Analysis of raw iron ores in Kenya: Case study of Mwingi North constituency in Kitui County

Joan J. Kiptarus, Alex M. Muumbo, Augustine B. Makokha

Abstract— Accurate prediction of downstream processing performance of a mineral ore is critical to resource evaluation and development decisions, where significant cost and productivity benefits can be realized through early determination of an ore's properties and processing potential. This study aimed at investigating the chemical, qualitative and quantitative composition of raw iron ore from the deposits in Katse area (Mwingi North Constituency in Kitui County) which lies in the Mozambique mobile belt. The quality of the iron ore was evaluated to establish its suitability as a raw material for iron production in Kenya. Samples were obtained along the perimeter vertices and centre of a land parcel measuring $150m^2$ with each excavation being 50cm length, 50 cm width and 500cm depth. Detailed studies were conducted to establish the composition and properties of the 5 samples. X-ray Diffraction (XRD), X-ray Fluorescence (XRF) and Atomic Absorption Spectrometry (AAS) techniques were employed in the investigation. XRD studies revealed magnetite (above 86%) as the major mineral with subordinate amounts of hematite and quartz. XRF studies indicated a high content of iron (above 80%) with minor amounts of (5% Al_2O_3, < 5% TiO_2, 1-44% SiO_2, <1% of MnO, P_2O_5, SO_3, K_2O, V_2O_5). AAS experiment results indicated that the Iron content was above 90% with minor amounts of SiO_2, Al_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2 and MnO elements. The quality of this ore was compared to generalized world market standards and ores from other nations. The results indicated that Katse ore is a rich Magnetite grade with Fe content above 80% with minor amounts of hematite, quartz and clay as the major gangue (<1% SiO_2 and <1% Al_2O_3) and low contents of the deleterious elements (<1 %), which correspond to acceptable levels for commercial iron ores.

Keywords— AAS, iron ore, Magnetite, XRD, XRF.

I. INTRODUCTION

Analysis of a mineral ore is a very important step to perform before any processing takes place whereby quantity, grade or quality, densities, shape, and physical characteristics are so well established that they can be estimated with confidence sufficient to allow the appropriate application of technical and economic parameters to support production planning and evaluation of the economic viability of the deposit.

Iron ore is the most abundant rock forming element and composes about 5% of the Earth's Crust. The most importantly used iron-bearing minerals from which iron compounds can be extracted includes: hematite, Fe_2O_3 (70% Fe); magnetite, Fe_3O_4 (72% Fe) and of much less importance: limonite,

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$2Fe_2O_3 \cdot 3H_2O$ (60% Fe); siderite, $FeCO_3$ (48.3% Fe); pyrite, FeS_2 (46.6% Fe) [5], where these iron percentages are in their pure states. Kenya has ample iron ore deposits which are yet to be fully utilized for the development and economic growth of the nation. There are iron ore deposits in counties like Taita Taveta (Manyatta), Tharaka (marimanti) and Siaya (Samia) which have not been fully exploited and thus there is need to amass information on the quality of the iron ore deposits and the method for pre- processing as a precursor to setting up a steel plant [3]

Katse iron ore deposits are situated in Mwingi North constituency in Kitui County, Kenya (Lies between Latitudes 0° 03' and 1° 12' South and Longitudes 37° 47' East) about 236km off Nairobi - Garrissa road. However, they still lie unexploited and little study has been done on them. The deposits are located next to Mumoni Mountains in Kitui County.

The primary objective was to provide comprehensive data on the chemical composition. These included mineral phase analysis and elemental composition with a view of finding out and understanding the best possible technique by which this raw iron ore could possibly be processed. The analyzed chemical compositions of the ore are compared to those of major iron ore producing nations.

II. EXPERIMENTAL WORK

Representative iron ore samples were collected from the five locations within the Katse deposits area: location719, location 720, location 721, location 722 and location723. The samples were collected along the perimeter vertices and centre of a land parcel measuring $150m^2$ with each excavation being 50cm length, 50 cm width and 500cm depth as shown in figure 1. In this study, the ores were designated as: Sample 1, Sample 2, Sample 3, Sample 4 and Sample 5 respectively.

