The degrees of metallization obtained for Koton Karfe and Itakpe specimens A and B, C and D are found to be 91.17 and 89.85% on the average respectively. These values are higher compared to those obtained using Okaba coal as a metalizing agent for the same Itakpe and Koton Karfe specimens. This phenomenon could be attributed to the high percentage of the fixed carbon contained in the Obi coal compared to that of Okaba coal, hence, its high reducibility potential compared to Okaba coal. The results also obtained compared favourably with those cited in Table 2.6.

Conclusion

On the basis of the results obtained in this research work, it can be concluded that high degree of metallization was achieved for using the selective leached and inoculated Okaba coal than the as-received Obi coking in the reduction of Toto Muro iron concentrate while high degrees of metallization was achieved using the as-received Obi coking coal for the reduction of Itakpe and Koton Karfe iron concentrates than the selectively leached and inoculated Okaba coal. Though both coals degrees of metallization compared favourably with those values of degrees of metallization cited in the literature. Hence, both coals have to be upgraded before utilization in metallization process for iron and steel making.

Recommendation

(i) It is recommended that Okaba coal should be blended with other coals to determine the degree of their metallization using local iron concentrates.

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Table 2.1: Estimated reserves and quality in terms of iron content of some iron ore deposits in Nigeria are given in table below

Location of Deposit	Quality in terms of Fe content (% Fe)	Estimated Reserves in Million tonnes	Distance from Ajaokuta steel complex (km)
Itakpe	40.45	200	66
Ajabanoko	40.00	60	70
Agbaja	44.50	98	100
Enugu	32.00	20	400

Source: Ajaokuta Steel Company Limited published Report (1985)

Table 2.2: Chemical Composition of some Nigerian iron ore deposits

Deposit	K_2O	CaO	TiO_2	MnO	FeT	Mg0	Al_2O_3	SiO_2	P_2O_5	S
Chokochoko	0.53	0.15	0.16	0.08	34.45	0.18	9.67	51.07	0.02	0.007
Agbado-Okudu	0.04	0.72	0.37	0.14	47.80	0.38	9.60	10.89	2.08	0.12
Ajagbaoko	0.26	0.21	Trace	0.01	37.22	0.15	3.39	46.50	0.01	0.03
Bassa Nge	0.02	0.17	0.17	0.13	46.90	0.40	8.28	8.28	1.45	0.05

Source: RMRDC (2000)

Table 2.3: Coal deposits in Nigeria and their reserves

State	Location	Indicated in-situ (million tonnes)	Inferred reserves (million tonnes)	Overall reserve (million tonnes)
Enugu	Enugu Ezimo Inyi	54 56 20	200 60 Unknown	254 116 20
Kogi	Okaba Ogboyoga	73 107	250 320	323 427
Benue	Otukpo Ogboyoga	57 107	75 320	132 427
Delta Nassarawa Gombe	Asaba Obi Maiganga	250 22 22	Unknown Unknown Unknown	250 22 -
		661	905	1544

.Source: (Aderibigbe, 1989, Damisa ,2001)

Table 2.4: Summary of characteristics of good coking coal/coke

Parameter	Desire	Typical limit	Comments
Total moisture %	5 – 10	12	Limited for easy handling and grinding
Volatile matter (%)	Various	16 – 21 21 – 26 26 – 31	Low volatile coals Medium volatile coals High volatile coals
Total sulphur (air dry)	Low %	0.6 – 0.8	Sulphur content of coke should be low to limit take- Zip of sulphur by pig iron in blast furnace.
Free swelling index	7.9	Min. 6	
Roga index	60 – 90	Min. 50	
Gray king coke	G6 – G14	Min. G4 – G5	
Dilatometry	25 – 70 80 – 140 150 – 350	Min. 20 Min. 60 Min. 100	Low volatile coals Medium volatile coals High volatile coals
Plastometry Fluidity range	Min. 80 Min. 100 Min. 130	Min. 70 Min 80 Min. 100	Low volatile coals Medium volatile coals High volatile coals

Source: Aderibigbe, (1989) in Damisa, (2001); Eugene, (2008)

Table 2.5: Specifications for blast furnace coke/coa

Volatile matter	0.75 – 2% by weight
Ash	7.0 – 9.0% by weight
Sulphur	0.65 – 1% by weight
Shatter test (on 5cm)	70 – 78% by weight
Drop number	4
Drop resistance	4
Porosity	7-10%
Size	7 – 12cm
Fixed carbon	48.91 – 90%
Moisture content	Below 5%
Calorific value kcal/kg	7,652
Phosphorus	0.007%
Total Reactive	97.6%

Source: Weiss, (1985); Eugene, (2008).

Table 2.6: Chemical composition of metalized iron metal requirement

	Percentage (%)	Lumps	Fines
Fe (total)`	90-92	91.50	92.00
Fe (metallic)	81 – 84	80.00	82.00
Metallization	90.00	88.00	90.00
Sulphur	0.03	0.04	0.04
P_2O_5	0.05	0.45	0.45
Carbon	0.10	0.20	0.25
Gangue	6.80	5.00	5.00

Source: WWW.Trimilaspongy Iron.Org. (2008).

Table2.7: Proximate analysis of Okaba coal.

Proximate Analysis	Unwashed (%)	Selective Leaching /Inoculation (%)
Moisture (%)	9.56	1.22
Ash (%)	10.12	1.56
Volatile matter (%)	13.59	5.46
Fixed carbon (%)	65.97	80.35
Phosphorus	0.034	0.034
Sulphur (%)	0.72	0.045

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Table 2.8: Result of the chemical analysis carried out on as-received Obi coal using proximate method of analysis.

Item	Percentage
Fixed Carbon	52.64%
Sulphur	4.01%
Phosphorus	0.0081%
Moisture	7.99%
Volatile matter	24.62%
Ash	10.73%

Table 2.9: Chemical analysis of head sample

Ore	Fe_T	SiO_2	CaO	Na_2O	P_2O_5	S	Al_2O_3	V_2O
Toto Muro	33.6	54.14	2.39	0.28	0.3	0.20	0.12	0.08
Koton Karfe	43.40	10.14	1.23	-	2.14	-	-	-
Itakpe	36.88	44.80	0.30	-	0.18	0.05	1.00	-

Table 2.10: Degrees of metallization of the various types of iron concentrates reduced using Obi and Okaba coals samples

Type of Concentrate		Period of Reduction (hr.)	% Assay of Conc.	Wt. of Conc.	Type of Coal					
					Obi Coking			Okaba		
	Specimen				Wt (g)	% Fe in Spongy metal	% Degree of Metallization	Wt (g)	% Fe in Spongy metal	% Degree of Metallization
Koton Karfe	A	1.0	69.1	20	2.0	62.80	90.88	2.0	43.30	62.66
	B	1.0	69.1	20	2.0	63.20	91.46	2.0	43.30	62.66
Itakpe	C	1.0	64.0	20	2.0	57.00	89.10	2.0	45.20	70.63
	D	1.0	64.0	20	2.0	58.00	90.60	2.0	45.20	70.63
Toto Muro	E	1.0	57.1	20	2.0	50.60	88.48	2.0	56.50	98.79
	F	1.0	57.1	20	2.0	50.30	87.95	2.0	56.50	98.79

Table 2.11: Weight of charge materials required on the basis of material balance

Sample	Coal (g)	Iron ore (g)	Sodium carbonate as flux (g)
1	2.0	20	11.5

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Comparative Analyses of Changes in the Physicochemical Properties of Natural and Stockpiled Topsoils of Okaba Coal Mine in Kogi State, Nigeria

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Abstract
This study was carried out to investigate the changes in the physicochemical properties of natural and stockpiled topsoils of Okaba coal mine during mining operations. The two coal different topsoils were delineated by grid techniques respectively and samples were collected between 0 - 40c m depths. The physicochemical properties of the soils were determined using standard methods of testing and the results obtained were compared. The results showed that there were significant changes in the two different topsoils with the natural topsoil having an average pH of 6.7, electrical conductivity of 0.56 (µs/cm), moisture content of 7.35%, bulk density of 1.48g/cm^3, available nitrogen content of 33.40mg/kg and phosphorus content of 16.71mg/kg while stockpiled topsoil has a pH of 5.7, electrical conductivity of0.89 (µs/cm), moisture content of 4.05%, bulk density of 1.82g/cm^3; available nitrogen content of 13.82mg/kg and phosphorus content of 6.44mg/kg. It was deduced from the results that almost all the physicochemical properties of the natural topsoil were within the range of Food and Agricultural Organization (FAO) standard values while those of the stockpiled topsoils significantly deviated from standard values. The study therefore concludes that the nutrients from the stockpiled topsoil samples have been degraded and not good for agricultural purposes and recommended that the soil should be treated before it could be used for the proposed reclamation.

Keyword: Coal mining, mine, natural topsoil, physicochemical properties, stockpile

Introduction

Coal was first discovered in 1909 near Udi (central eastern Nigeria). In 1950, the Nigerian Coal Corporation (NCC) was formed and charged with the responsibility of exploring, developing and mining the coal resources (MMSD, 2012). The NCC, which is 100% owned by the Federal Government of Nigeria with the headquarters in Enugu, operated two underground mines (Okpara and Onyeama) and two surface mines (Orukpa and Okaba) all located on the eastern edge of the Anambra Coal Basin (Hinton, 2005). Between 1950 and 1959, coal production in the Enugu mines increased annually from 583,487 tonnes to a peak of 905,397 tonnes. After 1959, production decreased significantly each year including the Civil War period of 1966 to 1970 when no coal production was reported(Obaje, 2005). Production in the 1980s was less than 100,000 tons annually and decreased further in the 1990s. Much of this production was utilized by the Nigerian railway Corporation while some smaller tonnages were exported. NCC has not operated any coal mine for several years.

In the process of coal mining, the topsoil is removed and stockpiled for reclamation before it is re-vegetated. During topsoil storage, many of the attributes of the natural topsoil are modified leading to the degradation of the quality of agricultural soils resulting from the disruption of soil structure and increase in soil bulk density (Hill, 1979). Stripping and storage of topsoil is a characteristic of most mining engineering operations. The most immediate effect of stripping soils is compaction caused by a combination of the passage of heavy equipment and shear

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force during lifting of the soil (Bukrinski, 2000). The longer the stored soil remains in place the more the surface will be subjected to invasion by widely dispersed and undesirable open ground weed species.

Evidence of accumulation of various chemicals in the stripped and stored topsoil is the accumulation of ammonium that is usually found within the topsoil stored below a certain depth which depends on soil type and initial moisture content. Harris and Birch (2006) observed that there was an increase in the availability of metals, particularly iron and manganese, in conjunction with accumulation of ammonium which shows that anaerobic conditions prevail within the stockpiles, below a surface aerobic zone. Organic carbon decreases with increasing depth and time of storage (Harris and Birch, 2006). The purpose of this study is to assess changes in the physicochemical properties of natural and stockpiled topsoils of Okaba coal mine.

Methods and Materials

Description of the study Area

Operations at Okaba coal surface mine was commenced recently by Zuma 828 Coal Limited in Ankpa Local Government Area of Kogi State. The opening of Zuma Coal Mines in Okaba was necessitated to bolster the country's electricity generation capacity with coal (Douglas, 2012). Okaba has a total area of approximately 208,500 hectares of which 145,600 hectares were overlaid with coal (Nwajiuba, 2000). Okobo community has a total population of 4,280. The area is in the humid regionof Nigeria with annual rainfall of 1, 400 mm with biomedial peak in June and September (Nwajiuba, 2000). The area consists of a wooded savanna region bisected by the southward-flowing River Niger and Benue with a major tributary of the Niger, forming part of the State's northeastern border. The major inhabitants of the area are the Igala, Ebira and Yoruba tribes. Agriculture is the mainstay of the economy of the people in the area. The major crops in the area include yams, cassava (manioc), rice, sorghum, beans, corn (maize), and cotton. Fishing and coal mining are also carried out in the area (Nwajiuba, 2000).

Field Sampling

Natural and stockpiled topsoil of Okaba coal mine were delineated by grid techniques and samples were collected with spade between 0 - 40cm depth as shown in Figure 1. Each of the sampled soil was placed in a clean container where clods were removed. The samples were crushed and bulked to make composite samples per depth. 1kg of each of the samples was transferred into a clean plastic bag and the bags were properly labeled before being taken to the Postgraduate Laboratory, Federal University of Technology, Akure, Ondo State for analysis.

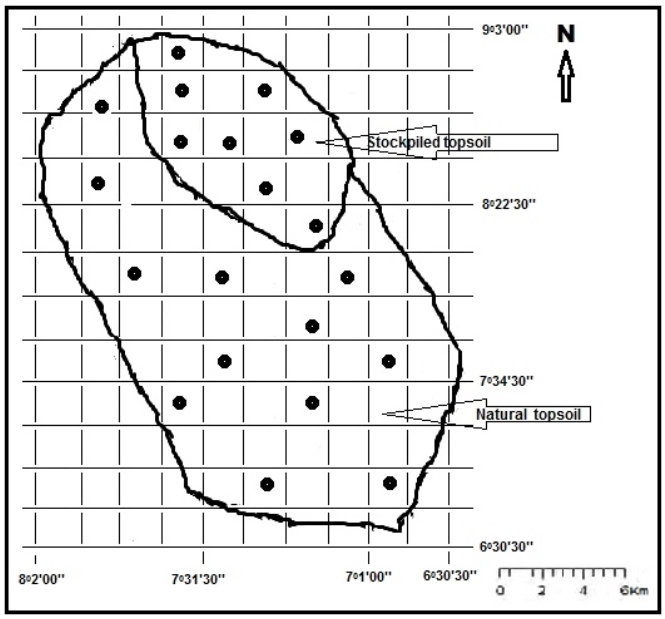

Figure 1: Study Area showing the sample locations

Laboratory Analysis

In the laboratory, each of the samples was air-dried, ground and sieved with 2mm mesh. Soil pH was measured with pH meter using a soil/water ratio of 1:2 (Ghosh., et al 1983) and electrical conductivity was measured with a conductivity meter using ratio of 1:5(Bower and Wilcox, 1965). The soil moisture content was determined by gravimetric method (Gee and Bauder, 1986) while soil texture was determined by

Bouyoucos hydrometer method (Bouyoucos, 1936). Soil bulk density was determined using the core method as described by Blake and Hartge, (1986), particle density was determined by the pycnometer method (Blake and Hartge, 1986) and total porosity was determined by the difference between bulk density and particle density (Blake and Hartge, 1986). Organic carbon, available nitrogen, phosphorus and potassium were determined using Walkley and Black method (Nelson and Summers, 1982), alkaline permanganate method (Keeney and Bremer, 1966) and Bray method (Bray and Kurtz, 1966) respectively. The soil micronutrients (Iron, Zinc, Manganese, and Copper) were determined by Atomic Absorption Spectrophotometer (AAS) model AA 6800 equipped with Zeaman background correction and graphite furnace.

