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Grindability and Mineralogical Characterization of Ikpeshi Basalt for Effective Soil Amendment

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Abstract. *This study assessed the grindability and mineralogical composition of basalt rock collected from Ikpeshi town, Edo State, Nigeria. Using the work index approach, its suitability as an amendment for agricultural soil was evaluated while calcite rock was used for comparison as the reference ore. The samples were crushed, milled, and pulverized to pass through a sieve of 1180µm, after which 100g portions were subjected to sieve analysis (1000–63µm) to establish data for their grindability potential. Results revealed a work index of 10.10 kWh/t for calcite and 18.722 kWh/t for Ikpeshi basalt, with actual grinding energy for basalt determined as 3.52 kWh. The elemental and chemical characterization of both rocks was carried out using the X-ray Fluorescence (XRF) and X-ray Diffraction (XR) approach, the mineralogical analysis revealed that the basalt rock contains minerals that are essential for improved soil fertility. The study highlights Ikpeshi basalt as a mineral resource with moderate grinding energy requirements and strong potential for sustainable use as a soil amendment.*

Keywords: *Grindability, Basalt, Sieve shaker, Comminution, Soil amendment.*

1. Introduction

Basalt is one of the most common types of volcanic rock on earth. It formed when low-viscosity lava cools quickly at or near the surface. These deposits are usually found at divergent plate borders, oceanic hotspots, and large igneous provinces (LIP). The Deccan Traps in India and the Columbia River Basalt Group in the United States are two of the most famous continental basalt formations. They were made during times of heavy volcanic activity that were connected to mantle plumes [1]. Basalt deposits in the water are very common, especially near mid-ocean ridges, where new oceanic crust is always being made [2]. Basalt differs from other intrusive igneous rocks like gabbro due to its fine-grained texture and mineral composition, which mostly consists of pyroxene and plagioclase. These characteristics suggest fast cooling. Over time, these massive basalt flows can create plateaus and cover sizeable areas, causing major changes in the ecosystem and geology [3].

Minerals like calcium, magnesium, and potassium, which are necessary for plant growth, are abundant in basalt, a volcanic rock [4]. It has been demonstrated that applying basalt as a soil supplement increases soil fertility and boosts agricultural yields [5]. Particularly in tropical and subtropical areas where weathering has reduced nutrient levels, the mineral makeup of basalt can aid in restoring nutrient-deficient soils [6]. In recent years, there has been a growing interest in investigating basalt as a soil supplement, especially in areas where the soil quality is not ideal for agricultural output. Because of its grindability, basalt especially that from Nigeria's Ikpeshi region offers a rare chance to evaluate its potential as a useful soil amendment. This paper summarizes the body of knowledge regarding the use of basalt in agriculture, the characteristics of basalt that make it a useful soil amendment, and the techniques used to determine how grindable it is.

According to a study by [7], basalt greatly improves the soil's micronutrient availability, which supports better growth of plants. Furthermore, basalt is a useful amendment in areas with high acidity because of its alkaline composition, which can help neutralize acidic soils [8]. Basalt's potential advantages in sustainable agriculture are highlighted by its dual function as a pH balancer and a supplier of soil nutrients. The physical and chemical characteristics of basalt are primarily responsible for its efficacy as a soil amendment. According to [9], basalt's high specific surface area can increase its reactivity in soil conditions. Better contact with soil particles and microorganisms is made possible by this characteristic, which promotes nutrient exchange and enhances soil structure [10].

Furthermore, depending on its geological genesis, basalt's mineralogical makeup varies greatly, which may affect how efficient it is as an amendment. For example, zeolites can improve the capacity to contain nutrients and retain water in some basalt deposits [11]. Therefore, in order to ascertain whether Ikpeshi basalt is suitable as a soil amendment, a thorough examination of its mineralogical composition is required. The usefulness of basalt as a soil amendment is largely dependent on its grindability. For a material to be used effectively in agricultural activities, it must be easy to convert to a powder, which is known as its grindability [12]. Numerous investigations have studied the grindability of different geological materials; frequently use the Bond work index as a benchmark [13]. In the case of basalt, the texture, mineral composition, and existence of any secondary minerals can all affect its grindability [14]. There is a substantial vacuum in the research because Ikpeshi basalt's grindability and mineral composition has not been investigated or reported, determining the economic viability of using basalt deposit as a soil supplement requires an understanding of its grindability.

