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PHYSICOCHEMICAL CHARACTERIZATION OF COPPER ORE FROM AKIRI, AWE L.GA, NASARAWA STATE

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ABSTRACT
The bulk density, compressional strength, hardness, particle study and chemical analysis of ore from Akiri were determined using standard methods and Energy Dispersive x-ray Fluorescence spectrometry (ED-XRFS). The results obtained indicated that the ore bulk density was 3.58 (g/cm^3), compressional strength 1.24 (%), and hardness 96.0(N). The particle size analysis of +0-90µm, +125-90µm, and +125-180µm, revealed over-size fractions above 250µm.The chemical composition of the ore in terms of oxide showed that the ore is composed of different minerals: 63.52% Fe_2O_3, 11.25% SO_3, 7.62% CuO, 4.30% MoO_3, 3.18% SiO_2, 1.73% BaO,1.20% ZnO,1.12% MnO,0.86% PbO,0.60% Re_2O_7, 0.54% $Eu_2O_3$and CaO, 0.27% RuO_2, 0.15% Cr_2O_3, 0.09% K_2O, 0.08% Yb_2O_3, 0.06% SrO, and TiO_2, 0.04% Nd_2O_3, and CeO_2, 0.03% Y_2O_3 and NiO respectively. The results of the elemental composition varied in the copper ore with an indication of a significant concentration of Cu compared to other elements, except Fe which showed a higher concentration. The value 35.% Fe, 6.10% Cu, 4.48% S, 3% Mo, 1.55% Ba, 1.48% Si, 1% Zn and Pb, 0.90% Mn, 0.5% Re, 0.45 Eu, 0.40% Ca, 0.21% Ru, 0.10% Cr, K, and Yb,0.04% Ti, Ni, Y, and Sr, 0.03 % Nd, and Ce obtained represent the individual elemental content in the ore. The result is an indication that the ore can be explored for the processing of valuable minerals.

INTRODUCTION

Due to the decline in the world deposit of high-grade ores and increasing demand for precious metals to match technological advancement, there is a need for the consideration of low-grade ores or lean resources (Alafara *et al*., 2014). In Nigeria, metal ores are usually mined and exported without adding value to them, while the over-reliance and dependence on oil is on the increase. The lack of exploitation of the ore resources has continued to cost the country a lot of fortunes in terms of revenue generation. The current effort towards exploring alternative sources of revenue and Nigeria's desire to become one of the twenty leading economies in the world in terms of mineral ore production has now gained attention. With the renewed commitment by the government towards exploring the mineral sector, there is the need to properly analyze the mineral deposits in order to ascertain their suitability and otherwise in a bid towards diversifying the economic base of the nation (Adebayo and Sarangi, 2011). The mineral sector is considered as the alternative to oil due to large mineral deposits in the country, the sector have the capacity of increasing the country's fortune thereby creating more jobs, grow the economy towards accelerated development and enhancement of industrialization. The prominent mineral resources endowed in the country include both metallic and non-metallic ores (Oyebola and Wahab, 2015) However, the continuous mining and export of both high-grade and lean ores, lack of beneficiation of the ore for applications has attracted the attention of scientists and technologists towards studying the natures, compositions and complexities of the ores, to further develop a model for their applicability. These methods include determining the chemical and mineralogical compositions of the ore, before advancing the materials to further stages of processing (Guettaf *et al.,* 2019). Most copper ores such as chalcopyrite, malachite or Chrysocolla deposit containing a significant quantity of copper metal are mostly of low grade due to high concentration of associated metals such as; Fe, Zn, Cd, Pb, Mg, Ca as impurities, therefore the need to treat such ores in order to obtain high-grade copper metal values (Adebayo and Sarangi, 2011).
More attention has been devoted to the analysis of ores, before subjecting them to processes of conventional hydrometallurgical routes (Baba *et al*., 2013). The hydrometallurgical processing is suitable for copper recovery from lean and complex ores, besides its environmental advantages. Large gangue ores containing calcite mostly absorb or consume acids during hydro-leaching, hence proper understanding of the nature of the ore is important to mitigating such concerns. With pyrometallurgy fast becoming obsolete due to associated problems of slag disposal and the evolution of gaseous pollutants that include NO_2 and SO_2into the environment, a proper understanding of ore characteristics will help in selecting the choice of processing route that is cost-effective (Olubambi *et al*., 2006; Habashi, 2002; Ghosh and Ray, 1991).
For the effective extraction of specific valuable minerals from their naturally occurring ores a process termed ore dressing or beneficiation is required. For most ores produced from mining operations, beneficiation is considered an important intermediate step in transforming natural ore to pure metal. The majority of ores mined are of low grade containing high concentrations of gangues. In order for the beneficiation to be successfully carried out a detailed analysis of the ore that includes both chemical and mineralogical is required for accurate application of processing strategy. Therefore, information on the composition of the ore in this study is important for process development. In order to achieve this, effective study of both the physico-chemical and mineralogical composition of the ore must be investigated, in order to ascertain the appropriate method and strategy to adopt for extracting the major metal in the ore matrix containing gangue (Craig and Vaughan, 1981).