Result and Discussion

The analyses of different physicochemical properties of natural and stockpiled topsoil of Okaba coal mine shows that there were noticeable changes in their values as shown in Table 2.

Table 2: Physicochemical Properties of Soil Sample

Physical Property	**Natural Topsoil**	**Stockpiled Topsoil**
Soil Texture	Sandy loam	Sandy-clay
Moisture Content (%)	7.35	4.05
Particle Density (g/cm^3)	2.62	2.99
Bulk Density (g/cm^3)	1.48	1.82
Porosity (%)	44	39
Carbon Content (%)	1.43	0.58
Chemical Property	**Natural Topsoil**	**Stockpiled Topsoil**
Soil pH	6.8	5.7
Electrical conductivity (µs/cm)	0.56	0.89
Available Nitrogen (mg/kg)	33.40	13.82
Available Phosphorus (mg/kg)	16.54	6.46
Available Potassium (mg/kg)	322.53	141.68
Iron (mg/kg)	4.94	3.43
Zinc (mg/kg)	1.42	0.83
Manganese (mg/kg)	1.23	0.60
Copper (mg/kg)	0.65	0.33

Physical Properties

Soil texture

The result of the analysis shows that soil texture has changed from sandy loam in the natural topsoil to sandy clay in the stockpiled topsoil. The increase in sand content in both samples could be accredited to the geologic formations of the study area (Igwe *et al,* 1999). The sandy loam texture of natural topsoil is good for agricultural purposes because it can hold enough water and nutrients that can sustain plants' growth while the sandy clay texture in the stockpiled topsoil cannot hold enough water and nutrients that can sustain plant growth.

Moisture content

Moisture content is the amount of water present in the soil. The average value of moisture content of natural topsoil (7.35%) is higher than stockpiled topsoil (4.05%). This is because there is less soil compaction in the natural topsoil when compared with the stockpiled topsoil. As a result of this,

natural topsoil retains more water that penetrates deeper than stockpiled topsoil which is good for plants' growth.

Soil bulk density

Soil bulk density is the mass of oven-dried solids divided by the bulk volume of the solids plus pore space at specified soil water content (Braddy and Well, 2002). Bulk density is a useful parameter, as it indicates soil structure and void space. It is required to calculate porosity when particle density is known. High bulk density is one of the factors that create physical barrier to root growth and development along with water flow (Braddy and Well, 2002). In the sampled soils, the average value of bulk density of natural topsoil (1.48g/cm3) was found lower than stockpiled topsoil (1.82g/cm3) due to the presence of higher value of organic matter in the natural topsoil. The higher bulk density in the stockpiled topsoil could be due to compaction as a result of heavy equipment used during soil stockpiling which created a medium that is impenetrable to plant roots.

Soil Porosity

Soil porosity is the ratio of the space taken up by pores in a soil to its total volume. It depends on the particle density as well as bulk density (Blake and Hartge, 1986). Low porosity decreases the amount of air and water that soil can hold. The natural topsoil of the investigated area has higher porosity value (44%) than stockpiled topsoil (39%) this could be due to higher organic carbon content and low bulk density in the natural topsoil which give the soil the ability to get enough air and water that can stimulate plant growth.

Soil carbon content

Carbon content increases both the physical and chemical properties of soil and has several beneficial effects on agricultural soil quality. It improves soil structure, enhances aeration, water penetration, and increases water-holding capacity and supplies nutrients for growth of plants (Saxena, 1987).Brenner *et al* (1984)found that organic matter and soil moisture were the primary factors limiting tree and shrub establishment. In the investigated area, the natural topsoil has higher carbon (1.43%) than stockpiled topsoil (0.58%) due to higher amount of microbes, humic substances, and decomposed weeds within the topsoil.

Chemical Properties

Soil pH

pH is a good measure of acidity and alkalinity of soil water suspension and it provides a good identification of the chemical nature of soils (Sharma, 2008). The pH of soil solution carries nutrients such as Nitrogen (N), Potassium (K) and Phosphorus (P) that plants need in specific amounts to grow and fight off diseases (Sharma, 2008). In the investigated sites, the pH of natural topsoil is higher than stockpiled topsoil due to oxidation of pyrite particles in the soil samples

Soil electrical conductivity (EC)

Electrical conductivity (EC) is the most common measure of soil salinity and is indicative of the ability of an aqueous solution to conduct electric current. The EC value depends on the dilution of the soil suspension, total salts and sodium content. In the investigated sites, the EC in the stockpiled topsoil (0.89 (µs/cm) is higher than that of the natural topsoil (0.56 (µs/cm)due to upward migration of different salts through fissures within the soil samples. The higher value of EC causes contamination to the plants and prevents them from obtaining water from the soil.

Soil macronutrients

Nitrogen (N) is the most important element for plant development. The higher nitrogen values (33.40mg/kg) obtained at natural topsoil was due to higher amount of mineralized organic nitrogen present in the soil samples while the lower values (13.82mg/kg) obtained at stockpiled topsoil site was due to loss of organic carbon which contains nitrogen and nitrogen fixing microorganisms in the soil samples.

Phosphorus (P) is an essential

macronutrient element for plant growth. Large amount of phosphorus is required for plant development. The average value of phosphorus content (6.46mg/kg) in the stockpiled topsoil site is lower compared with that of the natural topsoil (16.54mg/kg) due to acidic nature of the soil which restricted the microbial activities and resulting to very poor mineralization process of the soil.

Potassium (K) is an essential nutrient for plant growth. In the investigated soil, the potassium content of the natural topsoil is higher than in the stockpiled topsoil due to better weathering and mineralization process in the soils.

Soil Micronutrients

The following metallic micronutrient elements iron (Fe), zinc (Zn), Manganese (Mn) and copper (Cu) that is essential for plant growth were analyzed. These micronutrients are available in the soil due to continuous weathering of minerals mixed with primary minerals. The average values of these micronutrient elements in the stockpiled topsoil were lower than in the natural topsoil due to the acidic nature of the soil. The micronutrient elements were dissolved in the soil acidic solution to form toxic contaminants that deter plant growth (Barcelo and Poshenrieder, 2003). The average values of micronutrient elements obtained in natural topsoil are within ecologically sustainable reclamation standard (Lindsay and Norvell, 1978)

Conclusion and Recommendation

It was discovered from the study that there are significant changes in natural and stockpiled topsoil of Okaba coal mine. In all the stockpiled topsoil sampled, the concentrations of physicochemical properties (pH, moisture content, organic carbon, available nitrogen, phosphorus, potassium and so on) were found to be lower than those of the natural topsoil. The study therefore concluded that the stockpiled topsoil of Okaba coal mine was not environmentally safe for plantation, vegetation and agricultural purposes.

The study recommends that the acidic stockpiled topsoil of Okaba coal mine should be improved by planting metal tolerant plants that can grow in nutrient deficient soils with high metal content. Also, planting of grasses and trees of different species, rotating with legumes and native species should be done in the stockpiled topsoil of Okaba coal mine to restore the soil fertility. The stockpiling of subsequent topsoil should be carefully handled so that its physical and biological characteristics can be protected. The productivity of subsequently stored topsoil should be increased by adding various amendments such as hay, saw dust, bark mulch, wood chips, wood residues, sewage sludge, animal manures to stimulate the microbial activity which provides the nutrients (N, P) and organic carbon to soil.

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Influence of mineralogical composition on physico -mechanical properties of selected granite rocks in Ogun State, Nigeria

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Abstract

The influence of mineralogical composition on physico-mechanical properties of some selected granite rocks in Ogun State was investigated. In-situ and laboratory tests were conducted on the granite samples from four different locations – Milatex, CCECC, Jia Bao and CNC within the State. Schmidt hammer was used to carry out in-situ test while mineralogical compositions of the rock samples were determined in the laboratory using modal analysis. The rock samples were prepared for the determination of density, porosity, point load index and uniaxial compressive strength. The percentage microcline present ranged from 28.6 - 36.0 %; biotite present ranged from 7.7 - 23.9 %; hornblende present ranged from 0 - 25.4 %; quartz present ranged from 22.4 - 53.8 %; plagioclase feldspar present ranged from 20.9 – 71.4 %; orthoclase feldspar present ranged from 5.1 - 9.6 %; and 5.1 % mymakite present in CNC only. The average density of granite samples ranged from 2.69 - 2.71 g/cm^3 while average porosity ranged from 2.33 - 3.93 % classified as low porosity. The average uniaxial compressive strength value of granite samples ranged from 52.5 - 172.5 MPa classified having averagely high strength. The average point load index of granite samples ranged from 1.95 - 2.94 MPa classified as averagely medium strength, while average tensile strength ranged from 2.92 - 4.40 MPa which falls under high strength. The granite rock samples from quarries have good engineering properties for the construction of roads, dams, structures and other social amenities.

Keyword: Textural properties, mechanical properties, mineral composition, granite.

Introduction

Granite technically refers to a light-coloured granulose plutonic rock composed of felspars, plagioclase, quartz (felsic minerals) and minor amounts of mafic minerals, such as biotite, hornblende, pyroxene, iron oxides, etc. Rock can equally be defined as mixture of one or more different minerals (Barton *et al*., 1974). It has no definite chemical composition. The author defined rock further as an aggregate of fixed or compressed discreet mineral particles.

Being more resistant to wear and tear as well as weathering, granite is most sought-after stone to be used as building as well as decorative stone. The fascination for granite is due to its taking mirror-like polish, high compressive strength, longevity and beauty. In recent years granite has experienced a marked revival in use, most obviously as external cladding to steel or concrete framed structures. Against this background, there is a growing requirement from construction professionals for an increased understanding of physical, mechanical and durability properties of any granite proposed for use in construction.

It should be noted that physical properties do not only vary from rock to rock, rock location to rock location but also within the same rock mass because of the heterogeneous nature of rocks and various local geological condition. In addition to the direct properties of the rock and rock masses as described above, we have to

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remember that the natural rock environment can also have a profound effect on engineering properties of rock. In general, this is basically governed by the location, i.e. whether a structure is being built on the surface or is being created by excavation of the surface rock or is underground (Hoek and Brown, 1988). For the purpose of this project work, the influence of mineralogical composition on physico-mechanical properties of granite rock which makes it suitable for engineering applications is investigated

Description of the Study Area

The study area falls within the south west of Nigeria. Milatex Genework Company Limited is located in Ijebu East Local Government Area, CCECC Limited is located in Ijebu North Local Government Area, Jia Bao Quarry Limited is located in Obafemi/Owode Local Government Area, while CNC Engineering Company Limited is located in Odeda Local Government Area all in Ogun State.

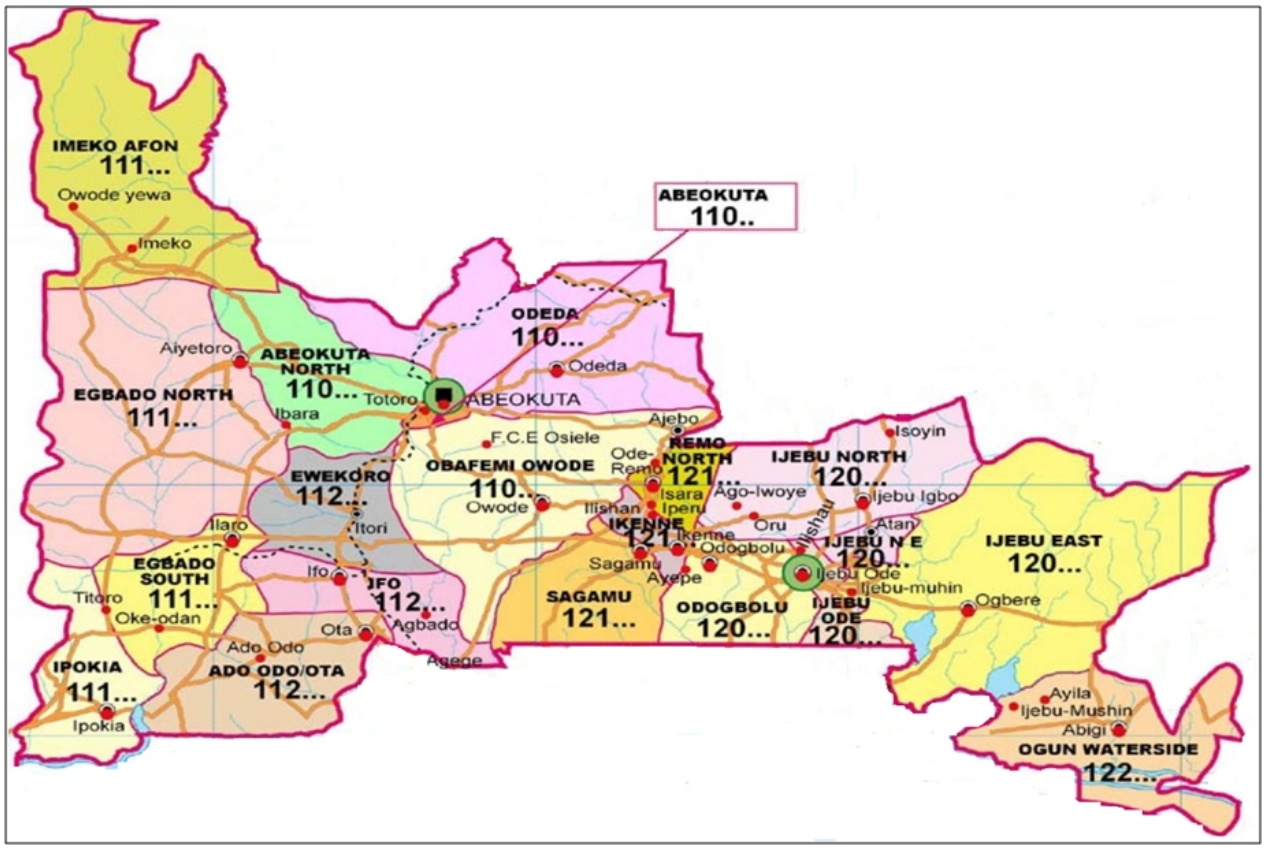

Figure 1: Map of Ogun State showing the study areas (source: NIPOST)

Materials and Methods

Determination of Mineral Composition

The thin sections prepared from the rock samples were viewed under a polarizing microscope, a modal analysis was used to determine and estimate the mineral composition of the rock samples and the photomicrograph of the samples were taken as presented in Tables 1-4 and Plates 1-4. The mineral composition was determined at the laboratory of Department of Geology, Federal University of Technology, Akure.

Determination of Density

The densities for the rock samples were obtained from the samples weighed and recorded. Water was poured inside the cylinder and the volume was noted as V_1 (cm^3) and the sample was dropped in the water in the cylinder and the volume were recorded as V_2 (cm^3). The change in volume

was calculated as $(V_2 - V_1)$ cm^3. The density was calculated from Eq. (1) as shown in Table 5.

$$\rho = \frac{M}{\Delta V}(g/cm^3) \qquad ...1$$

Where M is mass in g and ΔV is the change in volume in cm^3.

