Characterization of Some Selected Silica Sand Deposits in South West Nigeria for Sand Moulding in Foundry Industry

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Abstract

This study determined the clay content, chemical composition, grain fineness number, distribution and shape of some selected silica sand deposits in south west Nigeria. This is with a view to document the silica sand deposits in Nigeria for sand moulding in the foundry industry. The silica sand deposits were collected from four river bed deposits in Igbokoda (Ondo State), Ote (Ogun State), Opa (Osun State), and Osooro (Oyo State), respectively. The clay content off sand samples from these deposits were determined using washing off method; grain fineness number and distribution were evaluated using sieve analysis; grain shapes were observed using magnifying lens; chemical compositions were characterized by x-ray fluorescence; and the phases were characterized by x-ray diffractometer. The results showed that the clay content for samples taken from Igbokoda, Ote, Opa, Osooro are 2.18%, 2.40%, 3.44%, 6.96% respectively. The average grain fineness number of 48.23, 53.74, 61.82, and 68.48 were obtained for samples taken from Igbokoda, Ote, Opa and Osooro respectively. All the silica sands from the study area have a mixture of angular and sub-angular grain shapes. X-ray diffraction and fluorescence result showed quartz as the most prominent mineral in the selected sand deposits with silica contents of 83.14%, 80.56%, 86.46% and 82.71% for Igbokoda, Ote, Opa, and Osooro respectively. From the outcome of this study, it was concluded that all the silica sand deposit in the study area are grade D.

Keywords: Silica Sand; Clay; Grain Fineness; Grain Shape; Quartz; X-Ray Diffraction

1. INTRODUCTION

Silica sand is one of the most common minerals in the Earth Crust. It consists of pieces of broken quartz crystals which have been broken down into tiny granules over years through the action of water and weathering (Edem, 2014). It is an industrial term used for sand or easily disaggregated sandstone with a very high percentage of quartz (silica) grains. Quartz is one of the common crystals of silica and can also be termed as the second most common mineral on the earth's surface. It is found in almost every type of rock; igneous, metamorphic and sedimentary (Ketner, 1973; Bourne, 1994). The silica in the sand will normally be in the crystalline form of quartz. For industrial use, pure deposits of silica capable of yielding products of at least 95% SiO_2 are required. Often much higher purity values are needed. In manufacturing applications, silica deposits sand yielding products of at least 95% SiO_2 are preferred. Industrial sand's strength, silicon dioxide contribution and non-reactive properties make it an indispensable ingredient in the production of thousands of everyday products (Chang, 2002). In the United States for instance, silica sand production increased from 2.5 to 28.5 metric tons from 1996 to 1997 and out of this about 37% was used for glass making, 23% for foundry sand, 6% for hydraulics fracturing and 5% for abrasive (Langer, 2003). The US produces 30% of the world total silica sand from more than 150 operations and about three-fourths of production coming from the central US alone in 1992 (Dolley, 2004a).

In Africa however, the use of silica sand is quite limited on the domestic scale, as majority of the population only utilize it for road and building construction, while there are numerous silica deposits that have been left unattended to and underutilized and has prevented their exploration in spite of their valuable economic mineral content (Claude, 2002). Available evidence shows that this silica sand contains a high proportion of pure quartz (SiO_2) and can be directly or indirectly used in the manufacture of various industrial products especially glass and foundry products (Malu and Bassey, 2003).

In Nigeria there are abundant deposits of silica sand but these deposits are not characterized and well documented for her technological development as being obtained in European, North America and some Asian countries. It is therefore desirable to investigate the vast silica sand deposit in Nigeria for metal casting and other allied industries. Thus, the aim of this study is to characterize some selected silica sand deposits in south west Nigeria for sand moulding in the foundry industry.

2. METHODOLOGY

2.1 Study Area

The study area covers different locations in four states of southwest Nigeria (Figure 1). The locations and their classifications are as follow:

i. Osooro sand deposit (river bed sand) Oyo state.

ii. Opa sand deposit (river bed sand) Osun state.

iii. Igbokoda sand deposit (sea sand) Ondo state.

iv. Ote sand deposit (river bed sand) Ogun state.