Nigeria has not been able to have an effective mineral processing sector partly due to insufficient knowledge of the geology, processing techniques of the ore deposits and government lack of attention to the sector (Mantuano *et al*., 2006). Now that the country is making an effort towards diversification of the economy, there is a need for proper analyses of the available ore resources. Copper is a strategic metal with wide applications in so many industries that can be used for technological and economic transformation in

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Nigeria (Sahu *et al*., 2007).The exploitation of copper ore resources has contributed greatly to so many countries' economies in the world especially now that most countries are exploring the options of a knowledge-based economy towards development with copper as one of the major players in the competitive market. Copper mining in Akiri, Nigeria has the potential to promote foreign exchange, technological advancement, and job creation. Therefore, the physicochemical characterization of the copper ore will contribute to the ongoing government effort in the development and the beneficiation of the ore sector. This study is part of the ongoing effort in developing a road map for ore exploitation. Hence, the findings of this work will form the base for further analysis into the hydrometallurgical processing of the ore. This is necessary because the mineralogy of an ore is vital in selecting a method of ore processing.

MATERIALS AND METHODS

Study Area

The study area is Akiri town situated in Awe Local Government area of Nasarawa State (Fig.2). The area falls within the Middle-Belt trough of Nigeria that is very rich in minerals and as a result of that it is often considered a mineralized zone due to the presence of Pb, Zn, barite, coal, copper ore and other precious metals. The town itself is located on latitude N8.342825° and longitude E9.262246° on the global position system and has elevation of 365m above sea level. Awe Local Government area is located at about 99.3km away from Lafia, the state capital, along Markudi Road, Benue state. The vein which hosts the copper ore in Awe is about 5km East of Azara village. The three major geological components that make up the geology of Nigeria, namely, Basement Complex, Younger Granites and Sedimentary Rocks could be found in Nasarawa state. However, the Awe area is overlaid by sedimentary rock series with intrusions of tertiary volcanic rocks (Ambo *et al.,* 2023). Mining of different kinds of minerals is ongoing and is being carried out by small artisanal miners. The vast land is mostly used for farming, fishing activities; forestry conservation and wildlife. Agriculture therefore is the mainstay economic of the people in Awe, with over 70% of the population involved in subsistence farming. The increased activities of artisanal miners in the area have led to the unabated and propelled by continuous discovery of some minerals (Oyebola and Wahab, 2015).

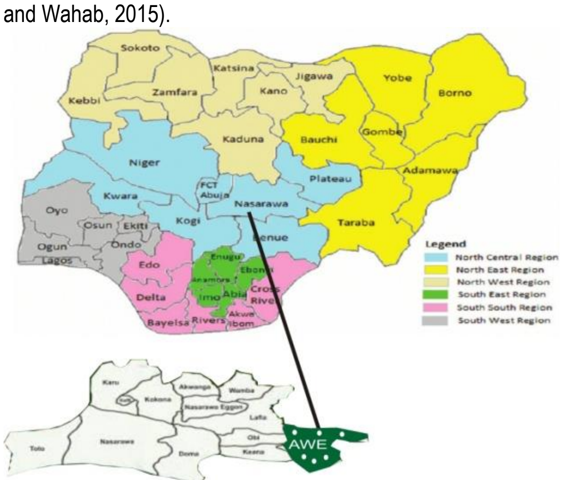

Figure 1: Map of Nigeria showing the location of Awe L.G.A (Source: Hamza *et al*., 2020)

Sample collection

The ores samples used for this analysis were collected from active mining sites in Akiri town, Nasarawa State with the assistance of miners. A total of 25 kg of the sample was collected into a plastic bag and transported to the laboratory for physical and chemical analysis.