The grindability of geological materials has been evaluated using a variety of techniques. The Bond work index, which measures the energy needed to grind a material to a particular size, is most commonly calculated using ball mills [13]. Other methods include the use of laboratory-scale grinding tests and empirical models that correlate grindability with physical properties [15]. Other approaches to evaluating grindability have been made possible by recent technological developments in addition to these conventional methods. For example, more thorough understanding of the grinding process and the resulting particle size distribution can be obtained by the use of digital photography and particle size analysis [16]. These developments have the potential to improve the precision of grindability evaluations, yielding more trustworthy information for assessing Ikpeshi basalt.

It's also important to think about how using basalt as a soil amendment may affect the environment. Carbon emissions and habitat disruption are two ecological effects of basalt extraction and processing [17]. The advantages of better soil health and higher agricultural productivity exceeded these disadvantages when used sparingly [18].

The economic factors are equally significant. It is necessary to compare the cost-effectiveness of applying and grinding basalt as a soil amendment to alternative techniques for improving soil quality [19]. Local farmers and food security may greatly benefit from the potential for basalt deposits to offer a sustainable and reasonably priced source of soil amendment.

The potential advantages of basalt as a soil additive for increasing crop yields and soil fertility are highlighted. Ikpeshi basalt, particular its grindability aspect is underexplored, therefore, more study is required to determine whether it is suitable for use in agriculture. By analyzing the characteristics of Ikpeshi basalt and using proper approach to evaluate its grindability, this study aims to fill a critical gap in the literature and contribute to the sustainable use of local geological resources in agriculture.

2. Materials and Method

2.1. Materials

Materials used for this research are basalt rock sample sourced from Ikpeshi town in Edo State Nigeria, while reference mineral was found from the test ore over burden in the same site at Etsako West Local Government Council.

2.2. Methods

Fifty (50) kilograms of the basalt rock sample was collected from five (5) different pits at Ikpeshi quarry site located in Etsako West Local Government with coordinate 7.0084^0N, 6.0143^0E in Edo state, Nigeria. These samples were collected at a dimension of 5 meters length by 5 meters breadth and depth of 13 meters and above [20] with a distance of 100 meters apart. The sourced samples were mixed thoroughly and homogenized to obtain a uniform sample using the cone and quartering method of sampling. The grab sampling method was used to collect ten (10) kilograms of calcite from each pit overburden. The lumpy basalt was crushed using a Yu Feng100 x 60 jaw crusher (model XL1349) and then ground using a ball mill (locally fabricated at Auchi Polytechnic) to a sieve aperture 1180 μm until 100% passing was obtained. Five hundred (500) grams of the ground Basalt was collected using Jones Riffle's random sampling methods and prepared for chemical characterization to determine their elemental compositions. Hundred (100) grams of the ground Basalt was charged into an array of sieves arranged in root two (√2) (that is, from 1000 – 63 μm) on a Jinling Ro–Tap automated sieve shaker machine (model 890212050023) and shook for 15 minutes after which the retained on each sieve were weighed and recorded as feed into a ball mill (Ft). Sample from this prepared sample was equally charged into a ball mill and ground for 20 minutes to obtain ball mill product from further size reduction. 100 grams of this ball mill product was equally charged into a set of sieves. Retained products on each sieve were weighed and recorded. From the Table, a log-log graph was used to plot the percentage of cumulative weight retained and passing against the sieve sizes in micrometers. These procedures were repeated for the reference mineral (calcite).