Determination of Porosity

Porosity was determined using saturation and buoyancy technique as suggested by ISRM (1989). The representative samples comprising at least 4 lumps of irregular geometry, each having a mass of at least 50g was prepared. The sample was saturated by water immersion in a bath with periodic agitation to remove trapped air for a period of at least 24 hours. The procedure adopted is according to ISRM and ASTM standards. The pore volume and porosity were determined using Equations 2 and 3.

$$\text{Pore Volume, } V_v = \frac{M_{sat} - M_s}{\rho_w} \qquad ...2$$

Where: ρ_w is the density of water in g/cm^3, M_{sat} is the mass of saturated sample in g and M_s is the mass of dry sample in g.

$$\text{Porosity, } \phi = \frac{100V_v}{V}\% \qquad ...3$$

Where: V_v is the pore volume in cm^3 and V is the bulk volume in cm^3.

Determination of Hardness

Hardness test involves the use of Schmidt Hammer of type L for the determination of the hardness of *in situ* rock. The rebound value of the Schmidt Hammer is used as an index value for the intact strength of rock material, but it is also used to give an indication of the compressive strength of rock material (ISRM, 1981). The standard method for the Schmidt Hammer test as described by ISRM (1981) and ASTM (1994) was adopted.

Determination of Uniaxial Compressive Strength (UCS)

The uniaxial compressive strength test is most widely used measure of the strength, deformation and fracture characteristics of the rock. The UCS values were estimated by using the chart named after Deere and Miller (1966).

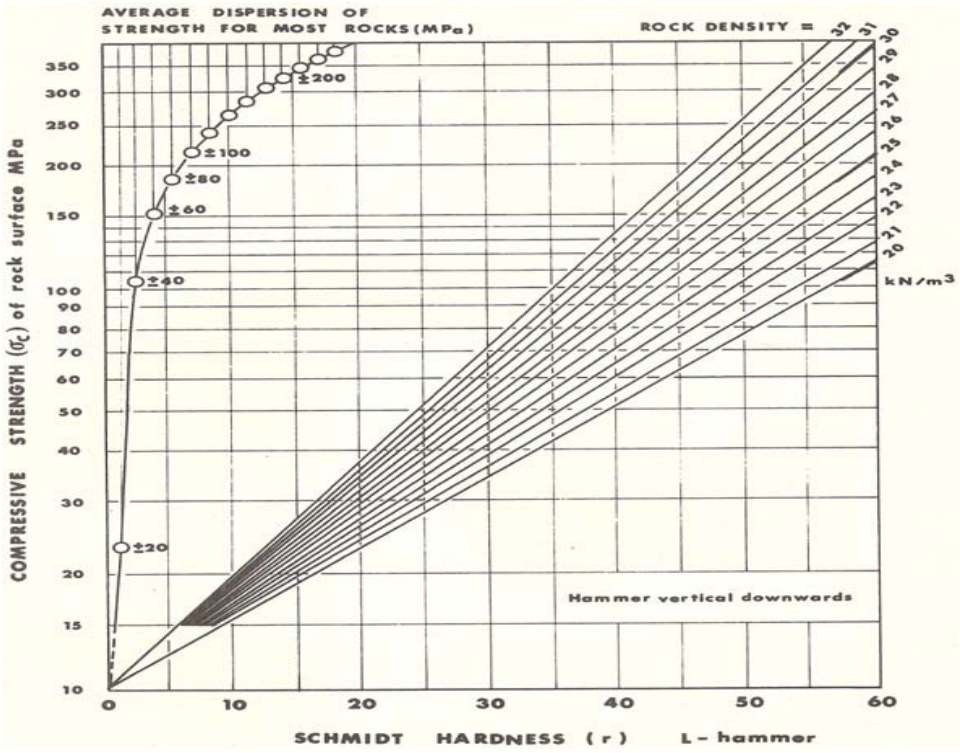

Figure 2: Correlation Chart for Schmidt (L) Hammer, Relating Rock Density, Compressive Strength and Rebound Number (After Deere and Miller, 1966).

Determination of Point Load Strength

The point load testing machine was used for the strength determination of rock samples. The samples used were of irregular shapes. Since the sample tested do not have a diameter of 50mm, the point load index has to be corrected to standard strength indices as proposed by Broch and Franklin (1972). Load at failure is recorded as P. Uncorrected point load strength, I_s, was calculated as written in Equation 4:

$$I_s = \frac{P}{D_e^2} \qquad ...4$$

The uncorrected point load strength index is corrected to the point load strength at equivalent core diameter of 50mm, for $D_e \neq$ 50mm; the size correction factor is given using (ISRM, 1985) in Equation 5:

$$F = \left(\frac{D_e}{50}\right)^{0.45} \qquad ...5$$

F is the size correction factor, P is the load at failure in kN, $I_{s(50)}$ is the point load index value for a standard core diameter (D) of 50mm in MPa and D_e is the equivalent core diameter in mm. The corrected point load strength index, $I_{s(50)}$ is calculated as stated in Equation 6:

$$I_{s(50)} = FI_s \qquad ...6$$

Determination of Tensile Strength

The tensile strength can be determined from the relationship between the point load strength ($I_{s(50)}$) and tensile strength (T_o) according to Brook (1993) and ISRM (1989) as shown in Equation 7:

$$T_0 = 1.5I_{s(50)} \qquad ...7$$

Results and Discussion

The result of the mineral composition is presented in Table 1 while Tables 2 – 6 present strength parameters. Also, photomicrograph of rock samples was presented in Plates 1 – 4.

Table 1: Mineral Composition of Selected Rocks

Minerals	% Prop. Milatex	% Prop. CCECC	% Prop. Jia Bao	% Prop. CNC
Quartz	0	22.4	53.8	33.3
Biotite	0	23.9	7.7	20.5
Plagioclase	71.4	20.9	28.9	0
Orthoclase	0	7.4	9.6	5.1
Microcline	28.6	0	0	36.0
Hornblende	0	25.4	0	0
Mymakite	0	0	0	5.1

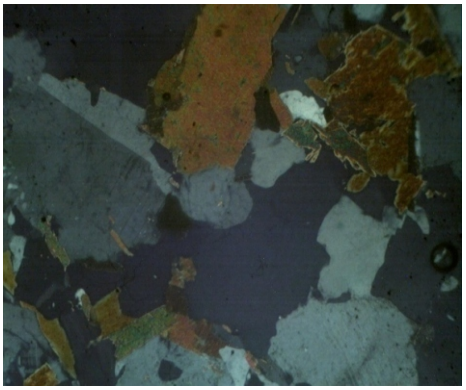

Plate 1: Photomicrograph of Milatex Rock

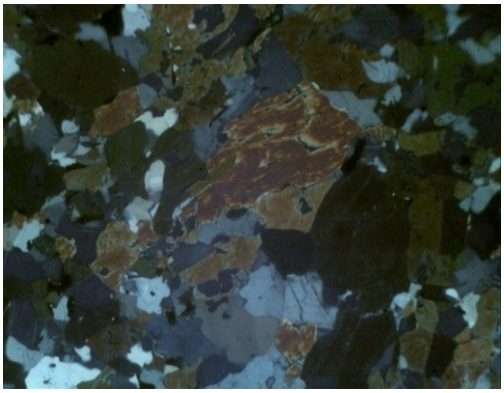

Plate 2: Photomicrograph of CCECC Rock

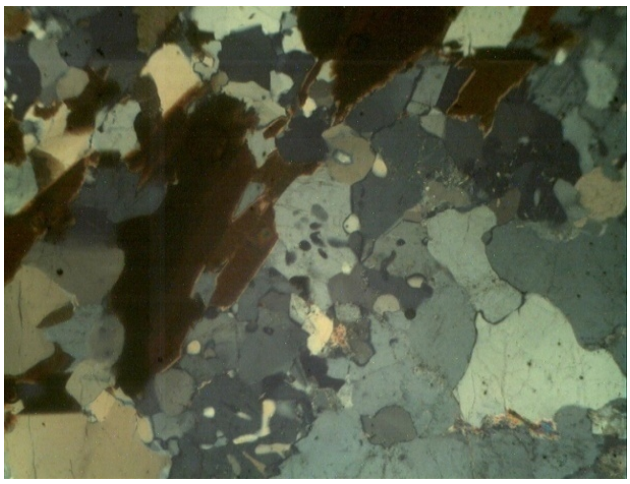

Plate 3: Photomicrograph of Jia Bao Rock

Plate 4: Photomicrograph of CNC Rock

Table 2: Density of Selected Rocks

Granite Location	Density (kg/m^3) Milatex	Density (kg/m^3) CCECC	Density (kg/m^3) Jia Bao	Density (kg/m^3) CNC
Sample 1	3.08	2.77	2.69	2.69
Sample 2	2.67	2.62	2.75	2.63
Sample 3	2.56	2.73	2.62	2.82
Sample 4	2.51	2.62	2.69	2.65
Average	2.71	2.69	2.69	2.70

Table 3: Porosity of Selected Rocks

Granite Location	Porosity (%) Milatex	Porosity (%) CCECC	Porosity (%) Jia Bao	Porosity (%) CNC
Sample 1	2.81	3.40	3.40	2.27
Sample 2	3.27	2.63	4.22	2.39
Sample 3	2.42	3.42	4.04	2.37
Sample 4	2.02	2.78	4.04	2.29
Average	2.61	3.06	3.93	2.33

Table 4: Uniaxial Compressive Strength of Selected Rocks

Granite Location	UCS (MPa) Milatex	UCS (MPa) CCECC	UCS (MPa) Jia Bao	UCS (MPa) CNC
Sample 1	220	80	75	190
Sample 2	150	100	55	150
Sample 3	180	80	35	170
Sample 4	140	90	45	150
Average	172.5	87.5	52.5	165

Table 5: Point Load Index of Selected Rocks

Granite Location	Milatex (MPa)	CCECC (MPa)	Jia Bao (MPa)	CNC (MPa)
Sample 1	1.14	2.67	2.56	2.66
Sample 2	3.33	2.03	1.08	1.60
Sample 3	2.55	4.61	2.26	4.87
Sample 4	2.15	2.36	1.88	2.63
Average	2.29	2.92	1.95	2.94

Table 6: Tensile Strength of Selected Rocks

Granite Location	Milatex (MPa)	CCECC (MPa)	Jia Bao (MPa)	CNC (MPa)
Sample 1	1.71	4.01	3.84	3.98
Sample 2	4.10	3.04	1.63	2.40
Sample 3	3.82	6.91	3.40	7.30
Sample 4	3.22	3.54	2.83	3.94
Average	3.21	4.37	2.92	4.40

From Table 1, the results of mineralogical composition of rock samples obtained from four different quarries. Milatex quarry samples have 28.6% microcline and 71.4% plagioclase respectively. CCECC quarry samples have 23.9% biotite, 22.4% quartz, 20.9% plagioclase feldspar, 7.4% orthoclase feldspar and 25.4% hornblende respectively. Jia Bao quarry samples have 7.7% biotite, 53.8% quartz, 28.9% plagioclase feldspar and 9.6% orthoclase feldspar respectively while CNC quarry samples have 36.0% microcline, 20.5% biotite, 33.3% quartz, 5.1% orthoclase feldspar and 5.1% mymakite respectively.

Physical Properties

From Table 2, the results of the density determined from laboratory analysis conducted on the rock samples from Milatex, CCECC, Jia Bao and CNC. The results of the analyses show that the value of density vary from 2.51 - 3.08 g/cm^3, 2.62 - 2.77 g/cm^3, 2.62 - 2.75 g/cm^3 and 2.63 - 2.82 g/cm^3 respectively. From the results obtained, Milatex have the highest density as a result of high feldspar content while Jia Bao, as high quartz content of the rock.

From Table 3, the porosity of the rock samples from Milatex, CCECC, Jia Bao and CNC. The results obtained from the analyses show that the porosity vary from 2.02 - 3.27 %, 2.63 - 3.42%, 3.40 - 4.22% and 2.27 - 2.39% respectively. Jia Bao has highest porosity as a result of low strength of the rock from this study area.

Mechanical Properties

From Table 4, the uniaxial compressive strength values of samples from Milatex, CCECC, Jia Bao and CNC which range from 140 - 220 MPa, 80 - 100 MPa, 35 - 75 MPa and 150 - 190 MPa respectively. It was deduced that the uniaxial compressive strength varies from high to very high strength according to ISRM (1985) classification.

From Table 5, the results of point load index value for samples from Milatex, CCECC, Jia Bao and CNC which varies from 1.14 - 3.33 MPa, 2.03 - 4.61 MPa, 1.08 - 2.56 MPa and 1.60 - 4.87 MPa respectively. It was classified from medium to high strength according to ISRM (1985) classification.

From Table 6, the results of tensile strength determined from point load index using relation generated by Brook (1993) and ISRM (1989). The tensile strength varies from 1.71 - 4.10 MPa, 3.04 - 6.91MPa, 1.63 - 3.84 MPa and 2.40 - 7.30 MPa respectively.

Conclusion

This research work analyzed the influence of mineralogical composition on physico-mechanical properties of selected granite rocks in accordance with ASTM and ISRM standards. In situ and laboratory tests were conducted on the granite samples. In Milatex, CCECC, Jia Bao and CNC, the percentage microcline present ranged from 28.6 - 36.0%, quartz 22.4 - 53.8%, plagioclase feldspar 20.9 - 71.4%, orthoclase feldspar 5.1 - 9.6%. The result of average density shows that granite rock value ranged from 2.69 - 2.71 g/cm^3. The average porosity of granite rock ranged from 2.33 - 3.93%. The result of average porosity indicates low porosity for the four locations. The strength characterization of the granite rock has average uniaxial compressive strength value ranged from 52.5 - 172.5 MPa, classified as high strength. The results of average point load index of granite samples ranged from 1.95 - 2.94 MPa, classified as averagely medium strength. The result of average tensile strength of granite samples ranged from 2.92 - 4.40 MPa classified as high strength. It was concluded that all the rock samples tested have good physical and mechanical properties.

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Chemical and mineralogical analysis of Akiri copper ore

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Abstract
The chemical and mineralogical analysis of Akiri copper ore was executed via chemical analysis using x-ray fluorescence and the thin sections under petrological microscope. Qualitatively it was revealed that the copper type was malachite (CuO) while quantitatively it was established as 2.5%Cu. Other elements detected include 39%Fe, 13.6%S, 6.11%Si, 1.7%Al, 3.1%Mo, whereas K, Ca, Ti, Cr, Mn, Ni, Ba, La, Eu, Yb and Zr were less than 1% in content. The studies recommended further investigation on the deposit as the copper content showed a lot of prospect having surpassed the minimum economic grade of 0.5% Cu element in an ore.

Keywords: Copper, Akiri, Mineralogical, Microscope, x-ray, fluorescence

Introduction

Development and advancement of nations are intimately related and tied to the level of development of natural resources. The advancement and sophistication in nuclear technology (both for war and peace), agriculture, medicine and other areas of human endeavours owe a lot to mineral resources exploitation (Usaini et al, 2014).

