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Research article

Investigating the Production of Ultrafine Engineering Material from Low-Grade Gariti Barite Ore Using Gravity Concentration Methods

Oladunni O. Alabi[a], Yemisi E. Gbadamosi[a,*]

[a]*Department of Metallurgical and Materials Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Akure, Ondo State, Nigeria.*

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* Corresponding author:

Yemisi E. Gbadamosi
E-mail: gbadamosiyemisi.e@gmail.com

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A B S T R A C T

The objective of this research is to upgrade the low-grade Gariti barite ore to produce an ultrafine engineering material that can be used for industrial application by the assessing gravity concentration method. The research focuses on chemical characterization, fractional sieve size analysis, scrubbing technique, wilfley shaking table technique, and air float technique. The sample was subjected to an energy-dispersive X-ray fluorescence spectrometer and fractional sieve analysis of the crude sample was carried out at a sieve range of 1400-63 µm towards the production of ultrafine mineral-based material for liberation size determination. Ten (10) kg, each of the actual liberation size were used for the scrubbing technique, wilfley shaking table technique, and air float technique respectively. The chemical analysis indicates the presence of major elements 79.20 % BaSO4, 14.4% SO3, 64.80% BaO, 3.80% Fe2O3, 5.15% SiO2, 1.40% TiO2, and other minor elements that confirms that the soured mineral is barite while the particle size analysis showed that -250+ 180 µm sieve size fraction assaying 89.11% BaSO4 is the ore's actual liberation size. The chemical analysis of the low-grade Gariti Barite ore after undergoing a concentration test at the economic liberation size revealed the values of concentrates from the scrubbing technique to be 86.60% BaSO4, Wilfley shaking table technique to be 86.10% BaSO4, and air float technique to be 88.30% BaSO4 and from this results, it shows that air float technique had the highest assaying value. Finally, the low-grade Gariti barite ore has been upgraded from 79.20% BaSO4 to ultrafine mineral-based engineering material of 86.60%, 48.6% 86.10%, and 88.30% BaSO4 via gravity concentration method.

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1. INTRODUCTION

The states of matter of natural resources are classified as solid (rocks), liquid (water), and gas (air). A mineral is a homogeneous, naturally occurring inorganic solid with a specific chemical composition that is economically valuable. Exploiting natural resources has become critical in various developing nations, including Nigeria, and to do so, they must go through the stages of exploration, mining, and processing or beneficiation [1-12].

Barite is a nonmetallic mineral formed by the combination of barium and sulfur. It is made up of barium sulfate (BaSO4) and appears as granular or crystalline masses, nodules, rosette-like aggregates, and laminated to enormous beds with fine crystallinity. It is also chemically inert and insoluble [9,13-16]. Barite is used as a weighing component in drilling mud and as an X-ray shielding agent in medicine. Barite is an opaque material that is used to suppress gamma and X-ray emissions in hospitals, power plants, and laboratories. When coarse sand-size barite is added to a glassmaking mixture, it acts as a flux, increasing the brightness of the glass [8].

Barite is used as a pigment in paints and as a weighted filler for paper, fabric, and rubber in the creation of "anti-sail" mudflaps for trucks [17]. The majority of barium compounds, such as barium sulfide, barium chloride, barium nitrate, barium carbonate, and others, are derived from bauxite. Barium chloride is used in the production of cloth and leather, barium oxides are used in glassmaking and electric furnace metallurgy, barium carbonate is a component of ceramic glazes and enamels, and barium nitrate is used in the production of detonators and flares [8, 13]. Other applications for barite include plastics, clutch pads, mold release compounds, sound-deadening material in automobiles, traffic cones, and brake linings.

Barite occurs in a variety of deposit types, including vein and cavity filling, residual deposits, and bedded deposits, with the vein deposit occurring in Zamfara State because of epigenetic hydrothermal fluids that leached barium from adjacent rocks and precipitated it in the vein [18-21]. The depth and width of these deposits range from a few centimeters to several meters (0.6m-2m), with a length of around 100 m. With huge to granular irregular fractures, the hue ranges from white to reddish-brown [12, 5, 7, 19]. The Gariti town, located at latitude 12°06'30"N and longitude 5°56'00"E in Zamfara State, is inside the schist belt of undifferentiated meta-sediments within the basement complex of North Central Nigeria. This study's sample was taken at a depth of 5-7 meters and is connected with quartz veins [20, 8].