2.3. Bond's work index determination

Gaudin Schumann's expression is often used to derive a modified approach for calculating the work index of Ikpeshi Basalt, which resulted in an 80% passing rate. Gaudin Schumann's expression thus:

$$P(X) = 100(\frac{X}{K})\alpha^{i} \tag{1}$$

Where:
P(X) = Cumulative percentage passing
x = Particle size
k = Size modulus
a = Distribution modulus

$$\alpha = \frac{Log\, P(x_2) - P\,(x_1)}{Log\,(x_2) - PLog\,(x_1)} \tag{2}$$

$$\alpha = x_2 = \frac{(Px_2)^2}{(Px_1)^2} \times x_1 \tag{3}$$

$P(x_2)$ = Percentage Passing Size at 80 % passing
$P(x_1)$ = Percentage Passing Size before 80 % passing
x_1 = Sieve size before 80 % passing
$\alpha = (x_2)$ = Sieve sizes at 80 % passing

Net power required P (KWhr) = $\frac{(Ploaded - Pempty)\ x\ th}{Mass\ of\ feed\ (tonnes)}$ (4)

Ploaded is electric power required to grind loaded rock feed (KW)
Pempty is standard idling electric power required without rock feed (KW)th is grinding or operating time (hrs)
m is mass of rock grinded (tonnes)

The work index of Ikpeshi basalt was determined using

$$(Wit) = \frac{P}{10\ (\frac{1}{\sqrt{Pt}} - \frac{1}{\sqrt{Ft}})} \quad (5)$$

Energy used in comminution of Ikpeshi basalt was determined using

$$Et = Wit(\frac{10}{\sqrt{Pt}} - \frac{10}{\sqrt{Ft}}) \quad (6)$$

Wit = Work index of rock feed
Et = energy required, kWh
Ft = Sieve size of Basalt feed into ball mill, 80% passing through 100 μm
Pt = Sieve size of Basalt Product from the ball mill, 80% passing through 100 μm
Frs = Sieve size of Reference ore feed into ball mill, 80% passing through 100 μm
Prs = Sieve sive of Reference ore Product from ball mill, 80% passing through 100 μm [13, 21].

2.4. Results and Discussion

Table 1. Mineral Composition of Ikpeshi Basaltic Rock (%)

Location	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	P_2O_5	TiO_2	LOI
Iesha Basalt	48.32	13.12	8.02	6.19	5.05	1.42	6.76	0.20	7.63	1.48	1.32

Table 2. X-ray Fluorescence Spectrometer (Chemical) Analysis of Ikpeshi Calcite

Elements	Intensity	Contents
Magnesium(Mg)	0.0004	0.5217
Aluminum(Al)	0.0038	1.2314
Silicon(Si)	0.0281	2.7804
Phosphorous(P)	0.0055	0.2573
Sulphur(S)	0.0076	0.5684
Calcium(Ca)	0.6241	61.2238
Titanium(Ti)	0.0001	0
Manganese(Mn)	0.0001	0.0015
Cobalt(Co)	0.0001	0.0007
Iron(Fe)	0.0096	0.9938
Nickel(Ni)	0.0002	0.0089

Elements	Intensity	Contents
Copper(Cu)	0.0006	0.0117
Zinc(Zn)	0.0007	0.022
Gold(Au)	0	0.0272
Silver(Ag)	0.0001	0.0025
Rubidium(Rb)	0.0004	0.0015

[22]

2.4.1. Results of Sieve Analysis of Ikpeshi basalt (test feed) to ball mill

Table 3. Sieve size analysis of Ikpeshi basalt (test feed) to ball mill.

Sieve size (µm)	Sieve size range (µm)	Weight retained (g)	% weight retained retained	Cumulative weight retained (%)	Cumulative weight passing (%)
1000	1000	13.383	13.502	13.502	86.498
-1000+710	710	3.791	3.825	17.327	82.673
-710 + 500	500	4.727	4.769	22.096	77.904
-500 +355	355	4.204	4.241	26.337	73.663
-355+ 250	250	15.772	15.913	42.250	57.750
-250 + 180	180	30.558	30.831	73.081	26.919
-180 + 125	125	0.022	0.022	73.103	26.897
-125 + 90	90	0.088	0.089	73.192	26.808
-90 +63	63	0.198	0.200	73.392	26.608
-63	Pan	26.373	26.608	100.00	0.00
Total		99.116			