2.2 Clay Content Test

A 100 g sample was dried at 110 ^{o}C and placed inside one-liter glass flask. Finally, 475 ml of distilled water and 25 ml of standard solution of caustic soda (NaOH) was added to the sample in the glass flask. This sample was thoroughly stirred. After the stirring for about five minutes, the sample was diluted with fresh water up to 150 mm graduation mark and the sample was left undisturbed for ten minutes to settle at the bottom and the clay particles washed from the sand was floating in the water. 125 mm of this water was siphoned off the flask and it was again topped at the same level and allowed to settle down for five minutes. The above operation was repeated till the water above the sand becomes clear, which will give an indication that all the clay in the deposit has been removed. Now, the sand was removed from the flask and dried by heating. The difference in weight of the dried sand and 100 g weight of sample gives the percentage clay content in the silica sand deposit.

2.3 AFS Sieve Analysis

A dried 100 g sample of the sand was placed on top of a series of sieves and shaken for 15 minutes. The sieves were arranged in such a way that the coarsest sieve was placed at the top and the finest at the bottom. There were ten standard sieves mounted one above the other and under the bottom-most sieve was placed a pan. After shaking period, the sand retained on each sieve was collected, weighed, and expressed as a percentage of the original sample weight. The percentage collected in each sieve was multiplied by its own multiplying number a given constant, for each

$$\frac{\text{Total product}}{\text{Total sum of \% collected in each sieve}}$$

sieve- and all the products were added as the total product (AFS, 1989). Thus;

AFS Grain Fineness Number = $\frac{\sum F_i A_i}{\sum A_i}$

That is;

AFS Grain Fineness Number (GFN) =

Where F_i = multiplying factor for the sieve

A_i = amount of sand retained on the ith sieve

To obtain the grain distribution the material present retained on each sieve were plotted against the sieve number and cumulative percentage curve showing the total percent obtained.

2.4 Grain Shape

This particular test strives to relate the grain shape to some factors such as the compaction and flowability. The samples were placed on a white platform under the magnifying lens and sphericity and degree of angularity examined at 9 mm magnification to the grain size of the samples to be tested. At least 70 grains of the samples were chosen and examined for sphericity and degree of angularity.

2.5 X-Ray Fluorescence Analysis (XRF) and X-Ray Fluorescence diffractometer (XRD)

X-ray fluorescence analysis was used to characterize the elemental composition of samples of selected sands deposit while X-Ray fluorescence diffractometer was used for phase characterization.

3. RESLUTS AND DISCUSSION

3.1 Clay Content

The results of clay content are as presented in Table 1, from these results Osooro sand deposit has the highest clay content (6.961%) while Igbokoda has the least (2.175%). Clay causes undesirable lowering of fusion point in silica sand and hence reduces it refractoriness. Thus, Igbokoda sand deposit with least clay content has the highest refractoriness while Osooro sand deposit with highest clay content the least refractoriness. Since refractoriness is the ability of moulding sand to withstand high temperature, Igbokoda sand deposit will be suitable for casting of metals with high melting temperature while Osooro sand deposit for low melting ones.

3.2 Size Distribution Analysis

The average grain fineness number for various sand deposits investigated is presented in Table 2. Osooro has the highest average fineness number (68.48) while Igbokoda has the least (48.23). The implication of this is that Igbokoda and Ote sand deposit are coarse while Opa and Osooro are the fine. The fineness and coarseness of silica sand affects the properties of moulding sand (Olawale *et al.*, 2011). Coarse silica sand has higher permeability compared with fine ones while the latter gives better mold strength (Yekinni and Bello, 2013).