1.1 Gravity concentration method

Gravity separation is an industrial process of separating two components from a granular mixture with different specific weights, in either suspension or dry. The separation of components uses gravity as the primary criterion. The cost-effectiveness and, in some situations, sound reduction are the most noticeable advantages of gravitational approaches [17, 6]. The concentration criterion is used to determine the appropriateness of ore to gravity concentration before concentration, as demonstrated mathematically in equation 1[19].

$$\text{Concentration criterion} = \frac{Dh-Df}{Dl-Df} \quad (1)$$

Where:

Dh is the specific gravity of the heavy mineral,

Dl is the specific gravity of the light mineral,

Df is the specific gravity of the fluid medium.

In general, when the quotient is more than 2.5, whether positive or negative, the ore is sensitive to gravity separation, with separation efficiency decreasing as the quotient value drops [18]. Gravity separation encompasses the following mineral dressing techniques: scrubbing, dense-medium separation, jigging, shaking table separation, air float technique, chute separation, and centrifugal separation.

The goal of this research is to determine the best mineral processing procedure for improving the low-grade Gariti Barite deposit, in Zamfara State for industrial such as a source of drilling mud in the oil industry, chemical, filler, glass, and aggregate shielding bricks on a laboratory scale. In this study, the scrubbing, Wilfley shaking table, and air float separation were utilized to improve the low-grade Gariti barite ore to ultrafine mineral-based material.

2. MATERIAL AND METHODS

2.1 Material

The crude sample of low-grade Gariti barite from Zamfara State, Nigeria, was used for the research.

2.1.1 Sample collection

The low-grade Gariti barite sample was collected from ten (10) distinct pits at the Gariti mining site; it was homogenized using a hand-held shovel on a flat cemented clean surface, and 20 kg was sampled out for this research utilizing the random sampling approach.

2.1.2 Sample preparation

The obtained 20 kg of crude sample was crushed in a Fritsch Pulveristte Laboratory Jaw Crusher. Then milled in a Denver Laboratory Milling Machine for a chemical characterization study.

2.2 Method

2.2.1 Chemical characterization of crude low-grade gariti barite ore using the Energy Dispersive X-ray Fluorescence Spectrometer (ED-XRFS)

To chemically evaluate the crude material, an energy-dispersive X-ray Fluorescence Spectrometer, model: PANanalytical Minipal7 is employed. 20 g of the sample was pulverized to pass through a 200-250 grit screen, appropriately combined with a cellulose flakes binder in a 5 g to 1 g cellulose flakes binder ratio, and pelletized in a pelletizing machine at a pressure of 10-15 tons/inch2. After storing the pelletizing sample in a desiccator for analysis, the ED-XRFS machine was turned on for 2 hours. Finally, relevant programs for detecting the presence or absence of specific constituents of interest were used to analyze the crude sample. The determined result was presented in % for minor and main element concentrations.

2.2.2 Particle size analysis of the crude low-grade gariti barite ore

100 g of the prepared sample was put through the highest sieve of a set of sieves arranged following the 2 series ranging from 1400 to -63 µm to achieve the barite ultrafine material size [10]. The final undersize is collected in a tight-fitting pan attached to the bottom sieve. A lid was also placed on top of the highest sieve to prevent the sample from escaping. The sieves were agitated for 30 minutes using an automated sieve shaker type EFL2mk11 [2]. Each sieve's retained particle weight was weighed.

2.2.3 Scrubbing separation technique of the produced ultrafine gariti barite ore

10 kg of liberation size - 250 + 180 µm highly concentrated pulp was created by adding 7 liters of water to the 10 kg of the crude sample, and the scrubbing test was performed for 5 minutes at a stirring rate of 1500 rpm. The density gauge was used to determine the pulp density of the combination. At room temperature, 20 g of Sodium Silicate was pre-dissolved in water (5 MLS) and it was added to the scrubbing suspension [4]. After scrubbing, the pulp was dispersed in 25 liters of water for 5 minutes. The float and sink products were collected into separate containers and left to settle for 24 hours before the water was decanted. The resulting pulp products were filtered using a 750-diameter filter paper, and the filtering cake was dried in a carbolite oven at 110ºC for 12 hours, yielding a nearly moisture-free 99.9% dry sample. To determine the chemical composition of the final products, samples were taken for analysis.

