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Upgrading of Tin in Kudedu Cassiterite (Tin Ore) Deposit Using Air Floating and 3 D-Magnetic Beneficiations Techniques

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Abstract

This work upgraded Tin in the tin ore deposit in Kudedu, Jos East Local Government Area of Plateau State, Nigeria with the aid of air floating gravity and 3 D-magnetic separations techniques. The ore was sampled by using cone and quartering method before size reduction through crushing and grinding using the Denver jaw crusher and Denver cone crusher. The sample obtained was subjected to sieve analysis to determine the liberation size. The chemical composition of the crude tin ore was analyzed with the aid of Energy Dispersive X-Ray Fluorescence Spectrometer (ED-XRFS). 10 kg of the crude ore at the liberation size was subjected to air floating gravity in order to separate the tailing and concentrate. The resulting concentrate was transferred into the 3-Disc magnetic separator to further add value to the mineral of interest before subjecting it to ED-XRFS to determine the chemical composition. It was observed from the sieve size analysis result and the plot of the cumulative weight percent retained against the cumulative weight percent passing that the liberation size of the ore is at -500+355 µm given an assay of 45.63% SnO_2. The ED-XRFS analysis of the crude ore reveals that the ore contains 15.75% SnO_2 with other associated minerals in different proportions while the value obtained after the value addition is 65.86% SnO_2 which implies that the value of the Kudedu cassiterit ore has been upgraded to meet the standard require as charge in the furnace to produce tin metal.

Keywords

Cassiterite, Tin, Air Floating, Gravity, Concentrate, Ore, Liberation Size

1. Introduction

The most important tin mineral is cassiterite (SnO_2). Cassiterite is the only tin mineral that is in sufficient abundance in the earth's crust to have any commercial value. When chemically pure, which is rare, cassiterite contains 78.6 percent tin but, when contaminated with impurities such as Quartz, muscovite, wolframite, tourmaline, topaz, fluorite, scheelite, lepidolite, arsenopyrite, bismuth, molybdenite, the tin content varies between 73 and 75 percent [1]. It belongs to rutile group of minerals [2]. Cassiterite is mainly found in two types of deposits. First type, it occurs as a primary accessory constituent of certain late-stage granitic intrusions, and is found in veins (In medium- to high-temperature hydrothermal) and fissures both in the granite (greisens) and surrounding country rock. The second type of deposit is of a secondary origin and occurs as alluvial or placer (granite pegmatite, rhyolite; rarely in contact metamorphic) and detrital deposits [1]. The principal ore of tin deposits are widespread. Some important localities are: in Germany, in Saxony, at Marienberg, Altenberg, Johanngeorgenstadt, and many other places. At Cínovec (Zinnwald) and Horní Slavkov (Schlaggenwald), Czech Republic. From La, Villeder, Morbihan, France. At Panasqueira and Cabreiros, Portugal. In England, at many mines in Cornwall, from St. Just and Carn Brae to Liskeard. From the Jos district, Nigeria. Fine crystals from Otjimbojo, Namibia. Economically important placers on the islands of Banka and Billiton, Indonesia; also in Perak and Selangor States, Malaysia. In Australia, from the New England Ranges, as at Emmaville and Elsmore, New South Wales, and from Greenbushes and Pilbara, Western Australia. At Mt. Bischoff and Mt. Zeehan, Tasmania. In China, from the Xue Bao Diang Mountains, Sichuan Province. Large crystals from Fazenda do Funil, Ferros, Minas Gerais, Brazil. Fine crystals from Bolivia, at Araca, Oruro, Potosí, Huanini, and Llallagua [2].

The main commercial tin fields of the world are as follows: West of England, Brittany, and Erzgeburge; Burma, Siam, Malay States, and Indonesia; Bolivia; Nigeria; Australasia; and Southern Africa. There is a clear association of cassiterite with highly acidic granitic rocks, and it is an interesting and significant fact that at not a single tin field in the world has cassiterite been found *in situ* except near granite or granite rocks. Because cassiterite is a chemically stable mineral, each type of primary deposit contributes to the secondary accumulations that are at present the major source of tin. The bulk of the world's supply of cassiterite comes from stanniferous alluvial deposits derived from mineralized areas in their neighbourhood [1].