Mineral depositions can be considered as naturally occurring substances existing in association with other substances formed as a result of geological processes (Hibbard, 2002). This nature of occurrence of most minerals as co-associates with other materials necessitated the characterization of their compositions for the purpose of establishing an insight into the status of valuable parts and the unwanted associates.

It has been established that Nigeria is endowed with mineral resources that are metallic, non-metallic, industrial, as well as energy generation varieties (Anon., 2012). However, the nature of these minerals types in a deposition ought to be established in order to facilitate the downstream enrichment processes. These processes are no doubt relative to the nature of the composition, for example copper's existence as chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS), malachite ($CuCO_3.Cu(OH)_2$), cuprite (Cu_2O), etc. is a typical case.

The extraction of specific valuable minerals from their naturally occurring ores is variously termed as “ore dressing” “mineral dressing” and “minerals beneficiation”. For most metalliferrous ores produced by mining operations, beneficiation is an important intermediate step in the transformation of natural ore to pure metal (Craig and Vaughan, 1981). Hence, it is imperative that the key to successful beneficiation of an ore is greatly attached to the amount of information available on the nature and properties of the various components making up the ore. Cognisant of the fact that achieving the aforementioned step is usually relative to the chemical and mineralogical studies of an ore; this work was conducted with the purpose of investigating such parameters of Akiri copper ore as demand for copper concentrate is on the increase. The justification by Yue (2009) indicated that, the sharp increase in copper consumption in the world due to the rapid development of Chinese economy, makes it one of the most important materials that are widely used in industries. Furthermore, the global demand-growth rate is estimated at 3.3% per year (Alvarado, 1999).

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Materials and Methods

Field Sampling

Representative samples were obtained from Akiri village of Awe Local Government Area of Nasarawa State at three random points located on latitude N08° 22' 783" and longitude E 009° 21' 573". Grab method of sampling was adopted to obtain the sample at an interval of 20m apart to be able to have a good representation.

Chemical Analysis

The chemical analysis of the ore was conducted using X-ray fluorescence machine using the following procedures;

1. The sample was ground manually with an agate mortar and pestle to grain size of less than 125 µm.
2. Pellets of 19mm diameter prepared from 0.5g powder was mixed with three drops of organic liquid binder and pressMineralogical investigations of ore thin sections were conducted with petrological micred afterwards at 10 tons with a hydraulic press.
3. Measurements were done using an annular 25mci ^{109}Cd as the excitation source, that emits Ag-K X-Rays (22.1 Kev) in which case all elements with lower characteristic excitation energies were accessible for determination in the sample. The system consists further of Si(Li) detector, with a resolution of 170 Kev for the 5.90 Kev line, coupled to a computer controlled ADC Card.
4. Quantitative analysis of the sample was carried out using the emission-transmission method, for which a number of quantification methods have been developed and applied.
5. Cd was used for the analysis of K, Ca, Cr, Mn, Fe, Co, Ni, Cu, Mo, V, Zr, etc.

Mineralogical Analysis

Microscope under plane polarized light and cross polarized light. The aim was for the identification of different constituents of the copper ore to reveal the major and minor constituent minerals. The following procedures were adopted in the preparation of the thin section in accordance with Gribble (2004):

1. The ore specimens were cut using an electric cutting machine to a thickness of about 2mm to 3mm to avoid unnecessary grinding.
2. After cutting, the sample was shaped into a rectangle on a rotating plate lubricated with water.
3. A hot plate was used to mount the sample on a glass slide. The sample was placed on the hot plate with the polished surface upward. Canada Balsam which melts between 100 ^{0}c-120 ^{0}c was placed on the glass slide, the slide , with the help of pair of tweezers was lifted and mounted over the rock chip gently from one end to get rid of excess Canada Balsam and expelled air bubbles which, could hinder proper observation if present. The mounted rock was allowed to cool.
4. Grinding followed mounting which reduced the thickness of the sample to about 30 microns. The grinding was done gradually using silicon carbide, at each stage, with different grades of the chemical, starting with a grade of 120, which was the coarsest, and finishing off with a grade of 1,000 which was the finest. After each stage, the sample was washed, dried and examined under the petrological microscope to note the progress.
5. After satisfying that the thin section is perfectly thin, the sample was covered with a very thin glass cover. An appropriate size was laid down on top of the section and Canada balsam was poured. Again a pair of tweezers was used to pick the cover by one end and turned over, with the edge first, andthen gradually lowered on the rock section. After cooling, the remaining Canada balsam was scrapped along the edges and washed thoroughly with methylated spirit and then water.

Results and Discussions

The results of the chemical and mineralogical tests carried out on the sample of the ore are presented in tables 1 and 2, as well as plates 1, 2, 3 and 4.

Chemical analysis using X-ray fluorescence machine was conducted on the sample of the ore which comprehensively revealed all the constituent elements as shown in table 1 and also in oxide form; table 2.

Table 1: Result of chemical analysis of head sample

Element	Composition (%)	Element	Composition (%)
Al	1.700	Fe	39.030
Si	6.110	Ni	0.140
S	13.600	Cu	2.500
K	0.160	Ba	0.099
Ca	0.390	La	0.030
Ti	0.0054	Eu	0.480
V	0.002	Yb	0.310
Cr	0.046	Zr	0.780
Mn	0.310	Mo	3.100

Table 2: Result of the chemical analysis of head sample converted to oxide

Oxide	Composition (%)	Oxide	Composition (%)
Al_2O_3	1	NiO	0.073
SiO_2	4.3	CuO	1.750
SiO_3	12	MoO_3	4.000
K_2O	0.13	Ag_2O	1.400
CaO	0.51	La_2O_3	0.140
MnO	0.24	Eu_2O_3	0.390
Fe_2O_3	30.29	Yb_2O_3	0.060

A prepared thin-section was viewed under petrological microscope and the following features were seen: The sections occur in dendritic form and host mineral is haematite, banded into lamellar.

The results of chemical analysis of the head sample of the copper ore are presented in tables 1 and 2. The results revealed the composition of copper element to be 2.5%, with about 39% Fe and a variety of other elements including, Aluminum (1.7%), Silicon (6.11%), Sulphur (13.6%), Nickel (0.14%), Molybdenum (3.1%) and a host of other minor constituents with less than 1% each. Also the oxide composition showed that copper oxide (CuO) is 1.75% and Fe_2O_3 is 30.29%, Al_2O_3 1%, SiO_3 12% and others of different percentages. The percentage composition of copper in the head sample of 2.5% assay grade gave a very good copper composition to technically warrant exploitation according to Wills and Napier-Munn (2006), which gave 0.5%-2% as a good grade for the feed to copper extraction.

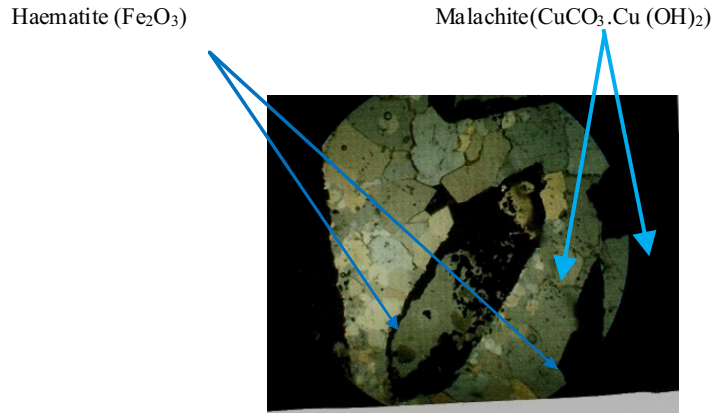

Plate1: Thin section under plane polarized light at vertical axis

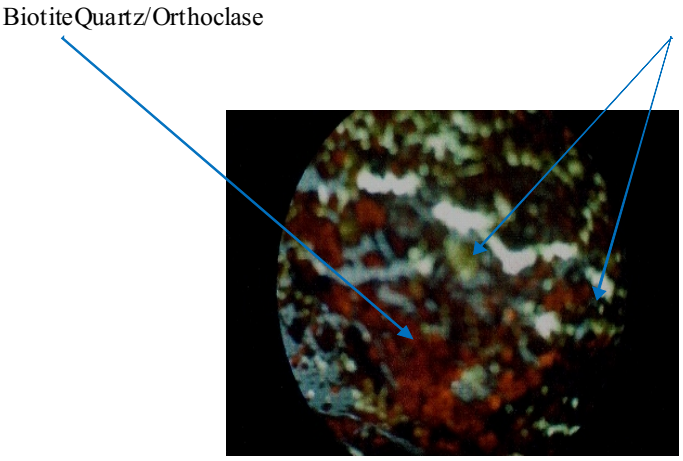

Plate2: Thin section under cross polarized light at horizontal axis

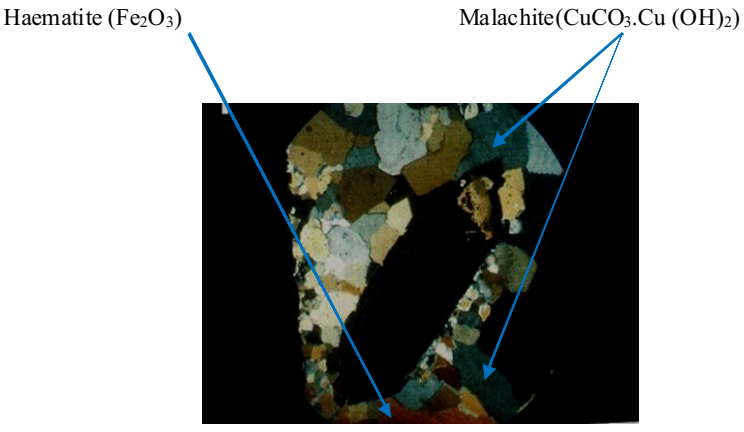

Plate 3: Thin section plane polarised light at vertical axis

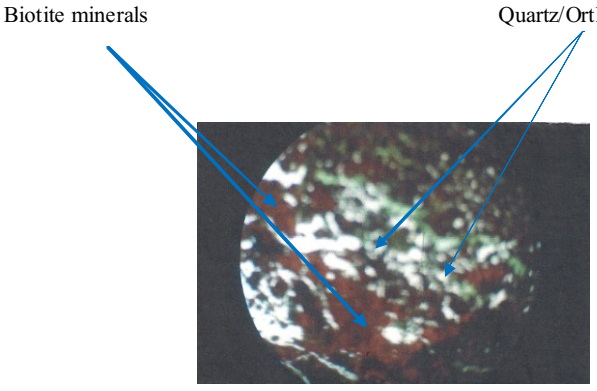

Plate 4: Thin Section under cross polarized light (vertical axis)

The thin sections were reviewed under plane and cross polarised light, as well as vertical and horizontal axes. Plate 1 presented the thin-section view under plane polarized light at vertical axis showing the ore of copper malachite - greenish in colour and ore of iron haematite - reddish brown in colour. In plate 2, the thin-section was viewed under cross polarized light at horizontal axis and quartz, biotite, orthoclase and opaque minerals were seen. The colourless materials are quartz and orthoclase, the brownish coloured substance is biotite. The thin-section in plate 3 showed plane polarized light viewed at vertical axis and the mineralized zone of iron and copper were observed. The mineralized zone showed the ore of copper, malachite, as greenish in colour and the ore of iron, haematite, as reddish brown in colour. Finally, plate 4 is the thin-section viewed under cross polarized light at vertical axis and quartz, biotite, orthoclase and opaque minerals were observed. The colourless materials are quartz and orthoclase, brownish coloured substance is biotite.

Therefore, both the chemical and petrological analysis revealed clearly that the copper ore is malachite and haematite is the host mineral.

Conclusions

The research study had established that:

- The Copper Ore is an oxide copper (Malachite) and on a host mineral (Haematite), with minor constituents of (Quartz and Biotite).
- The elemental composition of Copper in the sample is 2.5% and copper oxide of 1.7% showing very good prospect for the development and subsequent extraction of the copper metal.

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Olatunji K.J., Agbalajobi S.A., Tiamiyu A. & Abogunrin M. (2014) Nigerian Mining Journal, 12(1)43 - 45

Production of black powder for use in dimension stone industry using locally sourced materials

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Abstract
The manufacturing of black powder using locally available materials was carried out using local method of preparation with reference to standard ways of weight proportion of measurement. The materials used were bought in local market i.e. saltpetre and sulphur; while other material i.e. charcoal was sourced from local farm in Nigeria. The materials were sources adequately, burnt, ground mixed in proportion by weight, The mixing procedure was carried out using ratio 4:2:1 of charcoal, saltpeter and sulphur respectively by weight, sun dried and tested.

Keywords: black powder, local, saltpetre, ratio, sulphur, charcoal, mixing

Introduction
Gunpowder, also called black powder, is a mixture of sulphur, charcoal and potassium nitrate. It burns rapidly, producing volume of hot solids and gases which can be used as a propellant in firearms and as a pyrotechnic composition in fireworks (Wikipedia, 2012).

Black powder is a granular mixture of a nitrate, typically potassium nitrate ($KN0_3$)which supplies oxygen for the reaction. Charcoal, which provides carbon and other fuel for the reaction, simplified as carbon (C), Sulphur (S),which while also a fuel, lowers the temperature of the ignition and increase the speed of combustion. Potassium nitrate is the most important ingredient in terms of both bulk and function because the combustion process releases oxygen from the potassium nitrate, promoting the rapid burning of the other ingredients. To reduce the likelihood of accidental ignition by static electricity, the granules of modern black powder are typically coated with graphite, which prevents the buildup of electrostatic charge (Cocroft and Wayne, 2000).

Black powder was invented, documented and used in ancient China where the Chinese military forces used gunpowder base weapon technology (i.e. rocket, guns, canons) and explosive (i.e. grenades and different types of bombs) against the Mongols when they attempted to invade and breach the Chinese city fortifications on northern borders of China (Buchana and Brenda, 2006).

However, because of its low brisance, black powder causes fewer fracture and result in more useable stone compared to other explosives, making black powder useful for blasting monumental stone such as granite and marble (Brown,1998). Black powder is also used in fireworks for lifting shells, in rockets as fuel and in certain special effects (Kelly and Jack, 2004).

Black powder formulation where the nitrate used is sodium nitrate tends to be hygroscopic, unlike black powder where the nitrate used is saltpetre. Because of this, black powders which uses saltpetre can be stored unsealed and remain viable for centuries provided no water is ever introduced (Earl and Brian, 1978).

Materials and Methods
Three major materials were used in the production of the local explosives called black powder. The materials are saltpetre (KNO_3), sulphur (S) and charcoal of Siam weed botanical name;

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(ChromolaenaOdoratum). Saltpetre (KNO_3), which contains two major substances i.e. potassium and nitrate which is whitish in colour was bought in a local market. Sulphur(S), yellowish in colour and cylindrical in shape which varies in size. It was also bought in a local market. Charcoal of siam weed, (botanical name; ***ChromoleanaOdoratum***), was produced from dry wood of siam weed called Akintola tree locally which was burnt to charcoal.