The results of sieve analysis are as presented in Figures 2 to 5. The graph of percentage retained and cumulative percentage were used to divide the sieve analysis into three fractions: coarse, main and fine fractions. The main fraction is the percentage of sand grains represented by the middle portion of the curves, coarse fractions is the percentage of sand grains to the left of the middle portion and fine fractions is the percentage of sand grains to the right of the middle portion. From this analysis the distribution of silica sand in the study area is as presented in the Table 3. The main fraction constitutes 85.2%, 76.5%, 70.0% and 74.0% of sand distributions from samples taken from silica sand deposits in Igbokoda, Ote, Opa and Osooro respectively. This fraction is distributed on 3 screens in Igbokoda and Ote samples while on 4 screens in Opa and Osooro samples. Thus, Igbokoda and Ote sili-

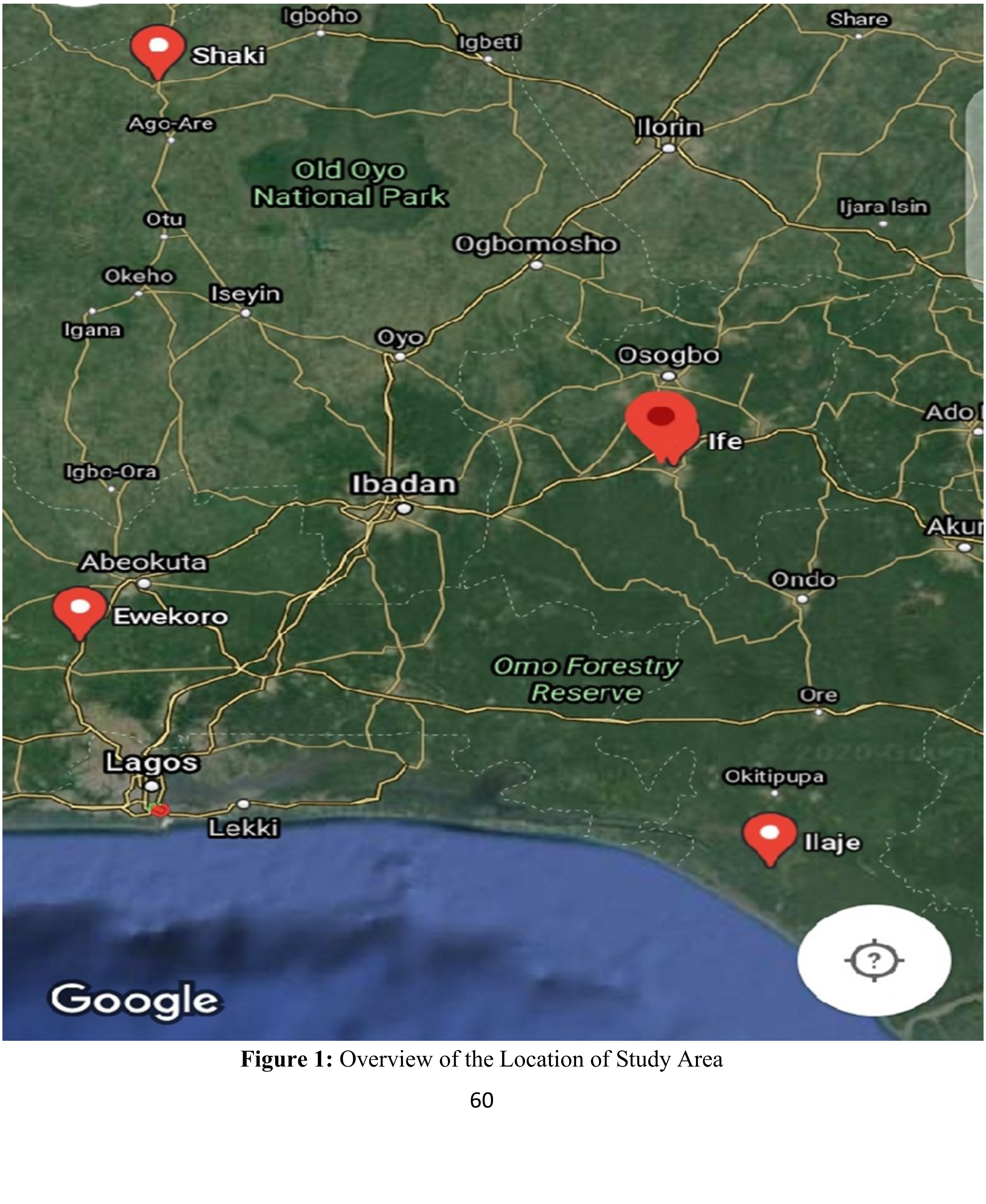

Figure 1: Overview of the Location of Study Area

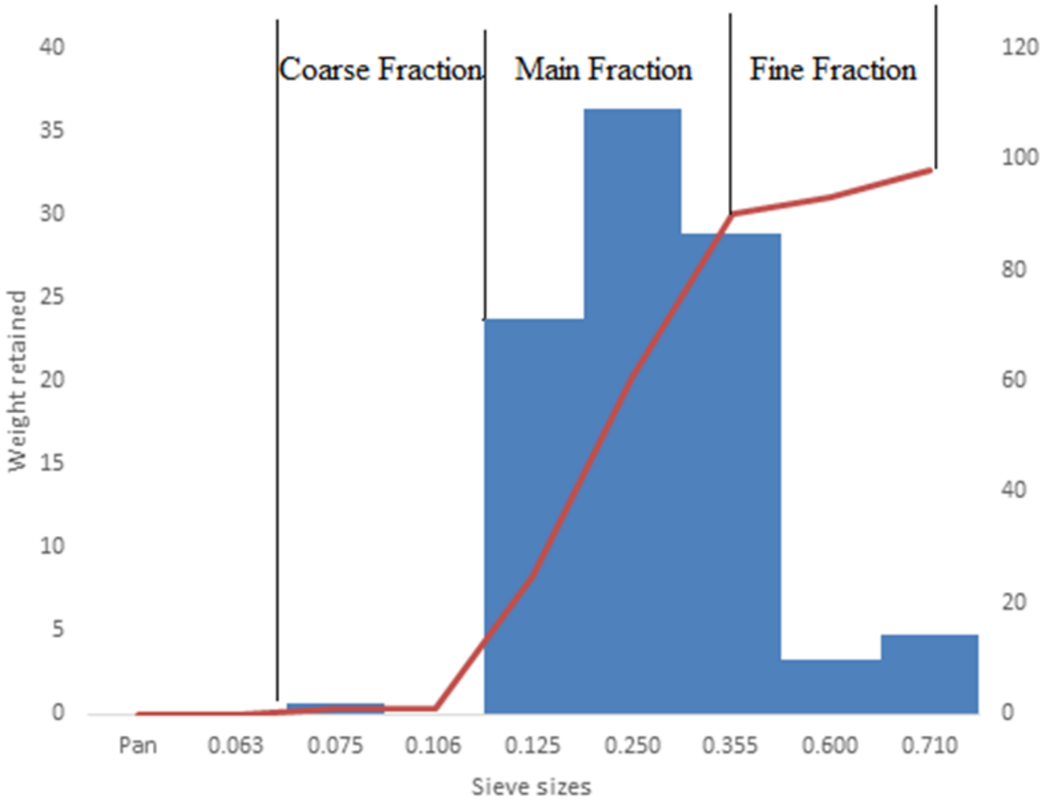

Figure 2: Graph of Grain Size Distribution of Igbokoda Silica Sand Deposits