Nigeria tin ore is in form of cassiterite with varying amounts of associated minerals [3]. The major sources of ore bearing cassiterite in Nigeria are the alluvial and elluvial deposits from the biotite granites within the jurssic alkaline ring complex of the Jos Plateau. More so, less than 5% of the total production has been recovered from the pegmatits within the largely Precambrian basement complex consisting of magnesites, gneisses, but with the rapidly depleting reserves [4]. Kudedu is a village in Jos East Local Government area of Plateau State; a typical mining area, 20 Km away from Jos town. Tin mining in Nigeria is over 100 years old. Prior to 1975, Nigeria was a major tin exporter of cassiterite concentrates which peaked at about 11,000 tonnes. There has been a dramatic decline to about 2000 tonnes. Among the factors accounting for the collapse of this tin industry include the inaccessibility of placer deposits and the current prohibitive cost of mining the ores beneath the basalt flows of Jos [5].

The malleability, ductility, and resistance to corrosion of tin render it suitable for use in a variety of applications. Tin is produced in almost equal amounts from ores (mostly conventionally mined but also via some artisanal mining) and secondary sources (recycled materials), both yielding some 300,000 tons per year [6]. Cassiterite is commonly concentrated by gravity separation methods owing to the differences between the density of the materials in the gangue (usually silicate) [7], and froth flotation techniques [8-10]. China and Indonesia together produce about 70% of the world’s tin, and it is in these countries where most of the world’s tin smelters are located.

It is obvious from the physical characteristics of cassiterite that its high relative density in relation to its gangue constituents makes it an ideal mineral for the application of gravity-separation techniques. Unfortunately, its relative hardness - approximately equal to that of steel - is accompanied by the unfortunate quality of extreme brittleness. This factor must be taken into account during the crushing and grinding operations prior to concentration, and leads to the general policy that cassiterite grains should, where possible, be recovered at the earliest possible stage and at their largest size. Once the particles have been reduced in size to below about 43μm*,* the efficiency of gravity-concentration processes decreases markedly [1].

The gravity techniques applied to the recovery of cassiterite basically fall into two categories: those applied to soft-rock, and those to hard-rock deposits. Soft-rock deposits, this category includes mainly alluvial deposits, which account for 70 to 80 per cent of the world reserves, and the beneficiation processes are relatively simple because of the high degree of liberation of the particles. For alluvial deposits, the simplest and probably the earliest method of recovery and concentration were by means of panning and other hand-washing devices. Hard-rock Deposits, for hard-rock ores, liberation of the cassiterite from the associated gangue minerals is achieved by conventional crushing and grinding. However, because of cassiterite extreme brittleness, significant quantities of very fine particles can be produced at this stage, resulting in losses of tin in the succeeding processing stages. It is pertinent to mention that froth flotation, which is used to upgrade particles less than 43μm, is not able to treat particles smaller than 6μm in size. In some cases, the unrecoverable minus 6μm cassiterite can account for as much as 6 per cent of the metallic tin entering the plant. Most hard-rock tin concentrators use different combinations of the same crushing and milling equipment to effect the liberation, which are then followed by a wide variety of gravity-concentration devices for further beneficiation. The plant at Rooiberg Tin Mine illustrates these methods [1].

To upgrade the tin ore, gravity separation (air-floating technique) has been established as an efficient method to remove impurities from the ore in half a century’s practice around the world. The gravity concentrate will be subjected to cleaning by magnetic separators, which removed wolframite from the cassiterite product. Magnetic separators exploit the difference in magnetic properties between the ore minerals and are used to separate either valuable minerals from non-magnetic gangue, e.g. magnetite from quartz, or magnetic contaminants or other valuable minerals from the non-magnetic values. An example of this is the tin-beating mineral cassiterite, which is often associated with traces of magnetite or wolframite which can be removed by magnetic separators [11].

The optical properties of cassiterite are: transparent when light coloured, dark material nearly opaque; commonly zoned. *Color:* Black, brownish black, reddish brown, red, yellow, gray, white; rarely colorless; in transmitted light, colorless to brown, orange, yellow, green; in reflected light, light gray with white to brownish internal reflections. *Streak:* White, pale brown, pale gray. *Luster:* Adamantine to adamantine metallic, splendent; may be greasy on fractures. Whereas, the physical properties of cassiterite are: *Cleavage:* {100} imperfect, {110} indistinct; partings on {111} or {011}. *Fracture:* Subconchoidal to uneven. *Tenacity:* Brittle. Hardness = 6–7 VHN = 1239–1467 (200 g load). D (meas.) = 6.98–7.01 D (calc.) [2]. The demand for tin has been increasing for the last 30 years and is expected to grow by 2% per annum over the next 5–10 years [5]. A secure supply is essential for the construction business, the manufacture of vehicles, other consumer goods, and even packaging. One of its most important uses is in the manufacture of specialized solders for the electronics industry. Therefore, the aim of this study is to derive the most efficient route to upgrade the Kudedu cassiterite to a concentrate that meet the physical and chemical characteristics of Nigerian tin smelter. The study involved physical and chemical characterization of Kudedu cassiterite in Jos East Local Government Area and to upgrade the ore to a suitable grade concentrate by gravity separation (air-floating) and 3-disc magnetic separation techniques.

