Petrological, Chemical, and Mineralogical Characterization of Anka (Zamfara State) Manganese Ore

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Abstract: Manganese deposit reserves exist in Nigeria, which have potentials as raw materials for industrial applications such as batteries, steel and electrical appliances. The present level of exploitation of Manganese is very low and, in most cases, appropriate processing would be necessary to attain desirable qualities. This paper provides petrological, chemical and mineralogical characterization of manganese ore in Anka area of Zamfara state, Nigeria. A chip of about 1/8 of an inch and about 1 inch by 1 inch was cut from the lumps of Anka (Zamfara state) manganese sample using rock cutter, after which their surfaces were trimmed and the chip was mounted on a grinding machine to make the surface smooth. The samples were mounted on a slide and viewed using Leica Petrological Microscope. 500 g of the ore was weighed using digital weighing balance. The sample was crushed and ground until 80% passing of 250μm is achieved. The ground ore was blended homogenously before the analysis while for the ore microscopy study, true fraction representative of the manganese ore samples were prepared, polished mounts and characterized using Scanning Electron Microscope-energy dispersed X-ray (SEM/EDX). However, X-ray Fluorescence was used to determine the chemical composition while identification of the associate mineral phase was done using X-ray Diffraction. From the petrological analysis carried out on the crude samples reveals the presence of heavy mineral and segregation distribution of the mineral. The XRF results shows 77.81% MnO, 60.26% Mn, 10.9% Fe_2O_3, 4% Al_2O_3 while Spessartine ($3MnO.Al_2O_3$, 0.830), Silicon oxide (SiO_2, 1.122), Quartz (SiO_4, 0.728), Pyrolusite (MnO, 1.543), and Almandine ($Fe_3Al_2SiO_{12}$, 1.583) were identified as the major phases in the ore.

Keywords: Manganese, Beneficiation, Characterization, Chemical, Mineralogy, Ores, Manganese, Mineral

1. Introduction

The world has become a global village and metallurgical industries could become one of the major forces in the global economy occupying a vital position in the supply chain of raw material on sustainable basis [1]. However, the inadequate manganese supply for industrial use cannot be over emphasized in the metallurgical industries today due to the fact that there is no satisfactory substitute for its major application because steel cannot be formed or shaped without appropriate amount of manganese in it [2]. Manganese which occur in oxide, silicate and carbonate form are the source of manganese metals, which are used in the ferro alloy industry, in steel making for deoxidation and desulphurization. Steels containing them in appreciable amounts have improved hardness, tensile strength, high temperature applicability amongst others and therefore, have greater relevance from the industrial point of view [3]. The use of manganese in dyes,

paints, battery cells, glass and textiles industries are also of great importance. Other important applications are in the production of aluminum and cast iron. The metallurgical industries, account for over 95 % of its total usage. It is for this reason that manganese is listed amongst the strategic materials by most countries [4]. From literature, Nigeria's manganese shows that most of the manganese bearing mineral deposits is found in the schist belts in the basement complex. The schist belts include: Bauchi, Cross River, Benue, Borno, Adamawa, Kaduna, Kebbi, Katsina, Plateau, and Nasarawa.

Zamfara State is located in the northwest geopolitical zone of Nigeria. Zamfara occupies a land mass of abo ut 39 762 sq km and the Gusau is its capital. The state shares boundaries with Sokoto, Niger, Kebbi, Katsina and Kaduna State within the country and an international boundary with the Niger Republic [5]. Anka LGA is one of fourteen local

government areas that make up Zamfara state which is domiciled in the Northwest geopolitical zone of Nigeria. The headquarters of Anka LGA is in the town of Anka (the study area) while the Emir of Anka is the traditional ruler of the area. Anka LGA is made up of a number of towns and villages which include Bagega, Anka, Tangardaji, Kawaye, and Wuya.