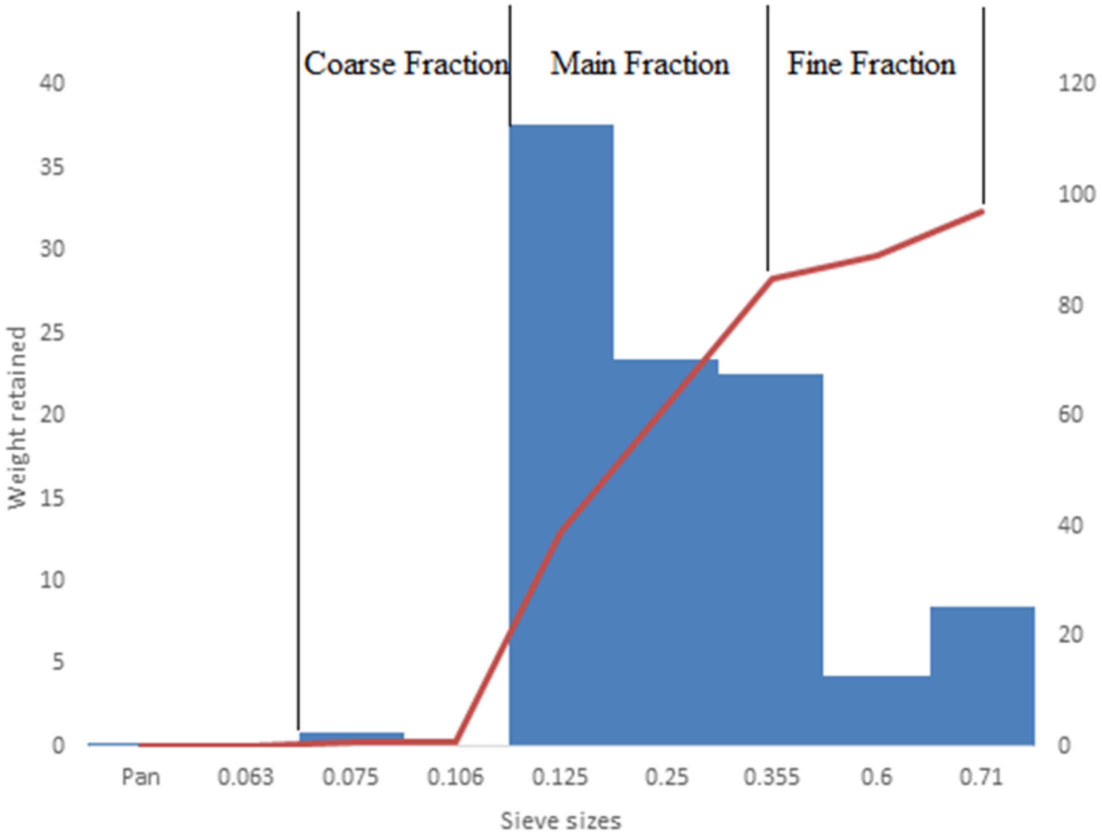

Figure 3: Graph of Grain Size Distribution of Ote Silica Sand Deposits

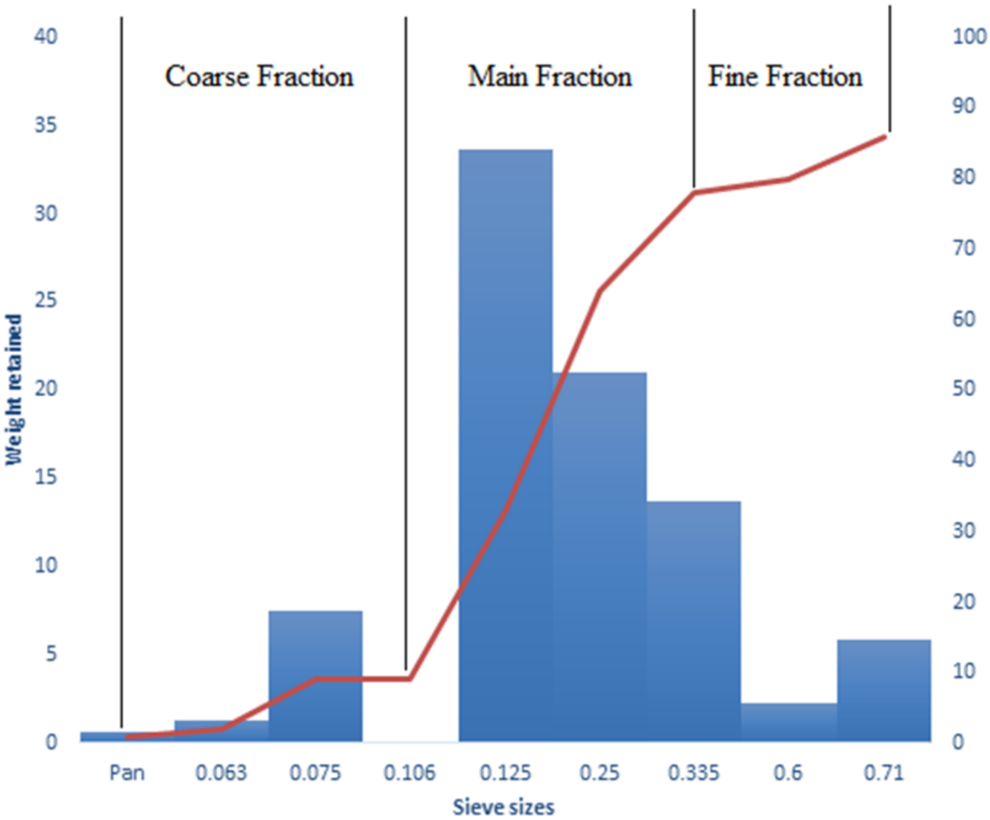

Figure 4: Graph of Grain Size Distribution of Opa Silica Sand Deposits

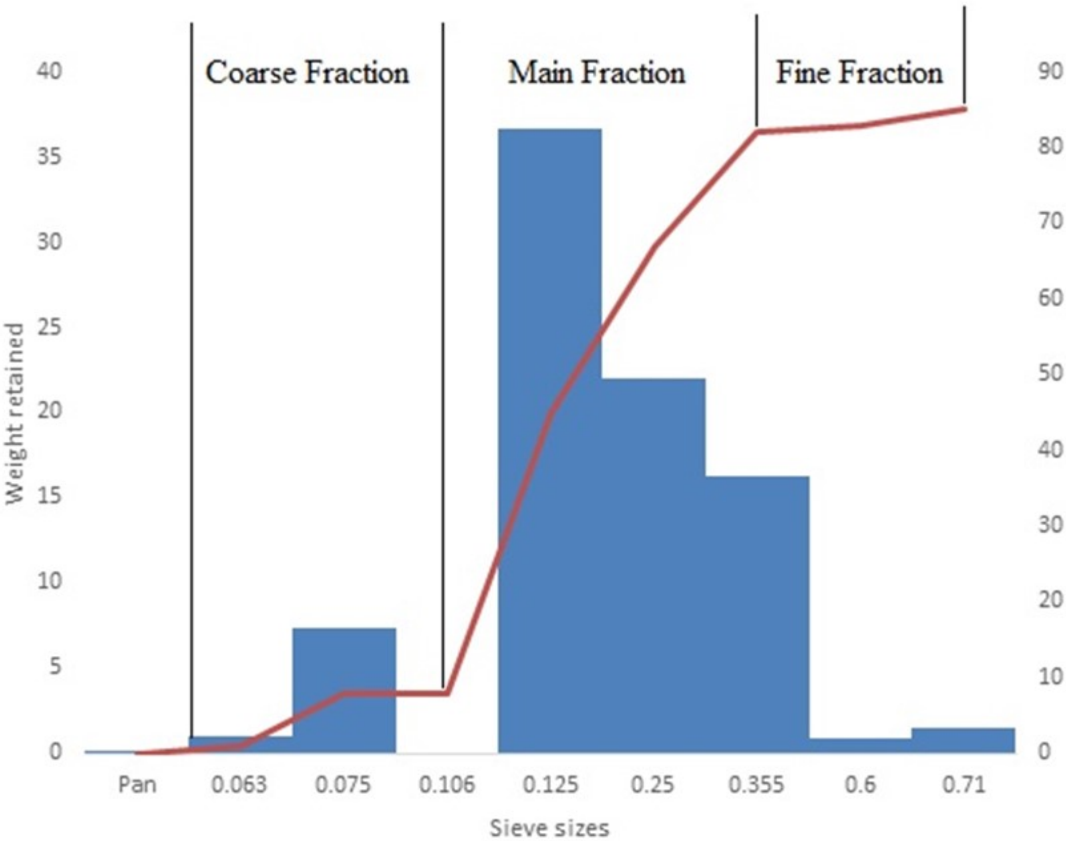

Figure 5: Graph of Grain Size Distribution of Osooro Silica Sand Deposits