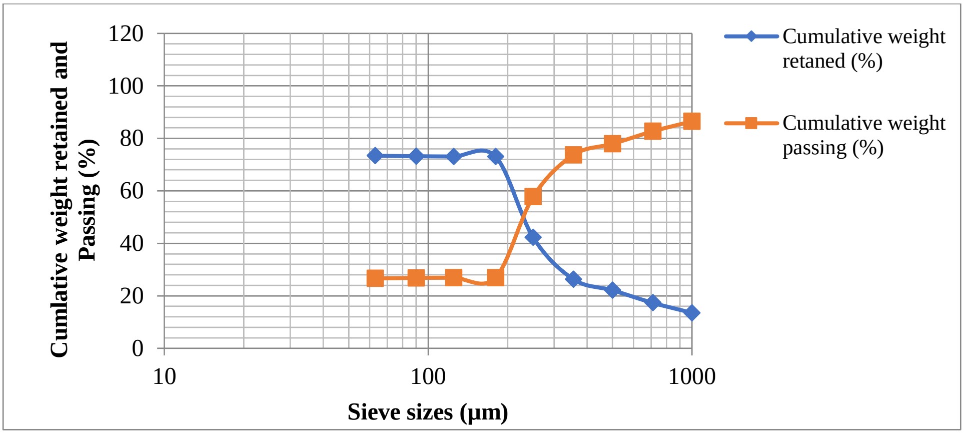

Figure 1. Cumulative weight retained (%) and cumulative weight passing (%) against Sieve size (µm) of Ikpeshi basalt feed to the ball mill

Therefore, from Table 2 and Figure 1, to obtain 80% passing, the size of the sieve will be calculated using the Guadin Schumann expression in Equation (3)

$$X\mu m = \left(\frac{\frac{80}{100}}{\frac{77.904}{100}}\right)^2 = 500 \times = \left(\frac{0.8000}{0.77904}\right)^2 \times 500 =$$
$$(1.026905)^2 \times 500 = 1.054534 \times 500 = 527.27\ \mu m$$

Test feed of Basalt (Ft) = 527.27 µm at 80%.

2.4.2. Sieve size analysis of Ikpeshi basalt (test product) from ball mill

Table 4. Sieve size analysis of Ikpeshi basalt (test product) from ball mill

Sieve size (µm)	Sieve size range (µm)	Weight retained (g)	% weight retained retained	Cumulative weight retained (%)	Cumulative Weight passing (%)
1000	1000	0.970	0.976	0.976	99.024
-1000+710	710	0.336	0.338	1.314	98.686
-710 + 500	500	0.561	0.564	1.878	98.122
-500 +355	355	0.475	0.478	2.356	97.644
-355+ 250	250	2.696	2.712	5.068	94.932
-250 + 180	180	27.815	27.981	33.049	66.951
-180 + 125	125	0.285	0.287	33.336	66.664
-125 + 90	90	0.186	0.187	33.523	66.477
-90 +63	63	0.463	0.466	33.989	66.011
-63	Pan	65.618	66.011	100.00	0.00
Total		99.405			

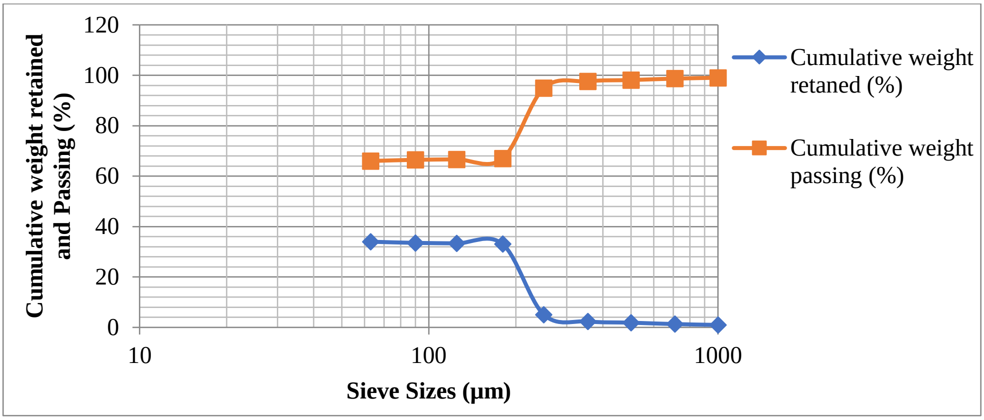

Figure 2. Cumulative weight retained (%) and cumulative weight passing (%) against Sieve size (µm) of Ikpeshi basalt product from the ball mill