The dominant tribes in Anka LGA include the Hausa and the Fulani ethnic groups. Islam is the widely practiced religion in Anka while the Hausa and Fufulde languages are commonly spoken in the area. Popular landmarks in Anka LGA include the Federal government college Anka and the palace of the Emir of Anka. Anka LGA covers a total area of 2746 km squared with the average temperature of the area estimated at 38 degrees centigrade.

1.1 Characterization of Ore

This involves establishing a relationship between structures of materials and the processing techniques of materials and the properties of performance of material by describing the features of the composition and structure of material that is the significant to the study of the properties, processing methods and application.

1.1.1 Energy Dispersive X-Ray Fluorescence Spectrometry (ED-XRFS)

The ED-XRFS is a non-destructive method of quantitative and qualitative elemental analysis of solid and liquid sample materials. In this process, the high energy content of an X-Ray beam causes a sample to generate X-Rays characteristic of the atoms in the sample, when inner K, L, or M electrons are removed from target atoms and outer electrons fill the vacancies. Elements present in the sample are identified from the energies of this characteristic radiation and concentrations are evaluated from intensity measurements [6]. XRF spectrometers are capable of measuring elements from beryllium (Be) to uranium (U) and beyond at trace levels, often from below 1 ppm up to 100%. XRF spectrometers measure the characteristic wavelength of the fluorescent emission produced by a sample when irradiated with X-rays. ISO 9516 is an international standard method that describes the calibration and elemental contents of a full range of major, minor and trace elements. Some of the elements, which are usually determined in iron ores include iron (Fe), silicon (Si), aluminum (Al),magnesium (Mg), calcium (Ca), sodium (Na),

potassium (K), titanium (Ti), manganese (Mn), phosphorus (P), chromium (Cr) and Sulphur (S) [7].

1.1.2 X-Ray Diffractometric Analysis

X-ray diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The analyzed material is finely ground, homogenized, and average bulk composition is determined. X-ray diffraction is most widely used for the identification of unknown crystalline materials (e.g. minerals, inorganic compounds). Determination of unknown solids is critical to studies in geology, environmental science, material science, engineering and biology. An XRD pattern of a sample is the summation of diffraction pattern from each phase in that sample. This allows the identification of phases in the sample from their diffraction patterns. The amount of each phase in a mixture will relate to the strength of its signal in the final pattern and this allows the quantification of phase in mixtures. XRD is an important technique in mineral processing because it is the mineralogy rather than the chemistry that generally controls the mineral processing [8].

1.1.3 Scanning Electron Microscopic Analysis (SEM)

Scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition [9]. SEM also provides an optical image that can be processed and treated by image analysis techniques, permitting characterization of size, morphology, habit, and association [10]. Back-scattered electron imaging adds the possibility to search for minor or trace phases of interest, which are otherwise difficult to recognize using conventional microscopic procedures and to map their distribution. Backscattered scanning electron microscopy can also be used to reveal morphological attributes and mineral fabrics in appreciably more detail than conventional optical microscopy and is an indispensable tool for the investigation of many types of industrial mineral deposits.

2. Materials and Method

2.1 Material Sourcing

Sample of the Anka Manganese ore were sourced from different areas in the mine sites at Anka Local Government, Zamfara State, Nigeria, homogenized and weighed as 50 kg. 5 kg of the crude was sampled out via cone and quartering sampling method, homogenized and prepared towards analysis.

2.2 Petrological Analysis of the Manganese Ore Sample

A chip of about 1/8 of an inch and about 1 inch by 1 inch was cut from the lumps of Anka (Zamfara state) manganese sample using rock cutter, after which their surfaces were trimmed and the chip was mounted on a grinding machine to make the surface smooth. The samples were mounted on a slide and viewed using Leica Petrological Microscope to determine the microstructure of the ore at a satisfactory magnification and image display and the different minerals were identified.