2. Materials and Method

Tin ore used in this research was sourced from Kudedu Village in Jos East Local Government Area, Plateau State, Nigeria. 100 kg of the ore was obtained and sampled using cone and quartering method where the ore was poured into a conical heap and relying on its radial symmetry to give four identical samples when the heap was flattened and divided by a cross-shaped metal cutter. Two opposite corners were taken as the sample; the other two corners were discarded. The portion chosen as the sample was further coned and quartered, until the 50 kg of the ore was obtained. The ore was crushed and ground using the Denver jaw crusher and Denver cone crusher to obtain the particle size less than 2 mm at the mineral laboratory of the National Metallurgical Development Centre (NMDC), Jos.

2.1. Chemical Composition Analysis of Crude Cassiterite Sample

The sample was homogenized and subjected to riffles sampling. The representative sample was charged into the analysis cup and compacted before analyzing using the Energy Dispersive X-Ray Fluorescence Spectrometer (ED-XRFS) analyze

2.2. Sieves Size Analysis

The sieves used for the test were arranged in a stack, with the coarsest sieve on the top and the finest at the bottom. A tight- fitting pan was placed below the bottom sieve to receive the final undersize, and a lid was placed on top of the coarsest sieve to prevent escape of the sample. 400 g sample of alluvial cassiterite was charged into set of sieve on the vibrating sieve screen shaker and shook for 30 minutes. The duration of vibration was controlled by the sieve shaker automatic timer. After the required time, the stack was taken apart and the quantity of material retained on each sieve was weighed and analyzed with the Energy Dispersive X-Ray Fluorescence (ED-XRF).

2.3. Beneficiation Technique

Gravity (Airfloating) separation and 3-Disc magnetic separation techniques were employed during the beneficiation of the ore. 10 kg of the crude ore sample at a liberation size of -500+355 μm was charged into the Air floating machine at a speed rate of 50 kg per hour with an inlet opening at 20 mm at a deck slope tilted at 180^o to separate the tailing and concentrate. The concentrate obtained was transferred into the 3-Disc magnetic separator to further add value to it by removing the iron ore which is magnetic; columbite which is paramagnetic and the pure tin which is non-magnetic and was taken for ED-XRF analysis to determine the chemical composition.

3. Result

The result of the sieve size analysis of the ore is presented in table 1 while the graphical representation of the cumulative weight percent retained against the cumulative weight percent passing is shown in figure 1. The result obtained from the ED-XRF analysis of crude ore and the concentrate upgraded tin ore are indicated in tables 2 and 3 respectively.

Table 1. *Sieve Size Analysis of the Kudedu Tin Ore.*

Sizes (μm)	Weight (g)	Weight Percentage (%)	Cumulative (%) weight retained	Cumulative (%) weight passing	% SnO_2
+1000	16.04	4.02	4.02	95.98	34.80
−1000+850	12.47	3.13	7.15	92.85	31.45
−850+710	32.70	8.22	15.37	85.2	10.70
−710+500	77.41	19.45	34.82	84.63	23.75
−500+355	64.55	16.22	51.04	48.96	45.63
−355+250	107.47	27.00	78.04	21.96	33.72
−250+180	58.22	14.63	92.67	7.33	32.10
−180+125	20.65	5.19	97.86	2.14	38.10
−125+90	7.46	1.87	99.73	0.27	35.08
−90	1.06	0.27	100.00	0.00	30.78
Total	398.03				