Production of black Power

The black powder was prepared in the following steps using the three components and in the following procedure;

i. **Collection of dry siam weed in abundance**

Collection of the dry siam weed and breaking it into smaller pieces the fire for the Siam weed to be in charcoal form.

ii. **Grinding the charcoal (carbon)**

iii. **Burning and Grinding of the Sample**

Only the Siam weed called (Akintola tree locally) was burnt to form the needed charcoal while both the saltpetre and sulphur were ground to powdery form.

Actual Mixing Procedure

The mixing of the three components was done in the ratio 4:2:1 of charcoal, saltpetre and sulphur respectively. Because charcoal has a low water content, compared to saltpetre and sulphur which both have high water content and the lower water content the more effective the explosive performance, four tin (150ml) each of charcoal, two tin (150ml) each of saltpetre and one tin (150ml) each of sulphur was all mixed together to produce the Black powder.

Sieve Analysis

The ground mixture was sieved using to pass mesh size 0.05mm. After the sieving the product was sun dried for minimum of six hours to remove the water content making it more effective to use and finally the *Blackpowder* is ready for use.

Result and Discussion

Composition of the black powder

The explosive composed of three major materials namely, charcoal, sulphur and saltpetre which are in proportions by weight. Though the proportions varied over the centuries and by country depending on the purpose of the explosive, for instance, powder grades of black powder unsuitable for use in firearms may be adequate for blasting rock in quarrying operations, rather than the black powder with standard proportions of 70% nitrate,14%charcoal and 16%sulphur which is not adequate for blasting operation. Therefore the black powder that was prepared for blasting operation is in the proportion of 45% charcoal, 30% saltpetre and 25% sulphur, which is suitable for blasting and classified as a low explosive.

Tests on the black powder

A test was carried out on performance of the prepared black powder to evaluate its effectiveness as an explosive. The tests conducted are:

Water Resistance Test

This is an ability of an explosive to withstand exposure to water without it suffering detrimental effects in performance. The test shows that the black powder produced has water resistance.

Finally, a sample of rock was used to test the black powder. The sample was drilled, loaded and compacted after which a flame of fire was passed to the black powder to initiate and it blasted the sample rock into pieces. This shows that the black powder is effective and can be classified as low explosive.

Conclusion

The research work was based on the use of locally available materials to manufacture an explosive that will be readily available to serve blasting purpose at a relatively cheap rate. This will enhance the local industries development and providing job opportunities to the ever increasing

unemployed youth of the country.

Recommendation

It is recommended that government should encourage local production of explosive at a high quantity and make it more effective as imported explosive thereby promoting local industries and enhance the economy of the country through revenue generated. The guide provided in this study can be used as basis to improve on for further production.

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Physico-chemical appraisal of Agwada chalcopyrite ore, Nasarawa State

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Abstract
The physical, petrological and chemical analysis of chalcopyrite ore from Agwada, Kokona Local Government Area of Nasarawa State, Nigeria, was carried out using petrological microscope and XRF spectrophotometer. The physical analysis revealed the following: hardness 3.5, specific gravity 3.8, metallic lustre, light brown greenish colour with reddish brown streak, has an imperfect cleavage and brittle. The petrological analysis also showed that the associated minerals are Biotite, Plagioclase, Muscovite, Quartz, Orthoclase and Sanidine. The chemical analysis results obtained on average is as follows: 5.55% Al_2O_3, 19.49% SiO_2, 10.63% CaO, 32.91% Fe_2O_3, 0.64% MnO, 4.62% CuO, 1.88% ZnO, 4.57% K_2O and 16.82% SO_3. The petrological and chemical analyses of the sample indicate that the chalcopyrite ore is viable for exploitation.

Key words: Chalcopyrite, Physico-chemical analysis, Copper

INTRODUCTION

The limited success of Nigeria's investment drive in the mining sector can be linked to lack of bankable data. Knowledge of mineralogy is highly important for geological prospecting and exploration which depend primarily on accurate identification of minerals, which are subsequently relevant in the choice of processing route. Minerals are natural products of various physico- chemical processes going on in the earth's crust(Agol,1978). The careful description and identification of mineral commonly require highly specialized techniques such as chemical analysis, and measurement of physical properties among which are the gravity, hardness, optical properties and X-ray parameters that relate to the atomic structure of mineral (Klein, 2002).

Chalcopyrite is a copper, iron, sulphide mineral that crystallized in the tetragonal system. It has the chemical composition $CuFeS_2$. It has a brass to golden yellow colour and a hardness of 3.5 to 4 on the Mohr's scale (Read 2004). Chalcopyrite may also be found in coal seams associated with pyrite modules and as disseminations in carbonate sedimentary rock. Chalcopyrite is the principal commercial source of copper for which Nigeria is known to be a major consumer of copper final products in the forms of rod, tubes, wires and cast copper (Abdulrahman and Aye,2011).

Therefore, the need for the characterization and to have some database for Agwada chalcopyrite ore deposit necessitated this research work, in order to serve as invaluable repository to all stakeholders. It is hoped that this will enhance its development to meet both local and the international demand for potential investment opportunities.

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Geological setting

Nasarawa State is covered mainly by Basement Complex rocks which form about 60% of the total area of the state while the remaining 40% is made up of sedimentary rocks of the Middle Benue Trough. In the areas covered by the Basement Complex, magnetite gneisses along with the older granite rocks account for about 70% while rocks of schistose lithology and other meta-sediment series (quartizite, marble, iron stone) in the area around Lamiga,

Nasarawa, Gadabuke made up the remaining 30% (Obaje, et al 2005).The migmatite gneiss intricately are associated with the older granite occupy the area of Kokona, Keffi, Gawuku, Akwanga and its environs to the North-South.At south of Akwanga around Uba, large outcrop of dolerite trending NE – SW cross cut the large migmatite gneiss terrain. Quartzite, dolomite, marble, phyllite schist and gneisses in the area are genetically and pathologically related to the schist belt which occurs in Gadabuke, Laminge part of Nasarawa and Toto in the south western portion of the state (Obaje et al, 2005).

The mineral vein which host the chalcopyrite in Agwada is 210m North-east away from Agwada village,trending north-south direction. The length of the vein is about 1.5km and 3m wide exposed discontinuously along its length.

MATERIALS AND METHODS

The samples were obtained from the main bulk in Agwada, Nasarawa State from seven different locations with 15m interval between the points at depth of about 3.5m with thickness c from 1-1.5m. The samples were collected and labeled S1, S2, S3, S4, S5, S6, S7, and were taken in polythene bag to the laboratory. **Fig.1** shows the geological map of Nasarawa State showing the research area, while **Fig.2** shows the topographical map of the area and sampling points.

The samples of the chalcopyrite ore collected during the investigations were prepared for petrological analysis. The photo micrograph results are shown in **Plates1-3**.The others were crushed, processed to yield a representative powder for carrying out preliminary chemical analysis, the average results are shown in Tables1-2.

The physical analysis of the sample reveals on average also presented in Table 3; carried out at the Department of Mineral Resources Engineering, Kaduna Polytechnic, Kaduna.

X-ray florescence spectrophotometer was used to obtain the chemical composition of the ore; which was conducted at the Centre for Energy Research and Training (CERT) laboratory, Zaria.

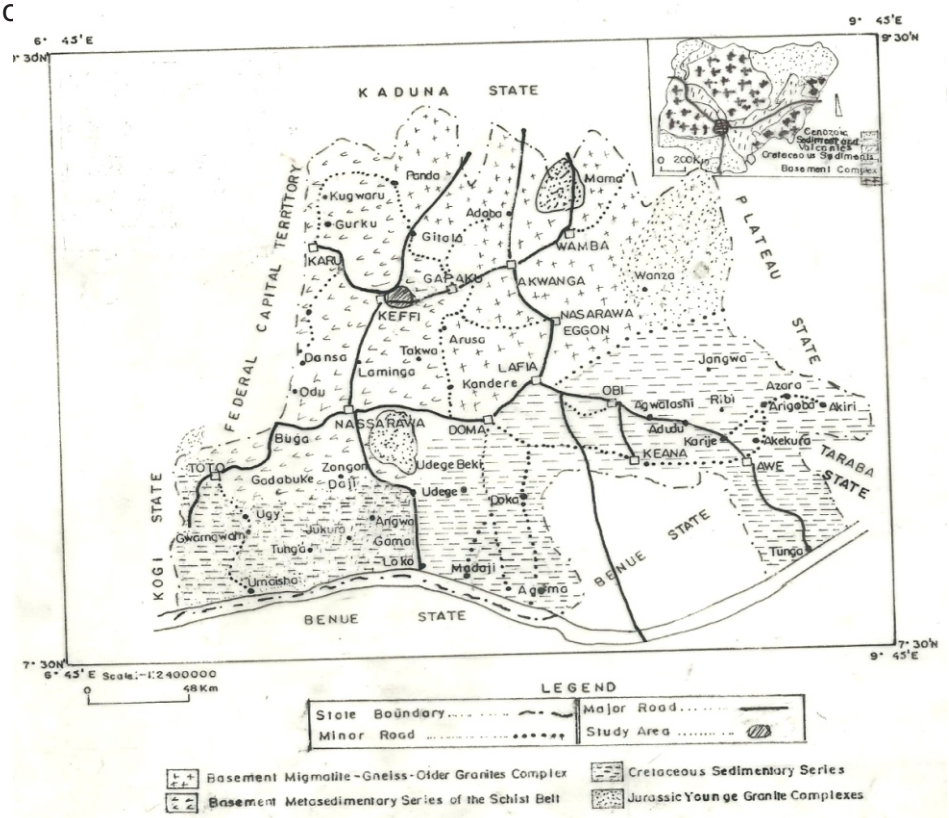

Fig.1: Geological map of Nasarawa State showing the research area

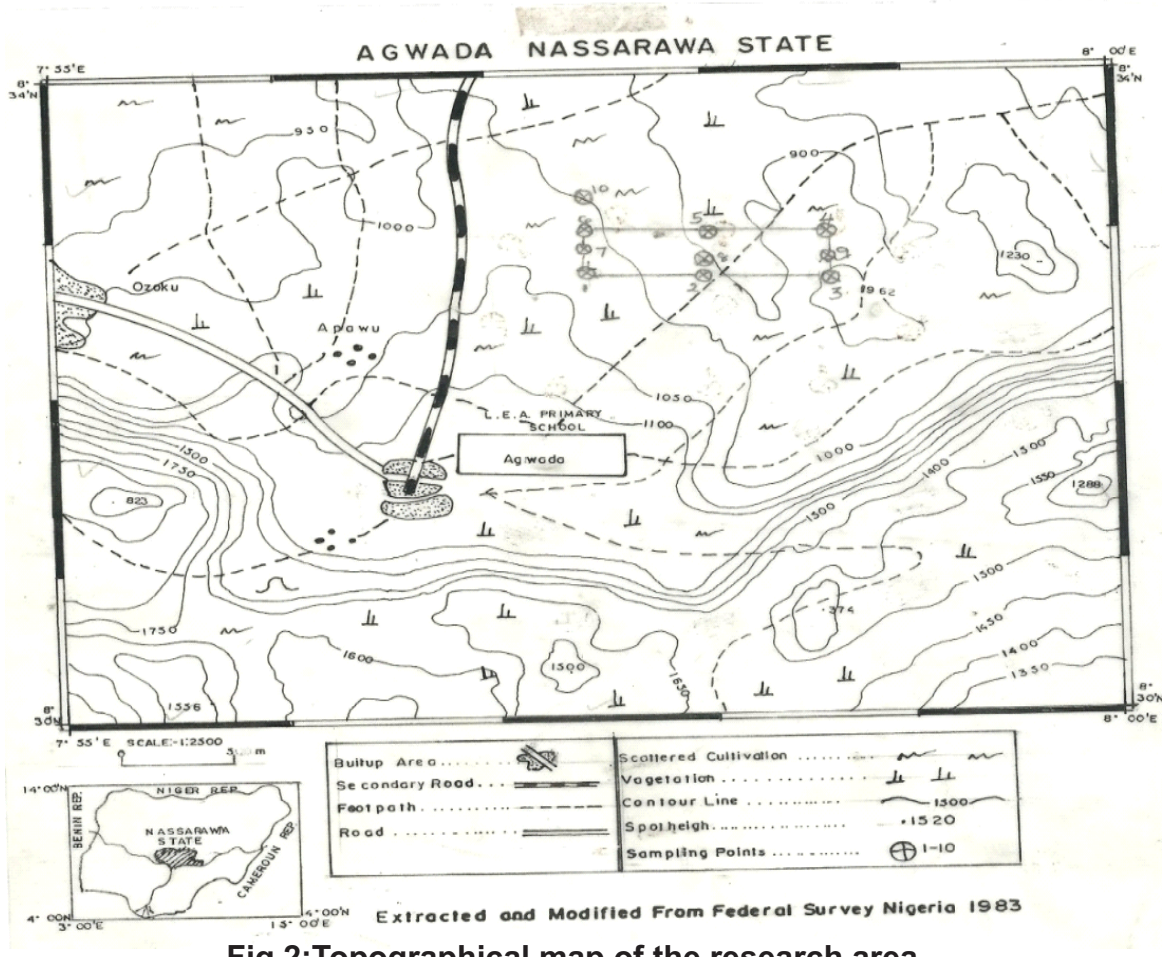

Fig 2:Topographical map of the research area

Table 1: Average chemical composition of the chalcopyrite ore in oxide form by XRF

Oxide	K_2O	Al_2O_3	SiO_2	CaO	Fe_2O_3	MnO	CuO	ZnO	SO_3
%	4.57	5.55	19.49	10.63	32.91	0.64	4.62	1.88	16.88

Table 2: Average chemical composition of chalcopyrite ore in elemental form by XRF

Elemental composition	K	Al	Si	Ca	Fe	Mn	Cu	Zn	S
%	6.43	4.99	15.43	12.88	39.12	0.83	6.20	2.56	11.46

Table 3: Average physical properties test of the chalcopyrite ore

Test	Remark
Hardness	3.5
Luster	Metallic luster
Grain size	Fine to coarse grain
Colour	Light brown and greenish ting observed
Cleavage	Imperfect cleavage
Tenacity	Brittle
Specific gravity	3.8