Therefore, from Table 3 and Figure 2, to obtain 80% passing, the sieve size will be calculated using the Gaudin Schumann expression in equation (3)

$$X\mu m = \left(\frac{\frac{80}{100}}{\frac{66.951}{100}}\right)^2 \times 180 = \left(\frac{0.8000}{0.66951}\right)^2 \times 180 =$$

$$(1.194904)^2 \times 180 = 1.427796 \times 180 = 257.00\ \mu m$$

Test product (Pt) of the Basalt = 257.00 μm at 80%.

2.4.3. Sieve size analysis of Ikpeshi calcite as reference mineral (test feed) to ball mill

Table 5. Sieve size analysis of Ikpeshi calcite as reference mineral (test feed) to ball mill

Sieve size (μm)	Sieve size range (μm)	Weight retained (g)	% weight retained retained	Cumulative weight retained (%)	Cumulative weight passing (%)
1000	1000	14.346	14.510	14.510	85.490
-1000+710	710	0.390	0.394	14.904	85.096
-710 + 500	500	0.451	0.456	15.360	84.640
-500 +355	355	0.440	0.445	15.805	84.195
-355+ 250	250	1.011	1.023	16.828	83.172
-250 + 180	180	35.979	36.391	53.219	46.781
-180 + 125	125	0.032	0.032	53.251	46.749
-125 + 90	90	0.313	0.317	53.568	46.432
-90 +63	63	0.304	0.308	53.876	46.124
-63	Pan	45.602	46.124	100.00	0.00
Total		98.868			

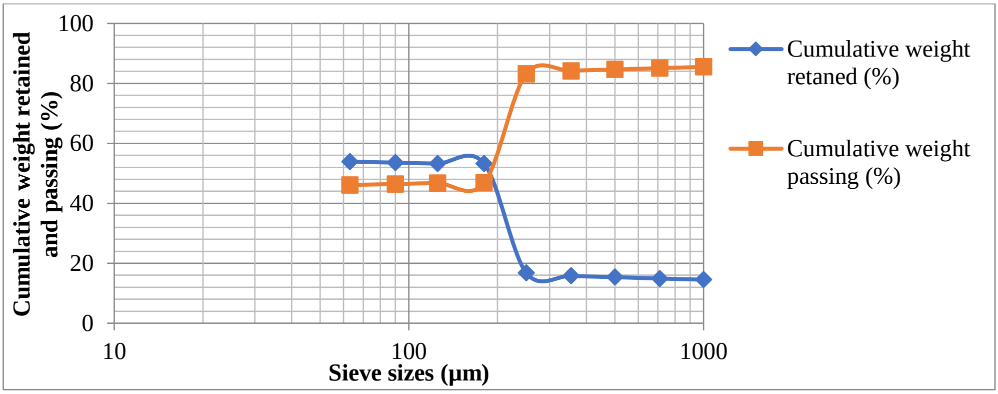

Figure 3. Cumulative weight retained (%) and cumulative weight passing (%) against Sieve size (μm) of Ikpeshi calcite (reference mineral) feed to the ball mill.

Therefore, from Table 4 and Figure 3, to obtain 80% passing, the sieve size will be calculated using the Gaudin Schumann expression in Equation (3)

$$X\mu m = \left(\frac{\frac{80}{100}}{\frac{83.172}{100}}\right)^2 \times 250 = \left(\frac{0.8000}{0.83172}\right)^2 \times 250 = (0.961862)^2 \times 250 = 0.925179 \times 250 = 231.29\mu m$$

Test feed of Calcite (Frs) = 231.29 μm at 80%.