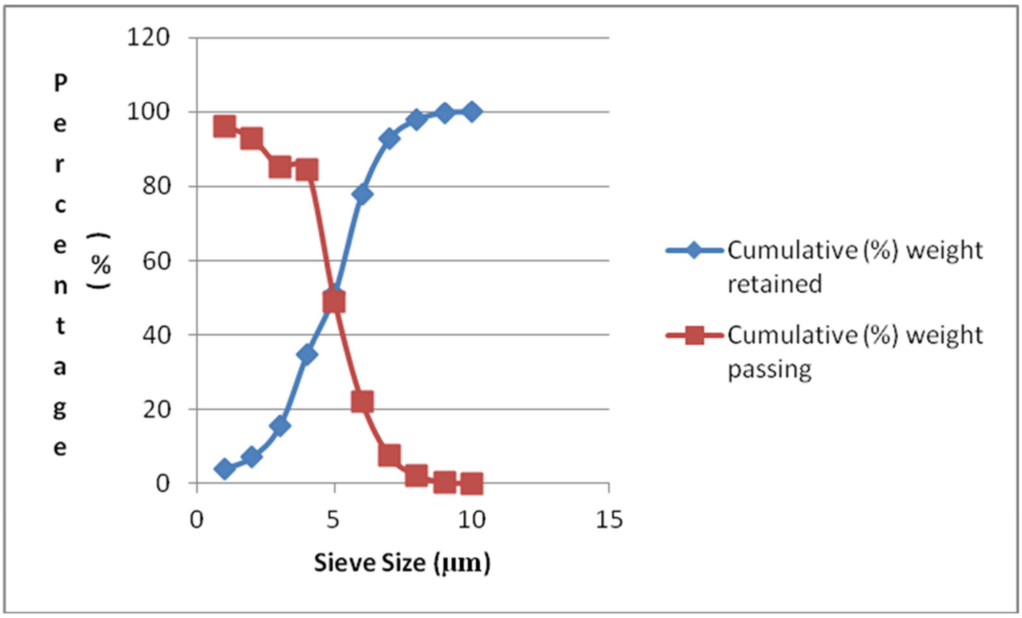

Figure 1. *Log-Log Plot of cumulative % weight retained against Cumulative % weight passing.*

Table 2. *Chemical Analysis Result of Crude Tin Ore.*

ZnO	SiO_2	ZrO_3	PbO	Ag_2O	CaO	SnO_2	Al_2O_3	Fe_2O_3	TiO_2	Nb_2O_5	Ta_2O_5	MnO
0.03	34.01	38.28	0.35	1.06	0.28	15.75	2.08	7.65	0.79	0.54	0.14	0.05

Table 3. *Chemical Analysis Result of the Upgraded Tin Ore*

ZnO	SiO_2	ZrO_3	PbO	Ag_2O	CaO	SnO_2	Al_2O_3	Fe_2O_3	TiO_2	Nb_2O_5	Ta_2O_5	MnO
0.01	4.58	8.74	0.42	2.03	0.04	65.86	0.03	5.25	0.82	0.62	1.03	0.06

4. Discussion of Results

Sieve size analysis is of great significant in determining the quality of grinding and in establishing the degree of liberation of the values from the gangue at various particle sizes. Size analysis of the products is used in the separation stage to determine the optimum size of the feed to the process for maximum efficiency. In table 1, it can be noted that the cumulative weight percent retained and the cumulative weight percent passing at particle size -500+355 µm are respectively 51.04 and 48.96 with an assay of 45.63% SnO_2. At this particle size, beneficiation of Kudedu cassiterite deposit can be said to be optimum and effective when compared to the other particle sizes because the particle sizes at the liberation size are coarse [12]. Also, it can be deduced from figure 1 that at 355 µm sieve size there is an intersection of the two curves which indicates the optimum sieve size where liberation can be effectively attained. Hence, the result obtained in table 1 is also confirmed in figure 1. It can be observed from the results obtained from the ED-XRF analysis (tables 2 and 3) that the initial value of Tin in the crude ore was 15.75% SnO_2 whereas, the value obtained after the upgrading was 65.86% SnO_2 which implies that the value of the Kudedu cassiterit ore has been improved to meet the standard concentrate required as charge in the furnace for tin smelting [13, 5] cassiterite is smelted to extract tin metal which is employed as an additive by injection into molten steel metal to improve its mechanical properties; production and sealing tin cans for packaging can food; for production of pewter and solder (alloy of lead and tin).

5. Conclusion

The value was added to the cassiterite (Tin ore) deposit of Kudedu, Jos East Local Government Area of Plateau State, Nigeria through the airfloating gravity and 3 D-magnetic separations techniques. Liberation size was attained at -500+355 µm sieve size with an assay of 45.63% SnO_2. The initial value of Tin in the crude ore as revealed by the ED-XRFS analysis was 15.75% SnO_2 while the value obtained after the value addition was 65.86% SnO_2. Hence, the value of Tin in the Kudedu cassiterite ore has been upgraded to meet the standard require as charge for tin smelting in the furnace.

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