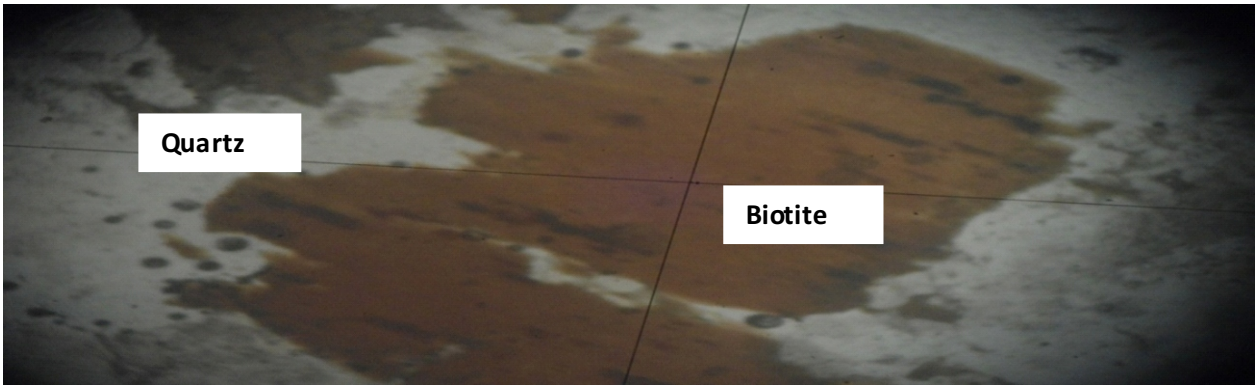

Plate 1: Photo micrograph of chalcopyrite under a cross polarized light

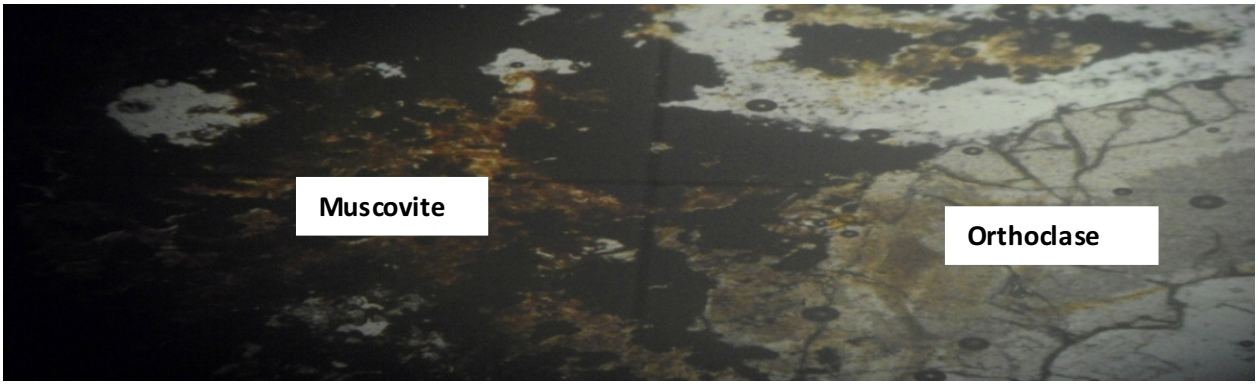

Plate 2: Photo micrograph of chalcopyrite under a cross polarized light

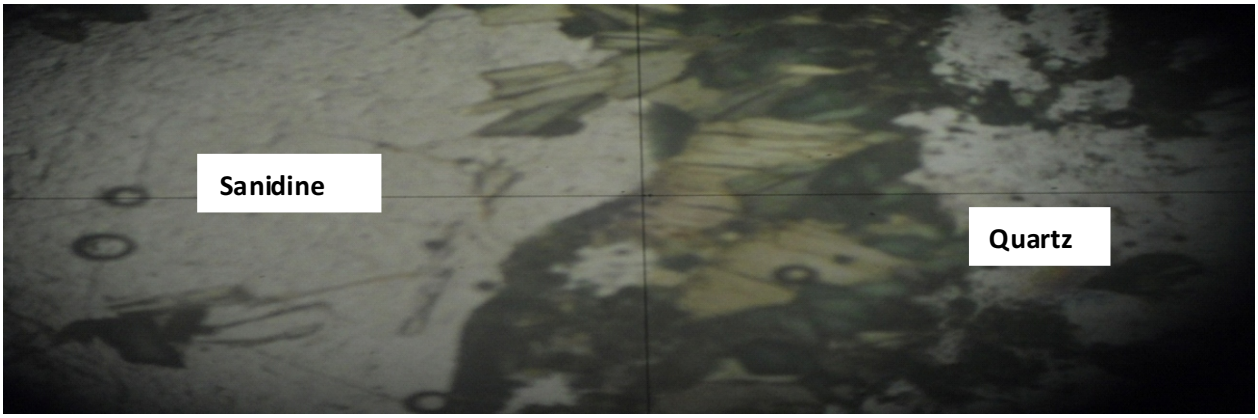

Plate 3: Photo micrograph of chalcopyrite under a cross polarized light

DISCUSSION

The examination of the thin sections of the chalcopyrite ore under cross polarization (petrological microscope) revealed biotite, muscovite, quartz, orthoclase plagioclase and sanidine to be the associated minerals. From Table1, the chemical composition obtained from the use of XRF spectrophotometer shown on average the copper content of 6.20% when compared to the cut-off grade for copper all over the world, which is noted to be between 0.6-1.0% copper content(Smith et al, 1977). The Agwada chalcopyrite ore is viewed to be highly economical and can attract investors based on the percentage of copper obtained. Also, the ore contains over 35% iron that can be beneficiated for iron and steel production.

CONCLUSION

The chalcopyrite ore deposit at Agwada in Kokona Local Government Area of Nasarawa State contained high grade of

copper on the average 6.20% compared to copper ore being mined in many parts of the world today. Iron in the ore was found to be 39.12% on average and suitable for production of steel when upgraded, though further work need to be done especially to determine the reserve estimates of the deposit as well as beneficiation routes for optimal recovery.

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An Assessment of the Socio-Economic Impact of Coal Mining on the Maiganga Communities in North-Eastern Nigeria

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Abstract

This paper tries to assess the level of social and economic impacts of coal mining by Ashaka Cement Company PLC located in Gombe State in north-eastern Nigeria on the Maiganga communities. The Environmental Impact Statement of the mine was studied, water samples were collected and analyzed, interviews were conducted and questionnaires were administered to compliment the study. The results show that the concentrations of most metals in the water samples were below the limits approved by Federal Environmental Protection Agency and, that the majority of the people in the neighbouring communities engage in subsistence agriculture and petty trading as the main sources of income. Common ailments identified in the study areas include stomachache, fever, cholera, skin diseases and on chocerci as is which may not be caused by the current mining activities in the area. Due to the differences between the data collected in the study and the baseline data, it is recommended that the surface and ground water at Maiganga should be thoroughly sampled and analysed to determine the actual impact of mining on the water quality in the mining communities.

Keywords: Socio-economic impacts; Coal Mining; Water Quality and Metal Concentrations

Introduction

Surface mining operations usually disturb the land, air and water systems in the area of operation. It causes deforestation, land degradation and also has many social and environmental impacts. In the past, the laws in most developing countries gave little attention to the protection of the environment. Currently, most countries require mining companies to conduct Environmental Impact Assessment (EIA) and conduct public hearings in the communities that will be affected by their operations before a mining permit is granted. Unfortunately, most mining companies do not comply with the environmental management plans (EMPs) spelt out in their Environmental Impact Statements. This often leads to conflicts between the host communities and the operating mines.

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Ashaka Cement Company Plc located in Gombe State in North-Eastern Nigeria, has been the largest cement producer in Northern Nigeria since 1979. It produces about 850,000 tons of cement annually. Black oil (fuel oil) is used to fire its kilns at the treatment plant. In 2005, an acute shortage of fueloil led to the stoppage of the kiln for two weeks. This led to over €1.83 million loss in revenue to the company (Bakura, 2007).The company commenced mining the Maiganga coal deposit in July 2007.This paper tries to assess the level of social and economic impacts of coal mining operations of Ashaka Cement Company on the Maiganga communities.

Location and Geology of Mine

Maiganga coal mine is located near Kumo in Akko local government area of Gombe State. It is 8 km from Gombe to Yola express way, 50 km from Gombe town, and 135 km from Ashaka Cement Company Works. It lies at Latitude 09º 15' 13" N and Longitude 11º 08' 40" E. Fig. 1 is a map of Nigeria showing the location of Maiganga, Gombe State.

Fig. 1 Map of Nigeria showing Location of Maiganga, Gombe State (Source: Anon, 2009)

Gombe State is geologically a part of the Upper Benue Trough. It constitutes a major sedimentary basin, with a fill of about 6,000 m of Cretaceous Tertiary Sedimentary rocks. The eastern part of Gombe State is geologically older than the west. Exposures of the non-marine Bima Sandstone, a sequence of Albian coarse sandstones, occur extensively in the south-eastern part of the state, succeeded westwards by the transitional beds of the Cenomanian Yalde and Jessu Formations. Maiganga district area falls into the sedimentary environment of Nigeria. The area is mainly underlain by coal and its associated rocks like sandstone, siltstone and sandy shale (Bakura, 2007).

Potential Impact Identification: The environmental impacts of coal mining were examined against the existing ecological and socio-economic baseline values of Maiganga communities. Both the negative and positive effects of mining are characterized accordingly.

Operation Description: The development phase of Maiganga coal project involved activities such as re-settling of people in the nearby local communities, clearing of vegetation and farmlands and the recovery of the topsoil. Other activities included diversion of water channels and road construction. From the records, the environmental impact assessment that was conducted covered biophysical environment as well as human health and safety (Anon, 2008).The first stage in the process involved the extraction of specific project activities and tasks that have environmental implications. Secondly, a screening criterion was used to identify the environmental aspects. This was followed by the evaluation of the significant aspects using a set of social and environmental criteria.

Environmental Impacts of Coal Mining: The negative environmental impacts of mining operations often appear in print and electronic media throughout the world (Anon, 1995). Mining of minerals affects the environmental and social conditions no matter where they occur. These changes, which may be positive or negative, are generally referred to as environmental impacts.

Saxena (1996) indicated that the socio-economic impacts of mining and associated activities include displacement of the people, loss of livelihood, changes in population dynamics, increased cost of living, water scarcity, health impacts, infrastructural facilities, employment opportunities, economic disparity and frustration.

Water Pollution: Different water protection regimesare deployed for mine and waste waters. Mine waters, which often have fluctuating low pH levels, carry with them non-soluble substances and, as a rule, have an increased content of metals. The first measure is to separate surface waters to reduce the volume of mine water to a minimum. Mine water is usuallyfirst treated in sedimentation ponds and then in mine water purification plants which work on the oxidation - neutralization principle. Primarily iron, manganese and other non-soluble substances are removed in the process.Acid Mine Drainage (AMD) is metal-rich water formed from the chemical reaction between water and rocks containing sulphur-bearing minerals. For example, pyrite reacts with air and water to form sulphuric acid and dissolved iron. This acid run-off dissolves heavy metals such as copper, lead and mercury into the ground and surface water.

Some management methods that can minimize the occurrence of AMD involve active or passive treatment (Ripley et al, 1996). Active treatment involves installing a water treatment plant, where the AMD is first dosed with lime to neutralize the acid and then passed through settling tanks to remove the sediment and particulate metals. Passive treatment methods usually have self-operating systems that can treat the effluent without constant human intervention.

Method and Material

This study made use of both primary and secondary data. The primary datainvolved administration of questionnaires as well as interviews with the people in neighbouring communities and personnel in government and institutions The secondary data (which was in the form of already existing data) was obtained from institutions like Ashaka Cement Company Plc, Nigerian Ministry of Mines and Steel Development (MMSD), Federal Ministry of Environment and National Environmental Standards and Regulation Enforcement Agency (NESREA) and Federal Environmental Protection Agency (FEPA). A study of the mine and its surrounding areas was undertaken. Physical observations of mine facilities were made. Preventive measures put in place by the mine to mitigate the environmental impactsof its operationswere inspected.

Population: The targeted population in this research consisted of the people of

Maiganga, TudunKuka, KayelBaga, management and staff of Ashaka Cement Company. A total sample size of 500 from these communities was used.

Result and Discussion

The primary and secondary data was analyzed statistically and the results are discussed in the next sections.

Resettlement of Maiganga Community

All the people that were living in Manganga areas were displaced. Field studies revealed the situation before and after mining operations began at Maiganga. As part of the mitigation measures by Ashaka Cement Company, the Maiganga communities were relocated from the old settlement to a new settlement. Fig. 2shows houses in the old settlement which depict typical rural settings such as mud houses covered with reeds and pit latrines were prevalent in the community. The houses in the new settlement were built with cement blocks and provided with modern facilities such as boreholes and water closets (see Fig. 3).

Fig. 2 Old Settlement at Maiganga

Fig. 3 New Settlement at Maiganga

Economic Generation

Economic issues associated with mining present significant unresolved challenges. Therefore, many mining companies are struggling with the management of social and economic issues of the people in their catchment areas. Various income generating activities of the people in Maiganga, Kayel Baga and Tudun Kuka communities were assessed and the results are presented in Figs. 4 to 9.

The results from the respondents revealed that farming is the predominant occupation of the people. About 34% of the people in Maiganga, 45% of the people in KayelBaga and 52% of the people in Tudun Kuka engage in farming (see Figs. 4 to 6). Animal rearing is the second highest revenue generating activity constituting 12%, 24% and 17% in the Maiganga, Kayel Baga and Tudun Kuka communities respectively. Fish smoking is another significant income generating activity in the communities with an average of 10% in each community. About 20% of income of the people is from general trading in Maiganga, while 5% of the population in Kayel Baga and Tudun Kuka are Civil Servants.

The results also show that about 4% of the population in each community earn between US$335.00 to US$700.00 (N50,000.00 to N100,000.00) per month; 65% receive between US$70.00 to US$335.00 (N10,000.00 to N50,000.00) and 22% of the population earn less than US$70.00 (N10,000.00) per month (see Figs. 7 to 9). In general the incomes of the people may be said to be low.