Fig. 1 Geological map of Katse Iron ore deposits

1 kg of each representative rock samples were dried in an oven at 105°C to a constant weight in a muffle furnace and

then allowed to cool at room temperature in a desiccator. The samples were then pulverized to 300microns for different analysis.

0.1g of each pulverized samples were put in a plastic bottle. The samples and the standard were analysed using AAS for Ti, Si, Al, Fe, Mn, Pb, Ca, Mg and Zn in the usual manner [1]. The Fe_2O_3 content was calculated from those results.

10 g of the pulverized sample was mixed with 5g of flux starch and the resultant mixture mixed in a mortar and pestle. The resultant mixture was made in to pellets using hydraulic press. The pellets were fed in to the XRF machine for analysis of Ti, Fe, S, P, K, CA, Mn, V, Cr, Si and Al as oxides [15]

Analysis of X-Ray Diffraction was performed on the iron ore. Each sample was placed in a standard sample holder on the gionometer of the RigakoMiniflex II X-ray diffractometer. It was configured with a counter monochromator, ICCD software and an environmental dust determination (SiO_2) software. The diffraction beam monochromate kβ foil filter operated at 30 kV and 15 mA with scanning range of -3 to 145° (2θ) and a scanning speed of 0.01 to 100°/min (2θ) with accuracy of ±0.02°. Minerals were identified using the ICDD software of the International Center for Diffraction Data.

III. RESULTS AND DISCUSSIONS

Iron ores should preferably have high Fe contents and low impurity element contents, in order to justify the investment during exploitation. In the world practice, no minimum standards have been set for iron, silica, alumina, calcium, and magnesium percentages in commercial iron ores, although certain generalizations can be made[10].The generalized contents of the most important elements in raw iron ores are given in Table 1

TABLE I
CLASSIFICATION OF THE MAJOR IRON ORES ACCORDING TO QUALITY GRADE

Iron ore type	Grade	Percentage amount of Fe content (%)
Hematite	High	>65 %
	Medium	(62-65) %
	Low	<62 %
Magnetite	Metallurgical	>38 % oxidized/ weathered ore
	Conditional	< 38 % un-oxidized ore, resources unclassified oxidized/ un- oxidized
	Coal washery	>70 % magnetite content

To understand and assess the quality of Katse ore, the contents of the major elements were compared with the composition of extracted ores from other nations. Among the biggest iron ore producing nations are China, Australia, Brazil, India, Russia, Ukraine, South Africa, USA, Canada, Iran, Sweden, Kazakhstan, Venezuela, Mexico, Mauritania and other countries.

A. Chemical Composition of Katse Iron Ores

Table 2 shows the results of the chemical analysis of Katse iron ore in weight percentages. Samples from four locations (719, 720, 721 and 723) exhibit very high iron content (90–92.5) %, with correspondingly low levels of silica (0.1–0.4) %

and alumina (0.3–0.52)%, respectively. However, sample (4) from location 722 has a low iron content (46.2%), lower alumina (0.13%) and higher silica content (49.3%). In addition, the ores contain other impurities such as CaO, MgO, Na_2O, K_2O, TiO_2 and MnO which exist in considerably negligible amounts. Alumina represents contamination in the steel making process and is specific targets during iron ore beneficiation [9].

TABLE 2
CHEMICAL COMPOSITION OF KATSE IRON ORE

Sample ore :	1	2	3	4	5
Chemical compositions (mass %)					
SiO_2	0.12	0.33	0.25	49.3	0.4
Al_2O_3	0.52	0.39	0.31	0.13	0.51
CaO	0.09	0.13	0.07	0.08	0.13
MgO	0.43	0.4	0.42	0.36	0.42
Na_2O	0.03	0.03	0.03	0.03	0.03
K_2O	0.06	0.05	0.07	0.05	0.09
TiO_2	4.11	4.74	4.31	2.72	4.31
MnO	1.4	1.4	1.33	0.87	1.3
Fe_2O_3	92.1	91.5	90.6	46.2	91.3

The ore from location 722 contains 46.2% Fe and correlates to the low-grade ores although it has a relatively high content of gangue materials (about 49.3%).