2.4.4. Sieve size analysis of Ikpeshi calcite as reference mineral (test product) from ball mill

Table 6. Sieve size analysis of Ikpeshi calcite deposit as reference mineral (test product) from ball mill

Sieve size (μm)	**Sieve size range (μm)**	**Weight retained (g)**	**% weight retained retained**	**Cumulative weight retained (%)**	**Cumulative weight passing (%)**
1000	1000	0.575	0.578	0.578	99.422
-1000+710	710	0.087	0.088	0.666	99.334
-710 + 500	500	0.107	0.108	0.774	99.226
-500 +355	355	0.052	0.052	0.826	99.174
-355+ 250	250	0.208	0.209	1.035	98.965
-250 + 180	180	18.976	19.091	20.126	79.874
-180 + 125	125	0.856	0.861	20.987	79.022
-125 + 90	90	0.291	0.293	21.280	78.720
-90 +63	63	0.755	0.760	22.040	77.96
-63	Pan	77.492	77.960	100.00	0.00
Total		99.399			

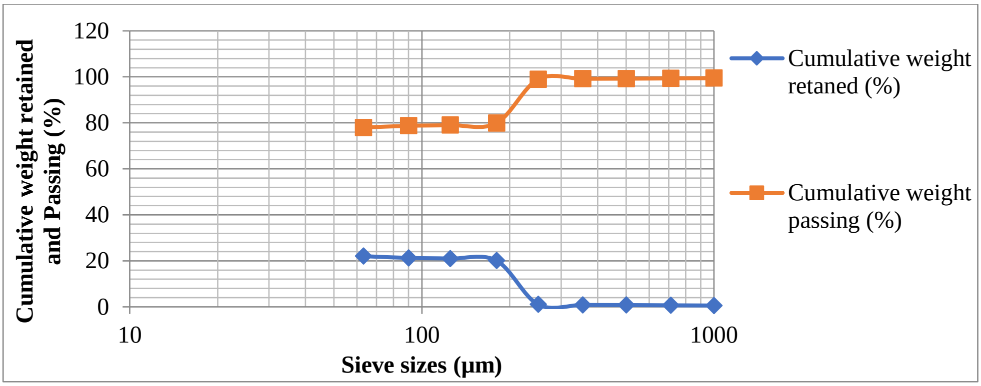

Figure 4. Cumulative weight retained (%) and cumulative weight passing (%) against Sieve size (μm) of Ikpeshi calcite product from the ball mill.

Therefore, from Table 5 and Figure 4, to obtain 80% passing, the sieve size will be calculated using the Gaudin Shumann expression in Equation (3)

$$\text{X}\mu\text{m} = \left(\frac{\frac{80}{100}}{79.874}\right)^2 \times 180 = \left(\frac{0.8000}{0.79874}\right)^2 \times 180 =$$
$$(1.001577)^2 \times 180 = 1.003156 \times 180 = 180.57\mu\text{m}$$

Test product of Calcite (Prs) = 180.57 µm at 80%

The work index (Wit) of Ikpeshi basalt was determined using equation (4), Wit = $\frac{P}{10\,(\frac{1}{\sqrt{Pt}} - \frac{1}{\sqrt{Ft}})}$

Where P is Net power required = 3.37KWh/t as estimated, Ft = 527.27 µm at 80% passing, Pt = 257.00 µm at 80% passing

Work index of Ikpeshi Basalt (Wit) = $\frac{3.37}{10\,(\frac{1}{\sqrt{257}} - \frac{1}{\sqrt{527.7}})} = \frac{3.37}{10\,(0.062 - 0.044)}$

Work index of Ikpeshi Basalt (Wit) = $\frac{3.37}{10\,(0.018)} = \frac{3.37}{(0.18)}$ = 18.722KWh/t

Therefore, the energy required for comminution of Ikpeshi Basalt to its liberation size is, using equation (6), $\text{Et} = \text{Wit}(\frac{10}{\sqrt{\text{Pt}}} - \frac{10}{\sqrt{\text{Ft}}})$

$$\text{Et} = 18.722(\frac{10}{\sqrt{257}} - \frac{10}{\sqrt{527.27}}) =$$
$$\text{Et} = 18.722(\frac{10}{16.0312} - \frac{10}{22.9624}) =$$
$$\text{Et} = 18.722(0.6238 - 0.4355) =$$
$$\text{Et} = 18.722 \times 0.1883 = 0.8756 = 3.52\text{KWh}$$

Therefore, the required energy for comminution of Ikpeshi Basalt to a size suitable for soil amendment is 3.52 KWh.