2.3 Chemical Characterization of the Manganese Ore Sample

Chemical characterization of the crude was carried out using Energy Dispersive X-ray Fluoresence Spectrometer (ED-XRFS). 20 g of the manganese ore sample was finely ground to pass through a 200-250 mesh sieve. Thereafter, the sample was intimately mixed with a binder in the ratio of 5.0g sample(s) to 1.0g cellulose flakes binder and pelletized at a pressure of 10-15 tons/inch2 in a pelletizing machine. At this stage, the pelletized sample(s) were stored in a desiccator for analysis. The machine ED-XRFS was switched on and allowed to warm up for 2 hours.

Finally, appropriate programs for the various elements of interest were employed to analyze the sample material(s) for their presence or absence. The result of analysis was either reported in parts per million (ppm) or percentage (%) for minor and major concentrations of elements.

2.4 X-Ray Diffractometric Analysis

XRD analysis was carried out on the prepared sample using a back loading preparation method. It was analyzed with a PANalytical Empyrean diffractometer with PIXcel detector and fixed slits with Fe filtered Co-Kα radiation. The phases were identified using X'PertHighscore plus software. The relative phase amounts (weight %) was using the Rietveld method.

2.5 Scanning Electron Microscopic Analysis (SEM):

Morphological and qualitative analyses of the bulk ore were performed using SEM-EDX. The SEM provided information on the physical properties of minerals, while EDX provided information on their chemistry. Scanning Electron Microscopy studies for mineral analysis of representative samples were conducted in two stages using SEM model JEOL 840. All the samples were carbon coated in order to make the minerals surface conductive. Samples for analysis were cut, polished, mounts in embedded epoxy resin, and finally polished to obtain a mirror-like surface. The polished surfaces were finally carbon coated before analysis. Qualitative chemical analyses of minerals were carried out on some mounts of them ore using (SEM/EDX) to produce Backscattered Images (BSI).

Results and Discussion

3.1 Results

Table 3.1 Chemical Composition of Crude Anka (Zamfara state) Manganese Ore

Al$_2$O$_3$	SiO$_2$	K$_2$O	CaO	TiO$_2$	V$_2$O$_5$	MnO	Fe$_2$O$_3$
4	4.8	0.32	0.949	0.30	0.12	77.81	10.9

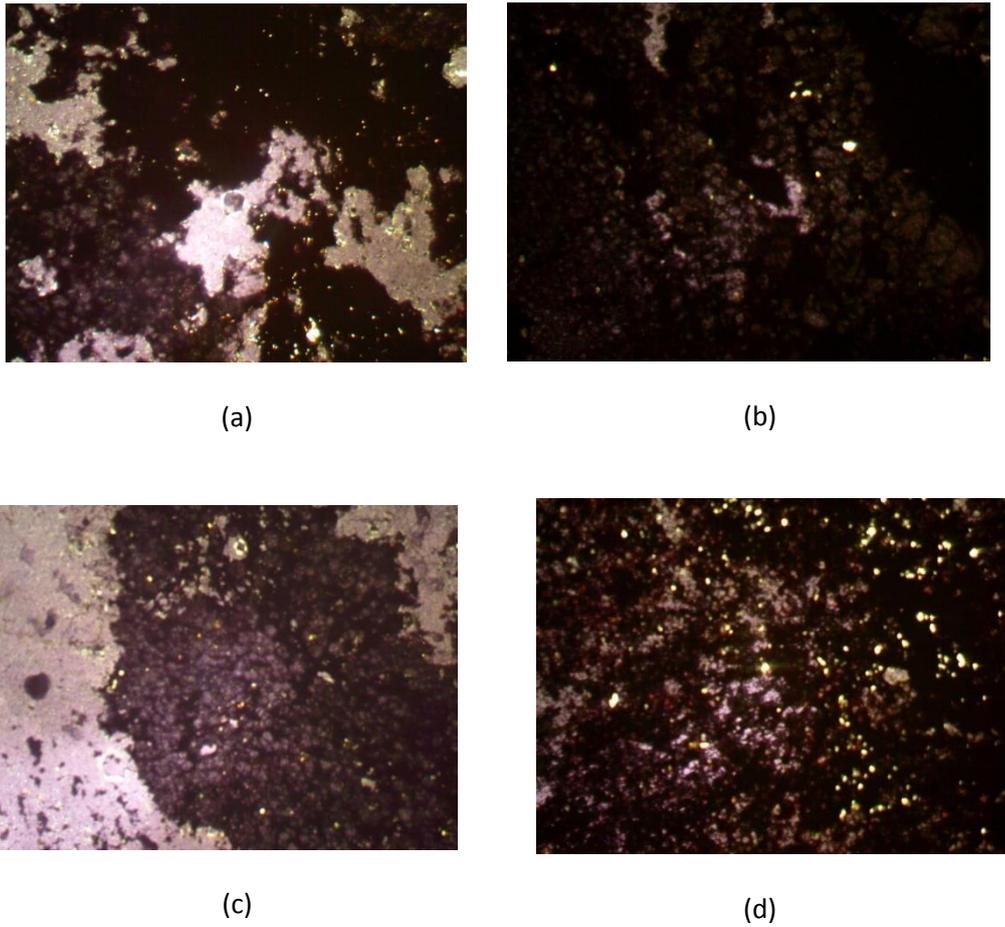| NiO	CuO	ZnO	SrO	ZrO$_2$	MoO$_3$	RuO$_2$	Re$_2$O$_7$	Mn
0.19	0.078	0.14	0.046	0.04	0.22	0.33	0.15	60.26