2.2.4 Wilfley shaking table technique of the produced ultrafine gariti barite ore

At a pulp density of 25-30% solids, 10 kilograms of the produced ultrafine Gariti barite ore sample with sieve size - 250 + 180 µm was mixed with water. The slurry was delivered onto the table via a distribution box at the high end of the table at an angle of 180º at a feed rate of 50 liters per hour and a deck speed of 1000 revolutions per minute (rpm) [3]. The water and ore particles flow diagonally across the table due to the table's motion. The heavy particles settle into the riffles formed by the wood strips and migrate across the table to the opposite end, where they are collected. The lightweight particles are swept across the riffles as they ride on top of the concentrate. The pulped product was filtered, and the filtering cake was dried in a carbolite oven model OV95C at a temperature of 110ºC to remove all moisture. The finished products were weighed and analyzed to determine their chemical compositions.

2.2.5 Air float technique of the produced ultrafine gariti barite ore

10 kg of ultrafine mineral-based material of low-grade Gariti barite ore was fed to the table by gravity. As the ore is fed to the machine the air going through the porous deck acts as a pneumatic cushion upon which the particles rest, which makes the entire deck load, becomes fluid. The heavy particles fall and displace the lighter ones as they move along the front end of the deck with the deck inclines at 30 degrees. The air inlet was controlled to open at level 2 meaning 20% volume of air passage into the air chamber of the machine vibrating at 1000 revolutions per minute (rpm) [3, 14, 15]. The resulting samples are discharged into six (6) bucket receivers according to their particle weights. The concentrate was realized at combined buckets one and two (1 and 2), tailing at combined buckets five and six (5 and 6), while buckets 4 and 5 contained the middling which was re-run to give a separation that was mixed with either concentrate or tailing receiver. Then, the resulting products were weighed, and sampled for the determination of their chemical composition.

3. RESULT

Table 1. Chemical composition of mined low-grade gariti barite ore.

Compositions	SiO_2	$BaSO_4$	SO_3	TiO_2	CaO	Fe_2O_3	CuO	ZnO	SrO	BaO	PbO	Al_2O_3
Content (%)	5.15	79.20	14.4	1.40	0.15	3.80	0.08	0.04	0.52	64.80	0.16	0.95

Table 2. Fractional sieve size analysis of mined low-grade gariti barite ore.

Sieve Size (μm)	Weight (gm)	Weight (%)	% Cumulative Weight Retained	% Cumulative Weight Passing	% $BaSO_4$ Assay	% SiO_2 Assay
+ 1400	22.19	22.22	22.22	77.78	84.43	6.30
- 1400 + 1000	13.08	13.10	35.32	64.68	83.51	6.70
- 1000 + 710	10.08	10.09	45.41	54.59	83.63	6.20
- 710 + 500	8.00	8.01	53.42	46.58	84.35	5.50
- 500 + 355	5.76	5.77	59.19	40.81	82.33	7.30
- 355 + 250	4.49	4.50	63.69	36.31	81.48	7.50
- 250 + 180	9.37	9.38	73.07	26.93	89.11	7.20
- 180 + 125	11.24	11.25	84.32	15.68	83.26	5.40
- 125 + 90	9.97	9.98	94.30	5.70	84.30	4.80
- 90 + 63	4.40	4.41	98.71	1.29	84.35	4.70
- 63	1.29	1.29	100	0	82.00	2.30
	99.87	100				