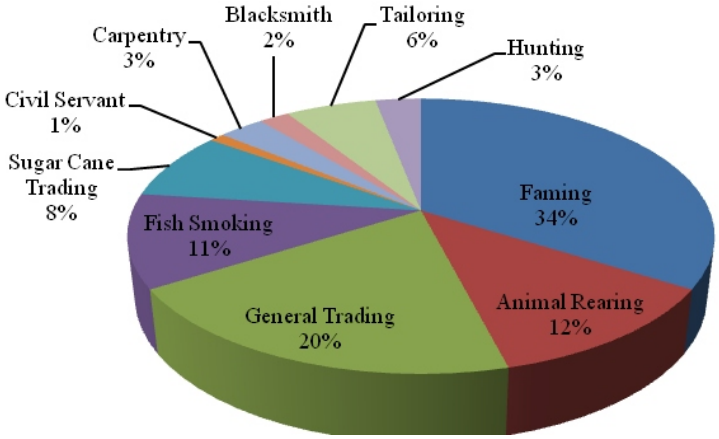

Fig. 4 Income Generating Activities of People in Maiganga

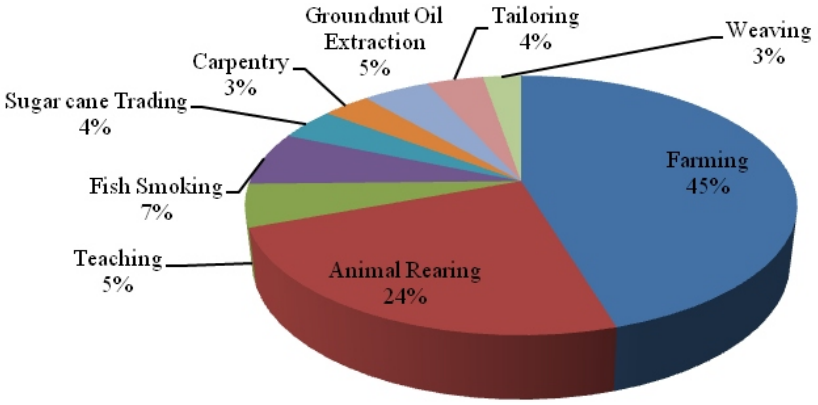

Fig. 5 Income Generating Activities of People in KayelBaga

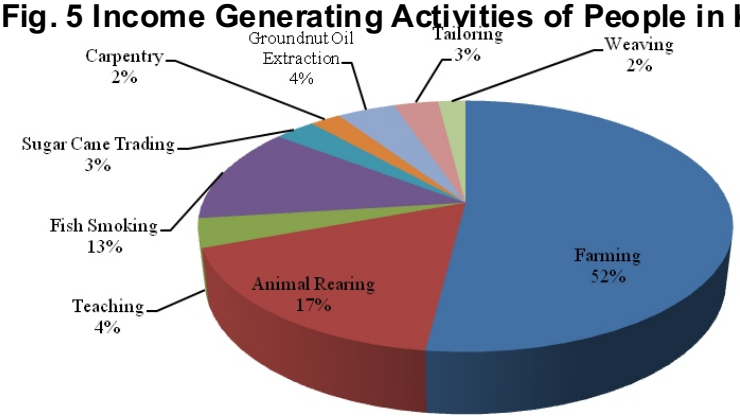

Fig. 6 Income Generating Activities of People in TudunKuka

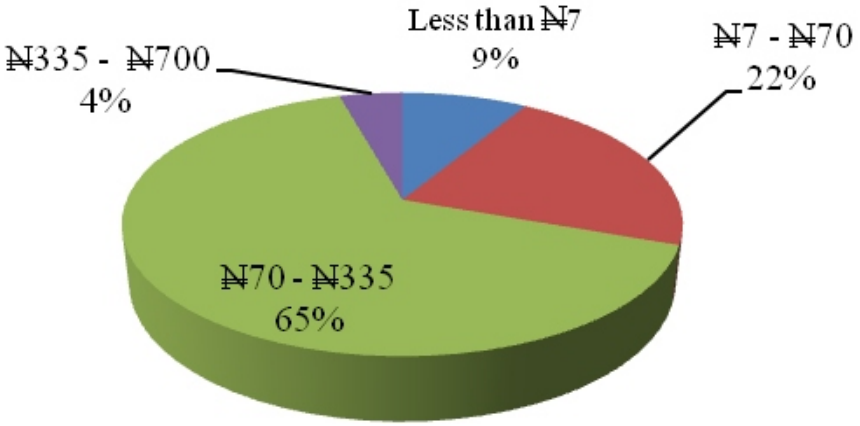

Fig. 7: Average Monthly Incomes of People in Maiganga Community

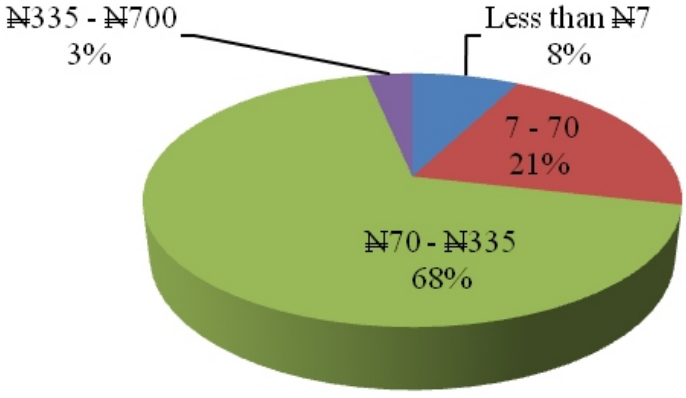

Fig. 8: Average Monthly Incomes of People in Kayel Baga Community

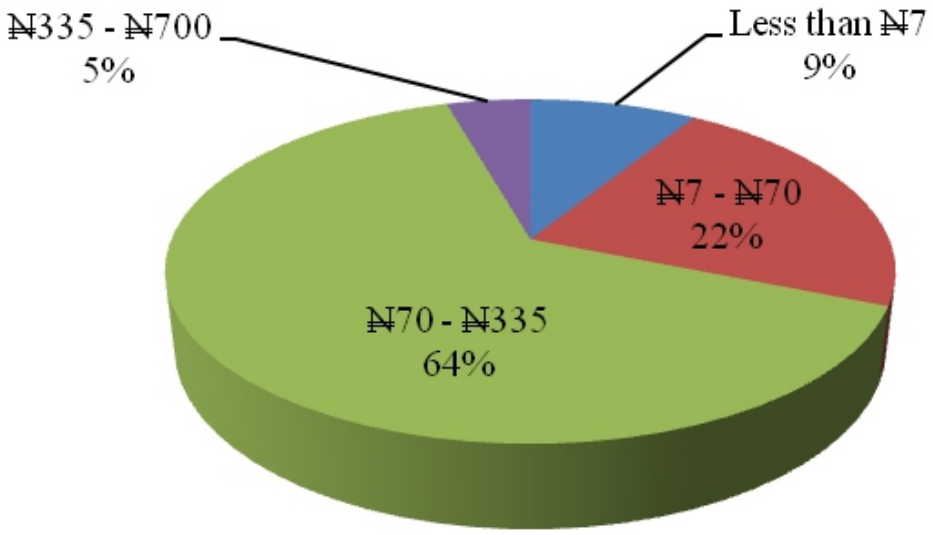

Fig. 9Average Monthly Incomes of People in Tudun Kuka Community

Infrastructural Development

The coal mining project has some positive impact on Maiganga community and its environs. Access roads, primary health care facilities and local transport systems were provided as part of the corporate social responsibility of the mine. However, some facilities such as potable water, secondary schools, market places and electricity are not provided in all the settlements. The main sources of water in these communities are rain, river, boreholes and wells. In all cases, an average of 57% of the population gets its potable water from wells while rain and borehole water contribute 14% each to the water requirements of the people. River and storage from run-off constitute 10.5% and 4.5% respectively of the requirements. The demand on boreholes for water supply is relatively low (13%) because most of them usually dry up in the dry season (Figs. 10 to 12). The baseline data of these communities indicates that TudunKuka dam and river are the main sources of water for cattle rearing, irrigation and fishing, while well and borehole water is used for drinking

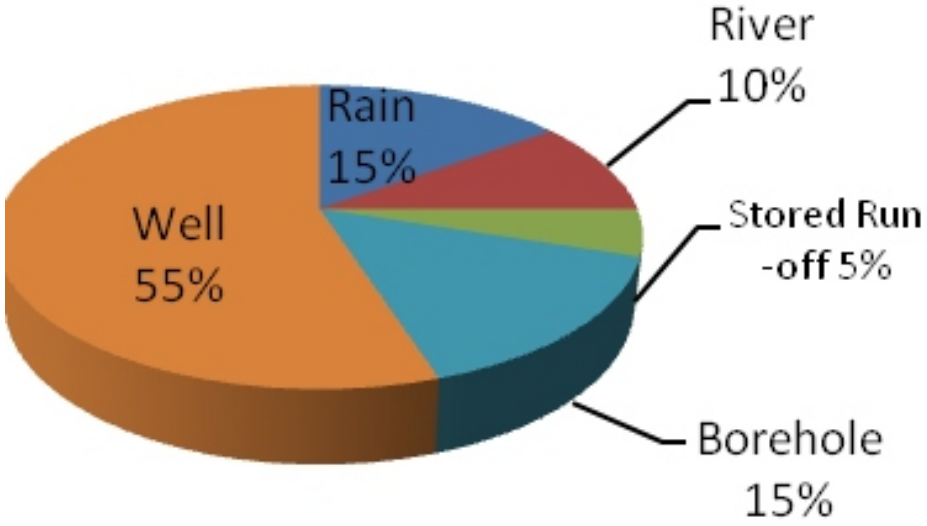

Fig. 10: Maiganga Water Supply

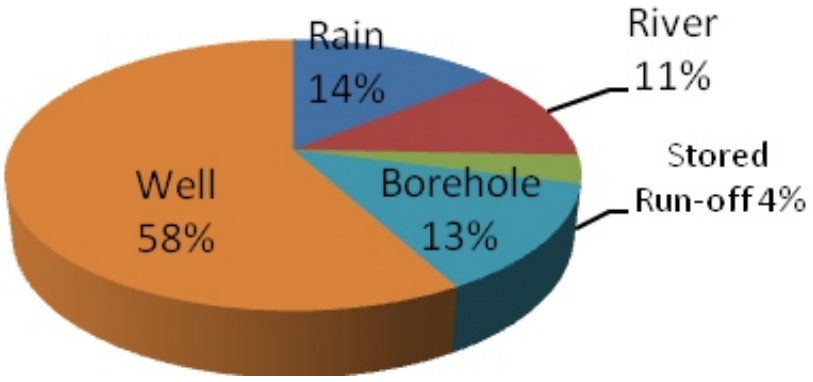

Fig. 11: KayelBaga Water Supply

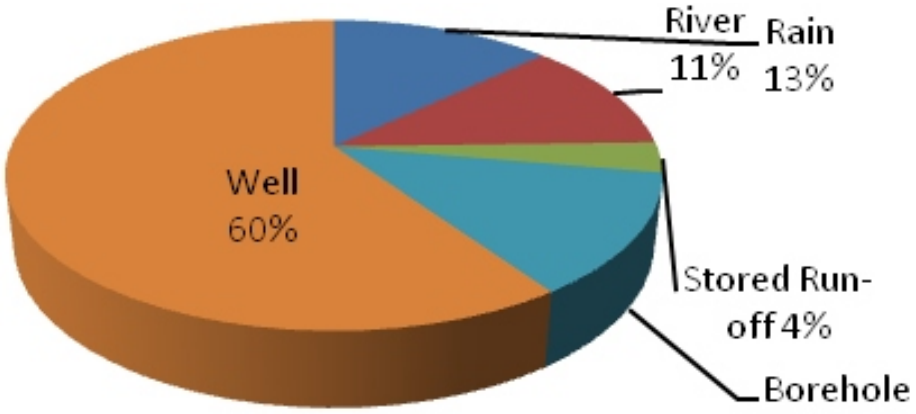

Fig. 12Tudun Kuka Water Supply

Health Impacts

The health and well-being of the people living in and around the mining area is affected by air and water pollutants as well as noise and vibrations from the mining operations. Assessment of common ailments in the study areas was made. It was found that the majority of people experience stomachaches, fever, cholera, skin diseases and onchocerciasis. These are mainly caused by poor water and sanitation systems. However, the baseline study revealed that the common ailments suffered by residents in these areas before the commencement of mining were malaria, measles, dysentery and HIV (Anon, 2008). Therefore, most of the reported ailments this study identified may probably be due to lack of potable water available in the immediate community and poor sanitation, which may not have any bearing on the current mining activities.

Water Analysis

Water quality assessment was focused on the impacts and effects from pits, streams, boreholes and wells within the mining communities. Water samples were obtained from the mine's pit, Maiganga borehole, Kayel Baga well, Tudun Kuka river and dam, and Kalkulum river and sent to the laboratory for analysis for metals, as well as determination of the pH and electrical conductivity. The analysis for metals in the water samples show that the concentrations of calcium, magnesium, iron and sodium were very low, while the concentrations of cadmium and chromium were below the detection limits of the instruments used. However, zinc and lead concentrations ranged from 0.02 to 0.21 mg/l. The water quality parameters are summarised in Table 1.

Table 1: Summary of Some Water Quality Parameters

Parameters	Concentration (mg/l)						
	Mine Pit	Maiganga Borehole	KayelBaga Well	TudunKuka River	TudunKuka Dam	Kalkulum River	FMEHUD Standards
pH	5.5	6.4	7.3	8.2	6.6	8.5	6.5 - 9.2
Ni	0.0070	0.006	0.002	0.002	0.0022	0.0016	0.1 max
Pb	0.020	0.015	0.002	< 0.001	0.0015	0.038	0.05 max
Zn	0.16	0.21	0.16	0.058	0.052	0.075	5.00 max
Cr	0.002	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	5.00 max
Cd	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	5.00 max
Ca	18.70	16.25	15.84	13.72	8.43	8.79	200
Mg	4.80	2.68	2.54	3.40	7.48	2.45	100 (WHO)
K	9.15	7.62	19.60	11.88	5.50	6.85	10 (WHO)
Na	8.70	11.64	23.70	25.66	12.67	11.86	250 (WHO)
TDS	320	237	345	260	110	295	1000 (WHO)
TSS	0.75	0.20	0.2	0.68	10.70	12.62	30 (FEPA)
SO_4^{2-}	212.20	195.45	45.50	257.48	45.60	204.40	500 (FEPA)
Fe	0.65	0.25	0.32	0.43	0.48	0.52	20 (FEPA)
EC (µS/cm)	620.38	450.70	654.00	503.35	217.60	582.75	1400 (WHO)

Conclusion

From the analysis in this study, the following conclusions are made:

a) The concentrations of elements such as Ca, Cr, Cd, Mg, K, Fe, Zn, Pb and Na in the water samples were below the limits approved by FEPA.

b) Socio-economic baseline conditions of the neighbouring communities revealed that the people engage in subsistence agriculture and petty trading as the main sources of income and livelihood.

c) Common ailments identified in the study areas such as stomachache, fever, cholera, skin diseases and onchocerciasis may not be caused by the current mining activities in the area.

d) Due to some differences between the data collected in this study against the baseline data, it is necessary that the surface and ground water sources at Maiganga should be thoroughly sampled and analyzed to determine the actual impact of mining on the water quality in the mining communities.

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Beneficiation of Madaka Manganese Ore by Jigging

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Abstract
This study investigates the beneficiation of Madaka manganese ore by jigging. Manganese ore was obtained from Madaka mining site, Niger state, Nigeria. The ore contains medium amount of manganese (28.23% MnO_2) and iron ore (17.91% Fe_2O_3) as revealed by chemical analysis was crushed using the laboratory jaw crusher and ground in a laboratory ball mill. Particle size analysis was carried out over the range of +355 and +80 in 7 different mesh sizes, and the ore was jigged. The operating variable used to determine the effectiveness of recovery is the particle size and was assessed by determining the percentage of MnO_2 in the underflow and overflow using x-ray fluorescence (XRF). Optimum MnO_2 recovery of 73.71% was achieved at particle size 125µm which also indicate the liberation size of the ore.