The total iron content of most exported iron ores in the world is in the range of 62–64% [12]. Therefore, the average quality of iron ores from the five locations of Katse deposit is above and comparable with the best iron ores nations hence are among the world high-grade ores which can be exploited.

TABLE 3
**GENERALIZED PERCENTAGES OF ELEMENTS OF MAJOR INTEREST IN ANALYZING IRON ORE**

| Components	Total iron content			SiO_2	AL_2O_3	P	S
	Low	Medium	High				
Content (Mass %)	< 58	62-64	>65	6	3- 4	0.05 - 0.07	0.1

[10]

It can be observed that the silica and alumina contents of Samples 1, 2, 3 and 5 (0.1 – 0.4% SiO_2 and 0.1 - 0.52% Al_2O_3) are within the acceptable limits for commercial ores. However, sample 4 has high silica content, which is above the acceptable level. The contents of SiO_2 and Al_2O_3 in commercial ores should be less than (6 and 4) %, respectively which corresponds to the four samples analyzed.

B. Elemental analysis of Katse iron ores

The results of X-ray Fluorescence analysis of iron ores from the 5 different locations of Katse deposits are as shown in figures: 2, 3, 4, 5 and 6 respectively.
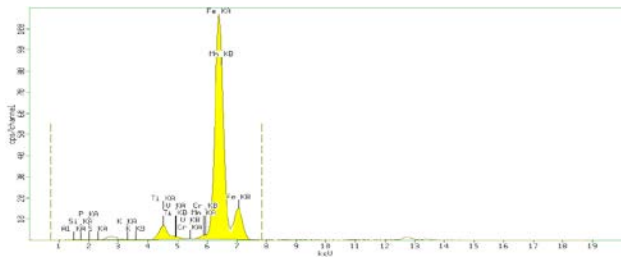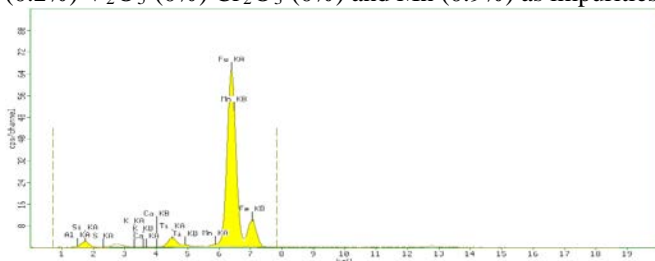

Fig. 2

Sample 1 showed high percentage of Fe_2O_3 (87.1%) and minor amounts of TiO_2 (4.5%), Al_2O_3 (5%) and SiO_2 (1%) with neglegible amounts of P_2O_5 (0.7%), SO_3 (0.4%), K_2O (0.2%) V_2O_5 (0.1%) Cr_2O_3 (0.03%) and Mn (0.96%)
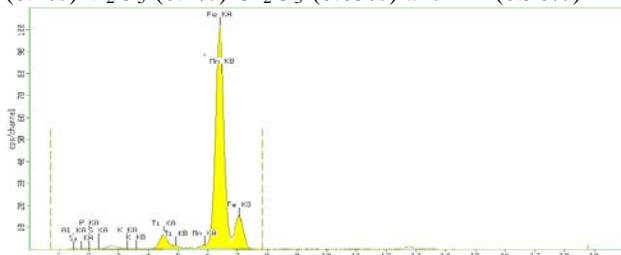
Fig. 3