2.5. Discussion

According to [23], basalt's mineralogy is categorized by the major constituents of calcic-plagioclase feldspar, partially olivine, and augite. With no elutriation or groundwater leaching, basalt is a primordial rock that is abundant in iron, calcium, magnesium, and trace minerals. According to [24], basalt rock dust is healthy for aquatic plants and animals and is not harmful. Plagioclase fieldspar, olivine, pyroxene, amphibole, and albite are the constituents of Ikpeshi basalt rock, according to the laboratory study. The results of X-ray Diffraction procedure on Ikpeshi basalt rock show a greater percentage of silicon oxide (48.32 %), followed by alumiium oxide (13.12%), followed by iron oxide (8.02%), and closely followed by phosphorus oxide, potassium oxide, and calcium oxide with a value range of (7.63, 6.76, and 6.19, respectively). Others include: magnessium oxide (5.05%), tin oxide (1.48%), sodium oxide (1.42%), and value for loss on ignition (1.32%) as shown in Table 1.

The results show that basalt aggregates of Ikpeshi are suitable as mineralizers for agricultural soil because of its high silicate, calcium, magnesium, and potassium contents.

Ikpeshi calcite with a chemical formula of $CaCO_3$, the chemical analysis shows that, the calcium intensity is 0.6241, with content of 61.2238, and other elements as shown in the table 2 above. The chemical analysis shows that the following: Mg, Al, Si, P, S, Ca, Ti, Mn, Co, Fe, Ni, Cu, Zn, Au, Ag, and Rb are the major element of the calcite sample [22].

The results of fractional sieve analysis on the feed to ball mill and product from the ball mill of Ikpeshi basalt samples are shown in Figure 1 and 2, while Figures 3 and 4 show the graph of the particle size analysis of reference ore for 80% passing for both feed and product sieve size fractions for the test basalt and reference ores (calcite). Figure 1 and 2 show that 80% passing was obtained to be 527.27 µm and 257.00 µm for the test feed (Ft) and product (Pt) of the Basalt respectively using equation (3). From Figure 3 and 4 to obtain 80% passing, the test feed (Frs) and product (Prs) sieve size of calcite as reference ore was calculated to be 231.29 µm and 180.57 µm respectively using equation (3).

Work index (Wit) of Ikpeshi basalt as test ore, was calculated to be 18.7222kWh/t with 10.1 kWh/t as work index of calcite as the reference mineral (Wrs) using equation (4), which is in line with international acceptable standard [25]. This led to the calculation of energy used in grinding Ikpeshi basalt to its liberation size to be 3.52 kWh using Equation (6), out of which part of the energy was used for actual grinding while others are converted into other forms such as heat and noise.

These shows that ball milling will effectively reduce the size of Ikpeshi basalt particles and processing Ikpeshi basalt can require more cost and energy for grinding compare to the overburden calcite. The value of the work index suggests advantageous features of the milling processes, which may result in moderate operational cost and improved processing techniques. Finally, the analysis offers important information on energy consumption and milling efficiency of Ikpeshi basalt to economic value for potential adoption as soil mineralizer.

3. Conclusion

The grindability of Ikpeshi basalt was successfully completed to enhance its suitability for soil amendment. The following conclusion was arrived;

(i) The work index of Ikpeshi basalt was calculated to be 18.722 KWh/ton compared to 10.10KWh/ton estimated for calcite.

(ii) The energy required to ground Ikpeshi basalt to its liberation size was calculated to be 3.52 kWh.

(iii) The findings highlight that processes such as crushing and ball milling will effectively reduce the size of Ikpeshi basalt, thereby making them to be more economical for agricultural use.

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Authors Contribution. All the authors contributed to formulating, developing, and drafting this research article.

Conflicts of Interest. The authors declare that there exist no known competing interests that could have appeared to influence the work reported in this paper.

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