Sample Preparation and Analysis

The entire sample was crushed using a Retsch steel jaw crusher (to -3mm), then milled using a tungsten–carbide Tema pot and ground to obtain 125/-0.90, 125/-180, and +0.90μm particles sizes. The ground sample was subsequently sieved using standard sieves as described by the American Standard sieve series to obtain different size fractions of 125/-0.90, 125/-180, and +0.90μm. Prior to analysis, the sample was homogenized (Amos *et al*., 2020). The physicochemical analysis (compression test, sieve analysis, bulk density and hardness were carried out according to the methods described by Ambo *et al.,* 2013, while the elemental content was analyzed using Energy Dispersive X-ray fluorescence spectrometry (ED-XRFS) (mini PAL 4 model (c) 2005) at the National Metallurgical Development Centre (NMDC), Jos.

RESULTS AND DISCUSSION

The result of the physical parameters of the copper ore revealed certain characteristics of copper ores (Table 1). From the analysis, the compression test clearly demonstrated that the relative deformation behavior of the copper ore was 1.24% with a force yield of 8329N. The bulk density (g/cm^3) was determined to be 3.58, while the hardness (N) of the copper ore was 96.0.A compression test is important in analyzing the elastic and compressive fracture properties of a brittle material or low-density material (Chee *et al*., 2017).It mostly describes the behavior or response of the copper ore under crushing loads, and measures the plastic flow behavior and ductile fracture limits of copper ore. The compressional test result obtained was lower compared to the result of7.33% reported for numerical and experimental studies of compression-tested copper, using the mortar contact method (Gabriel Jesus and Torrente Prato, 2017). The bulk density of copper ore is important in the area of impacting numerous operational factors, which include but not limited to mine design, mine planning, equipment selection and operational performances (Makhuvha and Harney, 2014). The bulk density result of 3.58 g/cm^3 is low when compared to the average bulk density range 2200-3700 kg/cm^3 reported by the institution of mining and metallurgy (Allen Benter*et al.,* 2013). The hardness test describes the resistance to permanent distortion, penetration, indentation and scratching, which serves as an important parameter from an engineering point of view because of it resistance to wear by either friction or erosion from steam, and oil (U.S Geological survey, 2020). The hardness result 96.0 (N) recorded for copper ore was higher than the range 3.5 to 4 using the Mohs hardness scale (Oyebola and Wahab, 2015)

Table 1: Result of Physical Parameters of Akiri copper ore Sample

SN	PARAMETERS	VALUES
1	Bulk Density (g/cm^3)	3.58
2	Compression Test (%)	1.24
3	Hardness (N)	96.0

The result of the particle size analysis (Table 2) indicated that the

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total weight of 4kg was retained on the oversize fractions (Above 250µm), 6kg on+125-180 with Normal Aperture Size (180 µm),5 kg on +125-90 with normal Aperture Size (90 µm) and 7kg on +0.90µm, respectively. This suggests the excellent grind ability and flotation behavior of the ore. The property could be explored for leaching and solvent extraction for effective recovery of copper metal from the ore. The chemical analysis of the ore is shown in Table 3. The ore is composed of mineral oxides in variable proportion in the ore matrix. The values of the mineral determined varied according to the ore composition; 63.52% Fe_2O_3,11.25% SO_3, 7.62% CuO, 4.30% MoO_3, 3.18% SiO_2, 1.73% BaO,1.20% ZnO, 1.12% MnO,0.86% PbO,0.60% Re_2O_7, 0.54% Eu_2O_3andCaO, 0.27% RuO_2, 0.15% Cr_2O_3, 0.09% K_2O, 0.08% Yb_2O_3, 0.06% SrO and TiO_2, 0.04% Nd_2O_3 and CeO_2, 0.03% Y_2O_3 and0.03% NiO respectively. The result indicated that the following mineral oxides are in significant concentrations than the rest (Fe_2O_3, SO_3, CuO, MoO_3, ZnO, and SiO_2). This infer that the presence of copper in ore and sulphur as significant constituent of the deposit. Thus the ore is probably a cuprite mineral present. The other minerals may exist in the ore in association with Cu in the ore and Fe having a higher concentration (Table 3).The ore can be explored for Cu and other valuable minerals that include Zn and Mo.