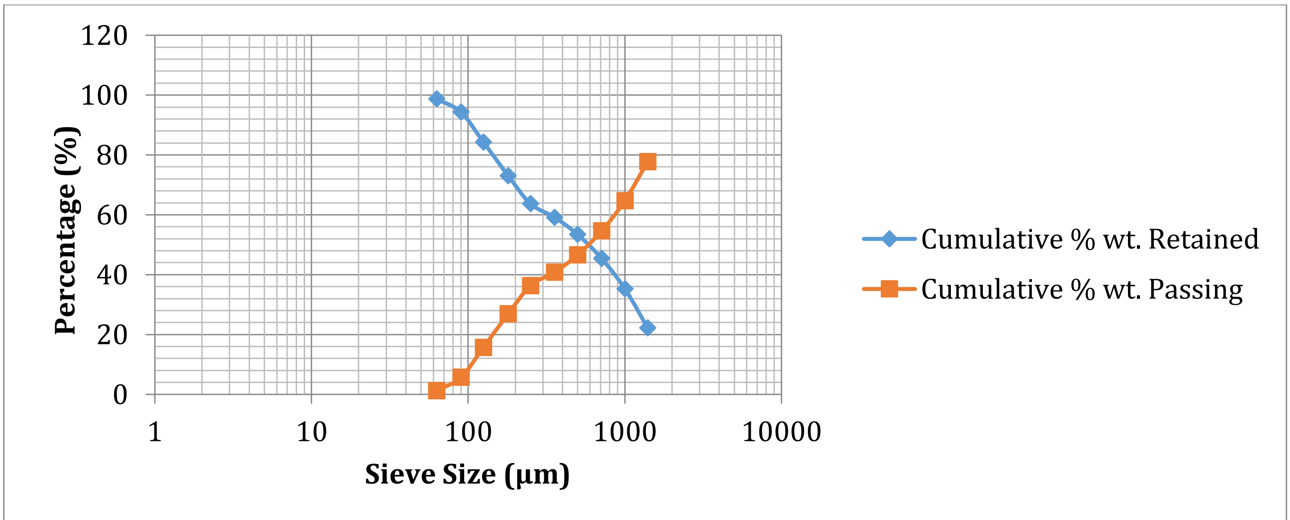

Fig. 1. A plot of log-log of percentage cumulative retained and passing against sieve sizes (μm) of the fractional analysis of mined low-grade Gariti barite ore.

Table 3. Yield results of scrubbing technique in weight (kg).

Barium Ore Sample	Weight (kg)
Charge	10.0
Concentrate	5.80
Tailing	3.30

Table 4. Chemical analysis of the product (concentrate and tailing) realized via the use of the scrubbing technique to produce ultrafine mineral-based material.

Sample	Al_2O_3	SiO_2	$BaSO_4$	SO_3	Fe_2O_3	CaO	TiO_2	CuO	ZnO	SrO	BaO	PbO
Concentrate	0.70	3.00	86.60	15.60	3.07	0.160	1.60	0.08	0.03	0.50	71.00	0.14
Tailing	1.50	5.90	30.50	14.40	4.95	0.23	1.30	0.07	0.06	0.50	66.20	0.24

Table 5. Yield results of Wilfley shaking table technique in weight (kg).

Barium Sample	Weight (kg)
Charge	10.0
Concentrate	6.70
Tailing	3.10

Table 6. chemical analysis of the product (concentrate and tailing) realized via the use of the Wilfley shaking table technique to produce ultrafine mineral-based material.

Sample	Al_2O_3	SiO_2	$BaSO_4$	SO_3	Fe_2O_3	CaO	TiO_2	CuO	ZnO	SrO	BaO	PbO
Concentrate	1.00	3.40	86.10	15.40	3.21	1.80	1.50	0.07	0.06	0.52	70.70	0.16
Tailing	1.40	5.70	30.30	14.10	4.58	0.23	1.40	0.07	0.04	0.49	66.20	0.24

Table 7. Yield results of air float separation technique in weight (kg).

Barium Ore Sample	Weight (kg)
Charge	10.0
Concentrate	7.30
Tailing	2.70

Table 8. Chemical analysis of the product (concentrate and tailing) realized via the use of air float technique technique to produced ultrafine mineral-based material.

Sample	SiO_2	$BaSO_4$	SO_3	Fe_2O_3	CaO	TiO_2	CuO	ZnO	SrO	BaO	PbO
Concentrate	2.00	88.30	15.50	2.53	0.19	1.60	0.07	0.03	0.54	72.80	0.15
Tailing	3.30	9.10	10.90	11.50	0.28	0.89	0.07	0.06	0.39	48.20	0.27

Table 9. Metallurgical accounting for scrubbing, Wilfley shaking table, and air float separation technique of the produced ultrafine mineral-based material.

Concentration Test	Processed Samples	Recovery (%)	Enrichment Ratio	Concentration Ratio	Grade (%)
Scrubbing Technique	Concentrate	63.42	1.1	1.7	86.60
	Tailings	12.71	0.4	3.0	30.50
Wifley Shaking Table Technique	Concentrate	72.80	1.0	1.5	86.10
	Tailings	11.90	0.4	3.2	30.30
Air Float Separation Technique	Concentrate	81.40	1.1	1.4	88.30
	Tailings	3.10	0.1	3.7	9.10

4. DISCUSSIONS

Table 1 shows the chemical composition of crude low-grade Gariti Barite ore using Energy energy-dispersive X-ray Fluorescence Spectrometer (ED-XRFS). The analysis revealed that the crude or mined ore sample contains 79.20 % $BaSO_4$, 14.4% SO_3, 64.80% BaO, 3.80% Fe_2O_3, 5.15% SiO_2, 1.40% TiO_2, and other compound in trace form, thus confirming the presence of barite in the crude ore.