(a)

(b)

(c)

(d)

Figure 3.1(a,b,c,d) Photomicrographs of Crude Anka (Zamfara state) Manganese Ore
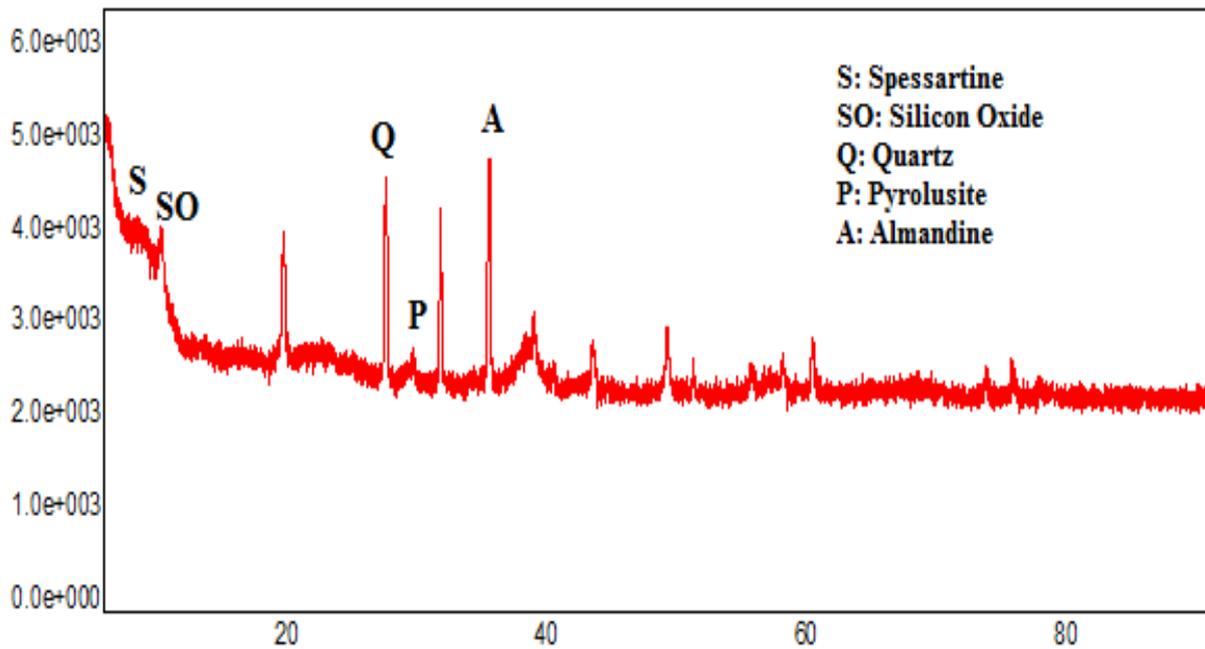