Table 2: Result of Particle Size Analysis of the Akiri Copper ore Sample

S/N	Particle Sizes (µm)	Weight (kg)	Normal Aperture Size (µm)
1.	+0.90	7	-
2.	+125-90	5	90
3.	+125-180	6	180
4.	Oversize (Above 250µm)	4	250

Table 3: Result of Chemical Analysis of the Akiri Copper Ore Sample in Oxide Form

S/N	Elements (Oxide form)	Composition (%)
1.	Fe_2O_3	63.52
2.	SO_3	11.25
3.	CuO	7.62
4.	MoO_3	4.30
5.	SiO_2	3.18
6.	BaO	1.73
7.	ZnO	1.20
8.	MnO	1.12
9.	PbO	0.86
10.	Re_2O_7	0.60
11.	EU_2O_3	0.54
12	CaO	0.54
13.	RuO_2	0.27
14.	Cr_2O_3	0.15
15.	K_2O	0.09
16.	Yb_2O_3	0.08
17.	SrO	0.06
18.	TiO_2	0.06
19.	Nd_2O_3,	0.04
20.	CeO	0.04
21.	Y_2O_3	0.03
22.	,NiO	0.03

The results in terms of elemental concentrations (Table 4) in the ore sample revealed that the ore contained elements in different concentrations that varied according to the oxide form of the mineral (Table 3). The variation observed may be as a result of the ore mineralogy. The calculated percentage of the different minerals contained in the ore showed that:35.0% Fe, 6.10% Cu, 4.48% S, 3% Mo, 1.55% Ba, 1.48% Si, 1% Zn and Pb, 0.90% Mn, 0.5% Re, 0.45 Eu, 0.40% Ca, 0.21% Ru, 0.10% Cr, K, and Yb, 0.04% Ti, Ni, Y, and Sr, and 0.03 % Nd, and Ce respectively. (Table 4) as shown in the table, the percentage of copper ores in Akiri could be seen as another potential source of copper mineral that can be beneficiated and utilized for the production of copper metal and alloys for the nation metallurgical industry. The value (6.10 **%)** reported for copper is higher than the average minimum exploitable grade value (0.4**%)** for a copper deposit **,** which equate to a concentration factor of around eighty (80), based on average crustal abundance. Also the greater percentage of Cu, Fe and S in the ore sample is an indication of the major chemical composition of a main copper ore (Ayres *et al*., 2002). However, Fe showed significant concentration due to its natural abundance in the earth crust (Oyebola *et al*., 2015). Although, the values of 4.30 % and 6.10% obtained in this work for copper oxide were lower when compared to the 11.90 % and 14.90 % oxide obtained by Usani *et al*. (2014).

Table4. Result of Chemical Analysis of Copper Ore in Elemental form

S/N	MINERALS	(%) COMPOSITIONS
1	Fe	35.00
2	Cu	6.10
3	S	4.48
4	Mo	3.00
5	Ba	1.55
6	Si	1.48
7	Zn,	1.00
8	Pb	1.00
9	Mn	0.90
10	Re	0.50
11	Eu	0.45
12	Ca	0.40
13	Ru	0.21
14	Cr,	0.10
15	K	0.10
16	Yb	0.10
17	Ti	0.04
18	Ni	0.04
19	Y	0.04
20	Sr	0.04
21	Nd,	0.03
22	Ce	0.03

Conclusion

The chemical and particle analysis of copper ore samples was carried out to evaluate their suitability for processing applications. The physical parameters examined revealed certain characteristics of the ore that are important in the area of impacting numerous operational factors, which include but not limited to mine design, mine planning, equipment selection and operational performances. The chemical analysis indicated the presence of copper in the ore in appreciable quantities for exploitation. This study underscores

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the potential of the ore as a resource for hydrometallurgical processing for copper recovery.

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