Sample 2 showed high percentage of Fe_2O_3 (84.4%) and minor amounts of TiO_2 (4.7%), Al_2O_3 (5%) and SiO_2 (0.8%) with neglegible amounts of P_2O_5 (0.2%), SO_3 (0.4%), K_2O (0.2%) V_2O_5 (0%) Cr_2O_3 (0%) and Mn (0.88%)
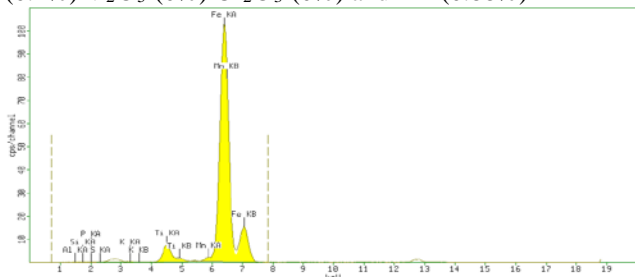

Fig. 4

Sample 3 showed high percentage of Fe_2O_3 (88.5%) and minor amounts of TiO_2 (5%), Al_2O_3 (3%) and SiO_2 (0.8%) with negligible amounts of P_2O_5 (0.7%), SO_3 (0.4%), K_2O (0.2%) V_2O_5 (0%) Cr_2O_3 (0%) and Mn (0.9%) as impurities

Fig. 5

Sample 4 showed moderate percentage of Fe_2O_3 (46.6%) and high amount of SiO_2 (44%). Minor amounts of TiO_2 (2.9%), Al_2O_3 (5%) with negligible amounts of P_2O_5 (0%), SO_3

(0.5%), K_2O (0%) V_2O_5 (0%) Cr_2O_3 (0%) and Mn (0.43%) Large percentage of impurities can be realized in this sample.
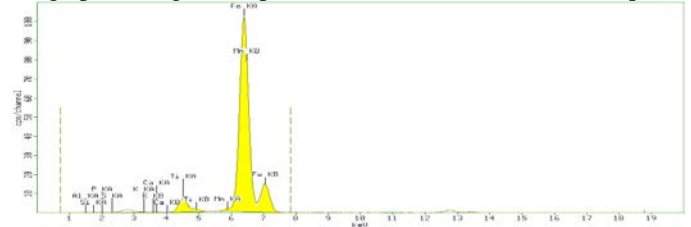

Fig. 6

Sample 5 showed high percentage of Fe_2O_3 (86%) and minor amounts of TiO_2 (5.1%), Al_2O_3 (5%) and SiO_2 (1%) with negligible amounts of P_2O_5 (0.6%), SO_3 (0.6%), K_2O (0.2%), CaO (0.07%) V_2O_5 (0%) Cr_2O_3 (0%) and Mn (0.82%) as impurities

According to obtained results of XRF analysis, it should be pointed out that the S and P contents in iron ores from the Katse deposit are significantly low and the iron content is high (above 80%) and thus are somewhat superior compared to the iron ore from other regions.

C. Mineralogical Analysis of Katse Iron Ores

XRD technique was used to show the phases that iron presented and other mineral phases present especially the silicas and provide the quantification of all the phases.

The typical results of X-ray diffraction analysis of the different iron ore samples are shown in Figures: 7, 8, 9, 10 and 11 respectively.
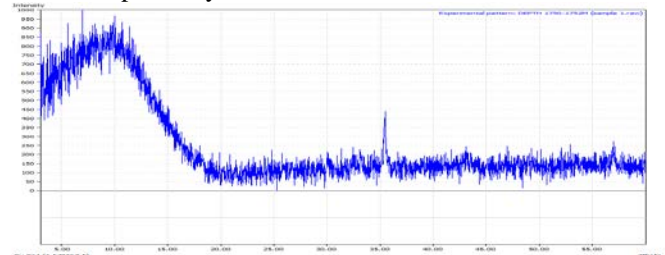
Fig. 7 **Sample 1**

Physical appearance-Reddish brown in colour and the sample was crushed to powder form

Mineralogical interpretation- Ferric oxide appears to be an in-situ with no adverse weathering /erosional effects