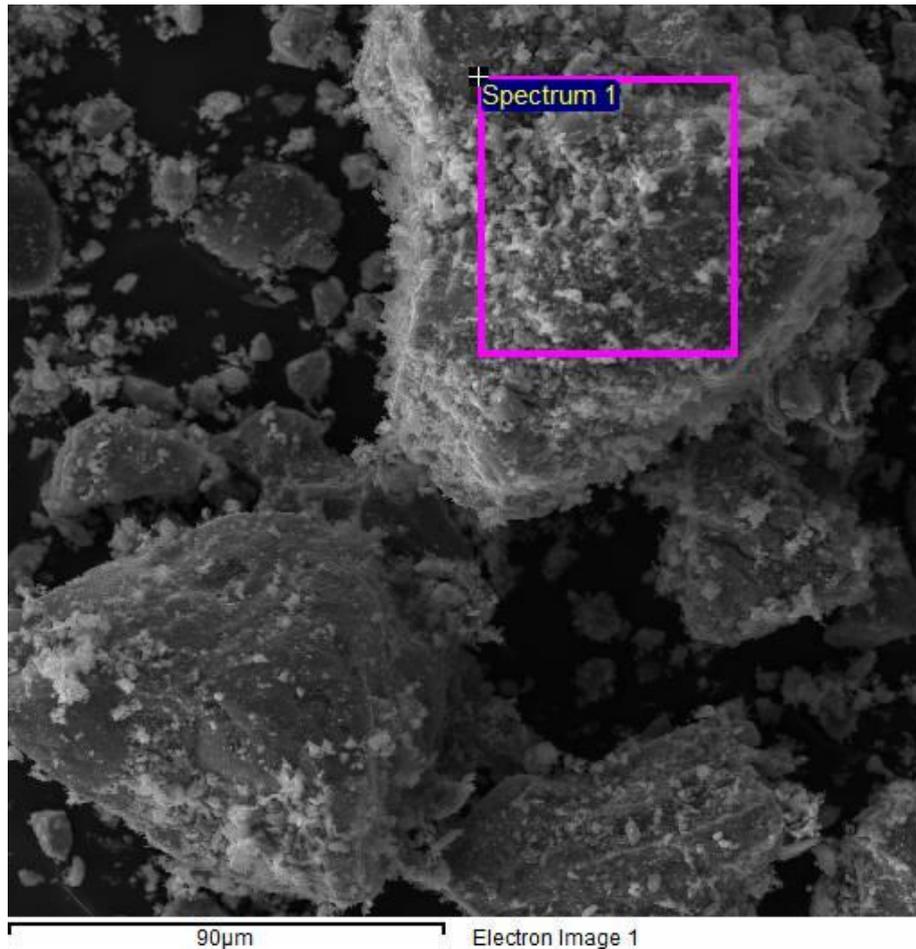**Figure 3.2** X-rays Diffractometer (XRD) of Crude Anka (Zamfara state) Manganese Ore