Table 2 Figure 1 shows the particle size analysis of the crude and the log-log plot of % cumulative weight retained and passing against sieves sizes respectively. Table 2 shows the percentage weight retained by each sieve fraction. From the graph, the two curves obtained are mirror images of each other and they intercept at - 710 + 500μm. Thus, the economic liberation size of the mineral is - 710 + 500 μm assaying 84.35 μm and the actual liberation size is - 250 + 180 μm assaying 89.11% $BaSO_4$ which is in line with the findings in the literature [11].

Table 3 – 4 reveals the yield and the chemical characterization of the processed samples of the scrubbing process. Table 3 shows that the yield of the concentrate after repeated scrubbing process is higher than the yield result of the tailings. Table 4 reveals the chemical composition of the processed sample from the scrubbing process of -250+180 μm sieve size fraction and $BaSO_4$ assay 86.60%, which shows an improvement in the percentage assay of the crude low-grade Gariti barite ore (79.20%) present in this mineral.

Tables 5 – 6 reveal the yield and the chemical characterization of the processed samples of the Wilfley shaking table process. From the result in Table 5, the yield for the resulting products for concentrate was higher when compared to that of the yield of the resulting products of the tailings. Table 5 shows the chemical composition of the concentrate and the economical liberation size assay of $BaSO_4$ which is 86.10%. This shows an improvement in the percentage assay of the produced ultrafine mineral-based material present in the low-grade Gariti barite ore.

Table 7 – 8 reveals the yield and the chemical characterization of the processed samples of the air float technique. From the result in Table 7, the yield for the resulting products for concentrate was higher when compared to that of the yield of the resulting products of the tailings. Table 8 shows the chemical composition of the concentrate and tailings. The economical liberation size assay of $BaSO_4$ is 88.30%. This shows an improvement in the percentage assay of the produced ultrafine mineral-based material present in the low-grade Gariti barite ore. In addition, it produced the highest percentage of $BaSO_4$ concentrate compared with the other techniques explored.

Table 9 presents the metallurgical accounting of the scrubbing, wifely shaking table, and air float separation technique of the produced ultrafine Gariti barite material, which reveals the metallurgical performance of the separation method at - 250 + 180 μm sieve fraction. Since enrichment and concentration ratio are parameters used to assess the separation efficiency of a separation method (Wills, 2006), it can be deduced that maximum separation efficiency was achieved at the scrubbing technique having enrichment and concentration ratios of 1.1 and 1.7 respectively. The concentrate obtained assayed 86.60% $BaSO_4$ at a recovery of 63.42%. However, optimum separation efficiency taking into consideration the optimum assay and recovery of concentrate was achieved at the air float separation technique having an enrichment and concentration ratio of 1.1 and 1.4 respectively. The air float separation technique concentrate obtained assayed 88.30% $BaSO_4$ at a recovery of 81.40% which is the highest compared with the two other concentration test that was explored.

5. CONCLUSION

Production of ultrafine engineering materials from an as mined low–grade Barite or mined at Gariti village was successfully carried out using gravity concentration methods. It was therefore concluded that:

1. The scrubbing and shaking table methods involved the use of water as the separation medium. Water and electricity input attracts cost depending on the quantity consumed. The air float method employed air as its medium of separation is a free commodity and does not attract any cost and it produced the highest percentage of $BaSO_4$ concentrate.

2. the grade barium of concentrates from the Wilfley Shaking Table was 86.10% $BaSO_4$, Scrubbing was 86.60% $BaSO_4$ and Air Float method was 88.30%. These grades do not meet the 90% $BaSO_4$ in barite for drilling, glass, chemical, and filler grade. Hence, the produced material can be used for aggregate and shielding bricks by careful selection and grading. And
3. finally, the foregoing air float method is the best in terms of percentage $BaSO_4$ concentrate, recovery, and operational cost-effectiveness.

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