Chemical formulae –Fe_3O_4> 86 %
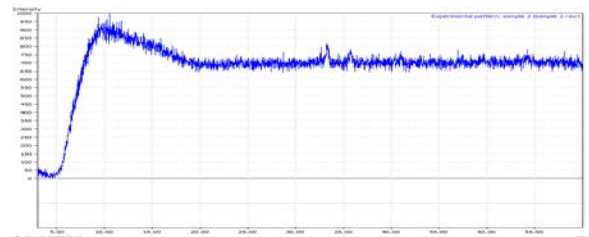
Fig. 8 **Sample 2**

Physical appearance-Reddish brown in colour and the sample was crushed to powder form

Mineralogical interpretation-Ferric oxide with high background in the peaks due to loosely bonded iron high amounts of haematite precipitate from weathering

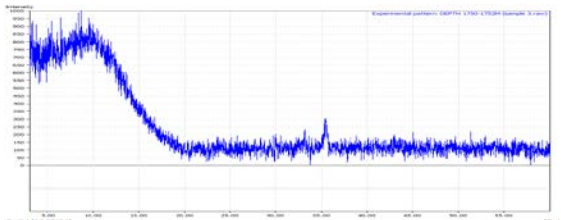**Chemical formulae** –Fe_3O_4 +Fe_2O_3>90 %

Fig. 9 **Sample 3**

Physical appearance-Reddish brown in colour and the sample was crushed to powder form

Mineralogical interpretation -Ferric oxide appears to have silica material embedded

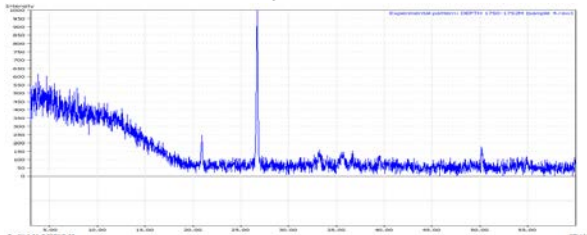**Chemical formulae** –Fe_3O_4> 86 %

Fig.10 **Sample 4**

Physical appearance-Reddish brown in colour and the sample was crushed to powder form

Mineralogical interpretation-Ferric oxide appears to be an in-situ with adverse weathering /erosional effects

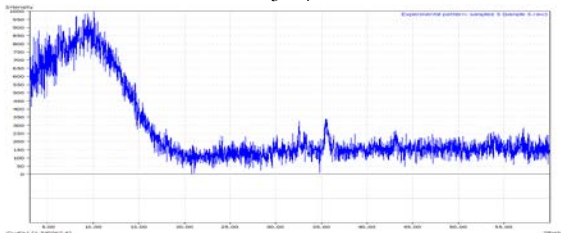**Chemical formulae** –Fe_3O_4> 80 %

Fig. 11 **Sample 5**

Physical appearance-Reddish brown in colour and the sample was crushed to powder form

Mineralogical interpretation-ferric oxide appears to have silica material embedded

Chemical formulae –Fe_3O_4> 86 %

From the results analysis, it is clear that the predominant crystalline element in each of the samples is magnetite (Fe_3O_4) which showed a very high phase of above 80%.

IV. CONCLUSION

Based on the results obtained, it can be concluded that most of Katse iron ores are a high-grade magnetite and low hematite ore that can be profitably exploited for the production of iron.

It can be observed that in its raw form, Katse ore occurs as Magnetite (Fe_3O_4) with low gangue content. Iron ore from four locations contains more than 82% Fe. This compares well with other iron ores from the main iron ore producing nations. The silica and alumina contents of these ores are also below 1.2% and 1.0%, respectively, with correspondingly low levels of S (<0.6%) and P (<0.7%). However, the iron ore from location 722 has lower iron content (about 46.2% Fe) and higher gangue content (49.6% SiO_2 and 6% Al_2O_3) at low

concentration of the deleterious elements (0% P and 0.5% S) which can be defined as a low-grade.

From the results obtained and literature findings, the most appropriate processing technique for this grade of iron ore (magnetite) is the HIsmelt process which is a simple and robust engineering technique with a high level of reliability.

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