Figure 3.3 SEM Image showing the Ore Microstructure at 90 μm
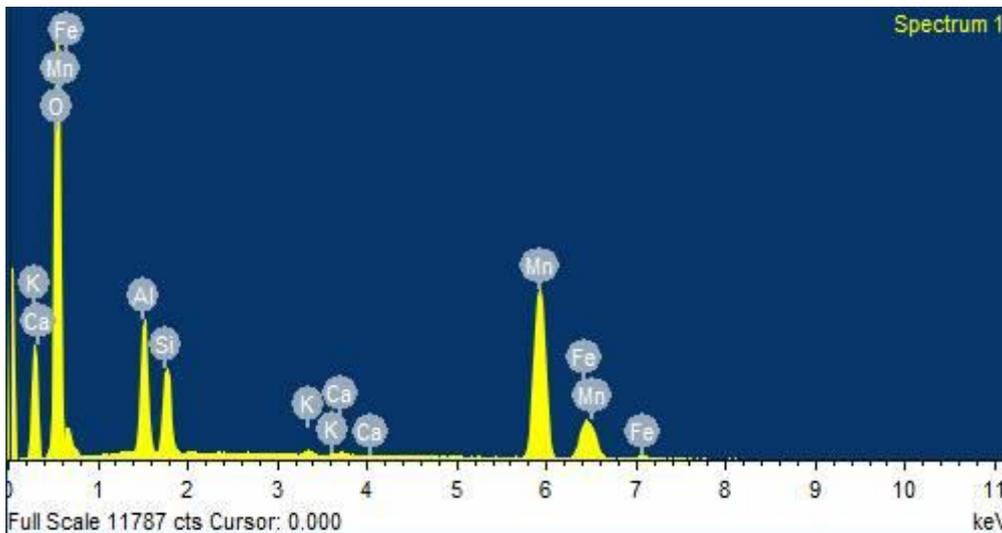

Figure 3.4 EDS analysis of spectrum "1".

3.2 Discussion

Figure 3.1 reveals the petrological analysis carried out on the crude Anka (Zamfara state) manganese ore reveals the presence of heavy mineral where figure 3.1a photomicrograph indicate the segregation distribution of the heavy mineral (Mn, Fe) and the associated mineral like quartz, Figure 3.1b photomicrograph shows a non evenly distributed heavy mineral and its other associated mineral, Figure 3.1c photomicrograph shows a sparingly distributed associated mineral with the heavy mineral and in the photomicrograph Figure 3.1d, an evenly distribution

was observed between the heavy mineral and associated mineral of the Anka Manganese Ore.

Table 3.1 is the result of chemical compositional analysis of crude Anka (Zamfara state) manganese ore and it reveals that it contains 77.81% MnO, 60.26% Mn, 10.9% Fe_2O_3, 4% Al_2O_3 and other constituent compounds. Yaro and Dodo (2016) emphasized that 52.50% Mn can be accommodated/ accepted for the production of ferromanganese alloys for iron and steel companies. Therefore, Anka (Zamfara state) manganese ore can be beneficiated to metallurgical grade before utilization in iron and steel companies to reduce the dependence on imported source of manganese.

Figure 3.2 presents the mineralogical assemblage of Anka (Zamfara state) manganese ore via XRD. The diffractogram shows the peaks of different minerals present within the ore matrix and their relative figure of merit. The minerals present and their relative figure of merit are as follows: Spessartine ($3MnO.Al_2O_3$, 0.830), Silicon oxide (SiO_2, 1.122), Quartz (SiO_4, 0.728), Pyrolusite (MnO, 1.543), and Almandine ($Fe_3Al_2SiO_{12}$, 1.583). From the diffractogram, Anka (Zamfara State) Manganese ore is a complex and metallurgical manganese ore composed of spessartine quartz, and pyrolusite.

Figure 3.3 and Figure 3.4 are the results of the SEM/EDS analysis for crude Anka (Zamfara State) manganese ore, the ore minerals morphology is revealed by SEM images which show the SEM micrographs (Figure 3.3) at 90 μm magnification. EDS analysis (Figure 3.4) established the elemental phases compositions and the spectra depicting the peaks of the elements present indicating that Manganese is top 2% of the element.

4. Conclusion

The characterization of Anka Manganese ore shows that the ore contained mineral in which beneficiation process need to be carried out in order to extract the mineral. Therefore, keen interest should be directed towards exploitation of Anka Manganese via any beneficiation technique so as to judiciously re-separate the valuable mineral from the tailings

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Yes

Conflict of interest

The authors have no conflicts of interest to declare that they are relevant to the content of this article.