Keyword: Manganese, Analysis, Particle size, Recovery.

Introduction
The present knowledge of manganese as one of the strategic metallic elements was recognized by a Swedish Chemist in 1974 and at present the metal is indispensable in the manufacture of steel, where it is used in the form of ferro - manganese and also as a direct feed to the blast furnace.

More than 90% of the world's mined manganese ends up in steel products. On average, one tonne of steel contains about 7.5kg of manganese (Roy, 1981). Manganese serves two functions in steel making first as an additive and second as an alloy (Anon, 2006).

It may be pointed out that steel, no matter what grade or type, cannot be made and shaped without the appropriate amount of manganese in it, and there is no satisfactory substitute for manganese. It is ultimately consumed in the production of iron and steel, either directly as ore in the blast furnace or as ferro-manganese and metal in steel making.

Manganese ore is mined by both underground and surface methods depending upon the geological setting of the deposit. The manganese ore is usually hand sorted in lump ore and fines.

Since the goal of every mineral processing operation is to effectively separate the valuable material from the gangue with minimum metal loss in tailings, the need to develop and employ a sustainable, effective and relatively economical method of separation is imperative. The concentration of the valuable minerals from the gangue involves exploitation of the differences in the mineral properties of the ore after effective comminution (Akande and Olaleye, 2000).

Reports from Geological Survey of Nigeria and National Steel Raw Materials Exploration Agency showed that Nigeria is blessed with large reserves of proven and unproven manganese deposit. However, the local industries have continued to depend on importation of manganese for all its required consumption either as metal or its alloys. This is because the local Manganese deposits are of low grade and require beneficiation before they could be used. Madaka manganese ore beneficiation was studied using the jigging method and the effect of particle size as a variable on the recovery of manganese using the laboratory jig was investigated.

Materials and Methods
The bulk ore used in this study was obtained from Madaka mine, Niger state.

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Its chemical composition as revealed by x-ray fluorescence (XRF) is shown in Table 1.
The ore was broken into sizes that could be fed into the jaw crusher using a sledge hammer. Crushing was carried out in a laboratory jaw crusher and ground in a laboratory ball mill. The ore sieving was carried out using sieve shaker. 200g of the ore was introduced into the nest of the ASTM sieves and the timer was set at 15 minutes. The sieves were taken apart after the stipulated time and the amount of material retained on each sieve was weighed and recorded. Table 2 shows the composition of the material retained on each sieve.
200 grams of the ore of the same size from the product of the sieve analysis was stored in a tray to form the feed for the jigging operation. The jig machine was rinsed with clean water to avoid any contamination with other materials. The spigot hutch compartment was placed properly with the rubber cork and filled with water to cover the ragging in the feed compartment. The feed was fed into the jig and the jigging operation was allowed for 5 minutes. At the end of each jigging operation, the spigot of the hutch compartment was opened and the product was collected as the underflow. The overflow materials left in the feeding compartment were scooped and washed out. The two products (underflow and overflow) were dewatered, dried, weighed and recorded. The experiments were repeated with varying particle sizes.
The amount of manganese ore in each of the underflow and overflow was evaluated by determining the percentages of manganese in the samples using x-ray fluorescence (XRF).

Results and Discussion

The result of the chemical analysis of Madaka manganese ore is presented in Table 1. From the result shown in the table, it is seen that the Madaka ore assays 28.23% of manganese oxide and can be classified to be of medium grade when compared with other deposits from Australia, Brazil and Gabon.

Table 1: Chemical Composition of Madaka Managanese Ore

Mineral	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO_2	Fe_2O_3	As_2O_3
Composition	11.50	33.92	1.27	1.97	1.09	0.11	28.23	17.91	0.99

Size Analysis

Table 2 shows the results obtained from the particle size analysis of the ore. It can be observed from table 2 that the smaller the aperture of the sieves, the lower the weight percentage of the material retained. The aperture range of 355μm has the most retained weight percent which is followed by 180μm and then 250μm respectively.

Table 2: Particle Size Analysis of Manganese Ore

Sieve Size Range (μm)	Normal Aperture (μm)	Weight Retained (g)	Percentage Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative Weights Passing (g)	Assay of Mn_2O %
+355	355	148.80	29.76	29.76	99.99	23.12
-355 + 250	250	76.40	15.28	45.04	70.24	25.06
-250 + 180	180	81.80	16.36	61.40	54.96	26.39
-180 + 125	125	75.90	15.18	76.58	38.60	24.34
-125 + 90	90	59.72	11.94	88.52	23.42	21.99
-90 + 80	80	40.32	8.06	96.58	11.48	21.06
-80 + 63	63	17.06	3.41	99.99	3.41	

The coarse component of the ore is quite significant as more than 50% weight falls within sieve size aperture 355 - 125µm. Also, the various size fractions obtained from the particle size analysis were subjected to chemical analysis. Sieve size 180µm gives the highest assay of MnO_2 as 26.39%.

Table 3: Jigging Operation Result

Sieve Size µm	Feed (g)	Underflow (U) Weight (g)	Underflow (U) Assay (%)	Overflow (O) Weight (g)	Overflow (O) Assay (%)	Losses 200-(u+O)	Recovery (%) $C(f-t)/F(c-t)$
250	200	162.5	35.90	31.10	21.94	6.40	60.30
150	200	135.4	41.02	61.00	18.34	3.60	66.78
125	200	110.0	38.60	85.00	18.01	5.00	73.71
90	200	99.7	33.54	96.00	16.20	4.30	54.64

The results, as shown in Table 3, revealed that manganese ore concentrate (underflow) was effectively separated from the tailings (overflow), which are essentially quartz and iron. From the results, it was observed that the overflow, i.e. the tailings still have an appreciable percentage of manganese. The effect of the particle size on the recovery of manganese is also shown in table 3. The highest recovery was achieved at 125µm to be 73.71%.

Conclusion

In early years, Nigeria had very little domestic use for manganese ore. In view of the changed situation, namely the increasing demand by the growing domestic production of steel coupled with limited reserves, it is considered advisable to adopt beneficiation process for manganese ore to achieve higher recovery of saleable ore.

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Physicochemical assessment of Igbeti marble, South Western, Nigeria

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Abstract
This research work examined the physicochemical properties of Igbeti marble, Oyo State, South Western Nigeria. The physical tests carried out on an average indicated a hardness of 3.20 on Mohr's scale, compressive strength of 85N/mm^2, specific gravity of 2.75 and grey-white colour. Chemical analysis using XRF spectrophotometer showed an average CaO content of 76.35%, SiO_2 2.26%, Fe_2O_3 1.01%, MnO 0.2% and Al_2O_3, & K_2O have less than 0.8%. The elemental analysis showed 95.88% Ca, 0.7%Fe and 6.6%Mn etc. Hence the high percentage of CaO in Igbeti marble supported its suitable for cement manufacturing, water softener, fertilizer production, and as absorbent in steel making. The high content of calcium (Ca) makes Igbeti marble ideal for the production of tooth paste, paints, plastics and poultry feed.

Key words: limestone, metarmophism, marble, sampling, sample preparation, physic-chemical analyses

Introduction

Nigeria is endowed with varieties of solid minerals across its 36 States including the Federal Capital Territory (FCT) Abuja (Anon, 2012). One of these minerals is marble; which is a metamorphosed limestone, composed mostly of a crystalline form of $CaCO_3$ (calcite). Pure white marble is the result of metamorphism of very pure coloured marble varieties and is usually due to various mineral impurities such as clay, silt, sand, iron oxide or chert which were present as grains or layers in the limestone (Usman, 2010). Colourless marble on the other hand, is a very pure source of calcium carbonate, which is used in a wide variety of industries. Fairly ground marble powder is a component in paints, toothpaste and plastics, while generation of calcium oxide (also known as lime) from it by reduction under high heat can serve as a primary component of most Portland cements (Ghafar, 2012).

According to Mehdi (2006), the world production of marble reaches over 100 million tonnes and total consumption is valued at about $40 billion per year. In 2010, the world export value of marble and granite was $62 billion. Since 1999, world marble production grew at a high rate of 8.9 percent and the industry is expected to grow over 8 percent till 2025.

Marble is produced in more than 40 countries in the world. Italy, Turkey, Spain, India and China are the top five dominant countries in terms of marble production and they control over half of the world marble market. Only Italy produces over 17% of world marble. A major part of the production is consumed locally by producing countries, and only a small percentage of their total production is exported (Mehdi, 2006).

According to Anon (2006), production of dimension marble in the United States in the same year was 46,400 tonnes valued at $18.1million, crushed marble for aggregate and industrial usage was 111.8million tonnes valued at $116 million, 6.5million tonnes of which was finely ground calcium carbonate and the rest was construction aggregate; thereby contributing immensely to the U.S. GDP.

In another development, the Raw Material Research and Development Council indicated in table 1 that Nigeria has a marble reserve of over 248.2 million tonnes (Anon, 2010). Considering the proven reserve of 46.5million tonnes of Igbeti marble (Jimoh, 2011) necessitated the need for physical and chemical assessment of the deposit in order to

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Table 1: Marble/dolomite deposit in Nigeria

S/N	State	Location	Estimated Reserve (million tonnes)
1	Ebonyi	Afikpo North, Abakaliki Ohaozara, Ezza	20
2	Abia	Ohafia	Not available
3.	Imo	Okigwe	Not available
4	Nassarawa	Toto-muro hills	10.6
5.	Kogi	Ekinrin-Ade Elebu Osara Jakura Ubo, Ajaokuta Oyo Iwa	Not available 17 68.00 70.00 80
6.	Benin	Itobe	10.00
7.	Niger	Kwakuti Takalafia	2.5 4.0
8.	FCT	Burum Takusara	16.6 12.0
9.	Oyo	Igbeti	64.5
10.	Edo	Ukpella, Ubo, Igara Ekpeshi Siluko etc	Not available
11.	Katsina	Kankara, Malumfashi	Not available

(Modified from Anon, 2010)

facilitate its investment potentials.

Geological Setting

The study area lies within latitude 8°40 and 9°05N, longitude 3°45 and 4°15E, spanning from Ookun to Yegun river and falls within the reactivated precambrian basement complex of the south-western part of Nigeria. The basement complex forms part of the Pan-Africa mobile belt which lies to the east of the West African craton. It consists of rocks belonging to the older granite suite to meta – igneous rocks and schists. The older granite rocks consist mainly of granites, amphibolites, gneisses and migmatites which have resulted into smooth shaped inselbergs particularly in areas around Iseyin, Igboho, Moshi, Kishi and the greater part of Oyo north. Certain groups of meta sediments which abound in areas around Ifedapo, Kajola and Ifeloju Local Government Areas include the quartzo-feldsparthic biotite schist, quartzite and marble. Larger quantities of quartzite are also found stretching from Ogbomoso and Oyo local government areas down to some parts of Igbeti. The marble trends NE-SW and thins out in the south – western directions (Jatau and Ogah, 2008).

Generally, Igbeti marble is grey to white in colour, medium to coarse grained in nature with mica specks. In some places mica schist and granulites intrude the marble. The marble is overlain by 3.5 to 5.0 meters thick overburden which comprises mainly of clayey soil that becomes rich sand-size marble particles (Jatau and Ogah, 2008).

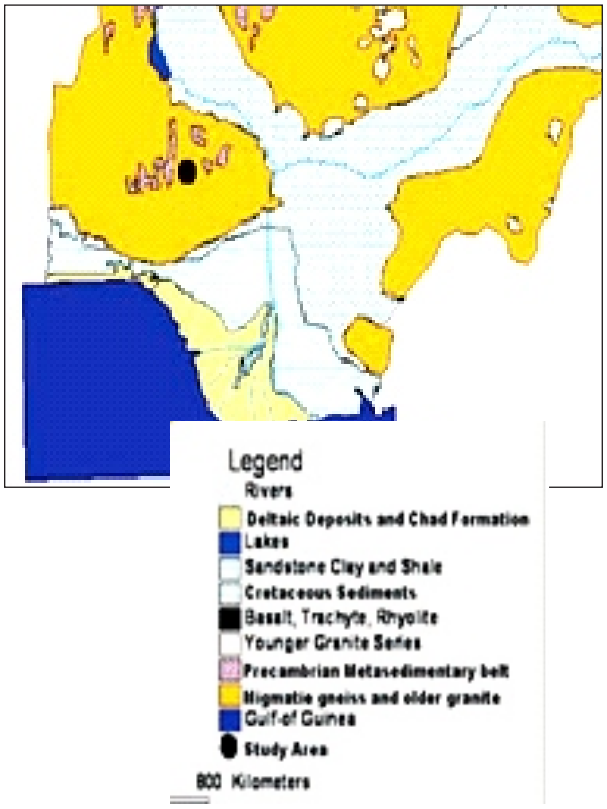

Fig 2: Geological map of Nigeria showing location of the study area

Materials and Methods

The marble samples used for physical and chemical analyses were obtained from Igbeti village in Olorunshogo Local Government Area of Oyo State. Ten samples were collected from ten different pit locations. The pits were dug 1m deep after clearing the overburden and spaced 50m by 35m apart. The samples were collected in lump sizes and were further reduced to smaller sizes, by crushing to about 10mm size. This was

then coned and quartered to yield a representative sample of 500 grammes.

X-ray fluorescence spectrometry was used in the chemical analysis to reveal the chemical composition of the pulverized marble; this was conducted at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria. The physical analyses of the representative sample which was conducted in the Department of Mineral Resources Engineering, Kaduna Polytechnic.

Results and Discussions

Tables 2 and 3 show the average chemical constituents of the representative sample in elemental and oxide form respectively.

Table 2: Average chemical composition of the marble in elemental form

Elemental Composition	% Composition
Si	
Ca	95.88
Fe	1.25
Mn	0.30
Mg	0.40

Table 3: Average chemical composition of the marble in oxide form

Compound Composition	% Composition
SiO_2	2.26
CaO	76.35
Fe_2O_3	1.01
MnO	0.22
NiO	Nil
MgO	0.65

The chemical analysis has shown that Igbeti marble contains 95.88% Ca elementally and 76.35% lime (CaO) compound wise. The concentration of silica is at a range between 1.86% Si elementally and 2.26% in oxide form of SiO_2. The physical properties tests revealed on average; hardness of 3.2 on Mohr's scale, compressive strength 85N/m^2, specific gravity 2.7 and grey to white colouration.

Conclusions

Form the foregoing, it has been inferred that the quality of Igbeti marble deposit placed it at leverage for the downstream industries by establishing its suitability either in cement manufacturing, as water softener, in fertilizer production and as absorbent in steel making.

Recommendations

Governmental and financial establishments should as a matter of urgency give extra priority to the Igbeti marble exploitation via funding so as to boost productivity in line with supplementing the already existing sources for the downstream sectors of the nation.

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