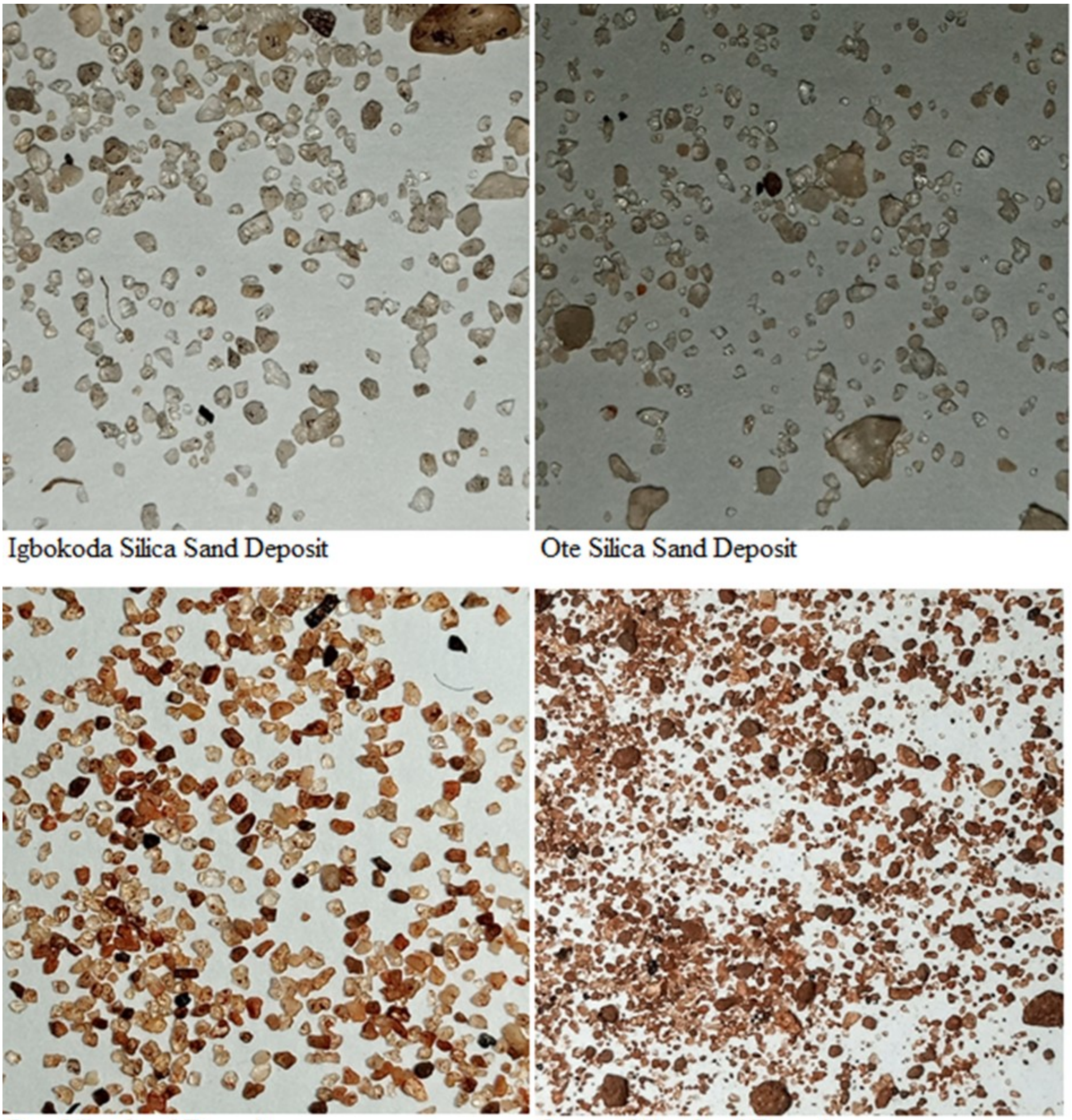

Figure 6: The Grain Shapes of the Various Silica Sand Deposits

Table 1: Results of clay content test

Sample	Sample Weight Before Washing (g)	Sample Weight After Washing (g)	Weight of Clay (g)	Clay Content (%)
Igbokoda	100	97.825	2.175	2.175
Ote	100	97.434	2.566	2.566
Opa	100	96.321	3.679	3.679
Osooro	100	93.039	6.961	6.961

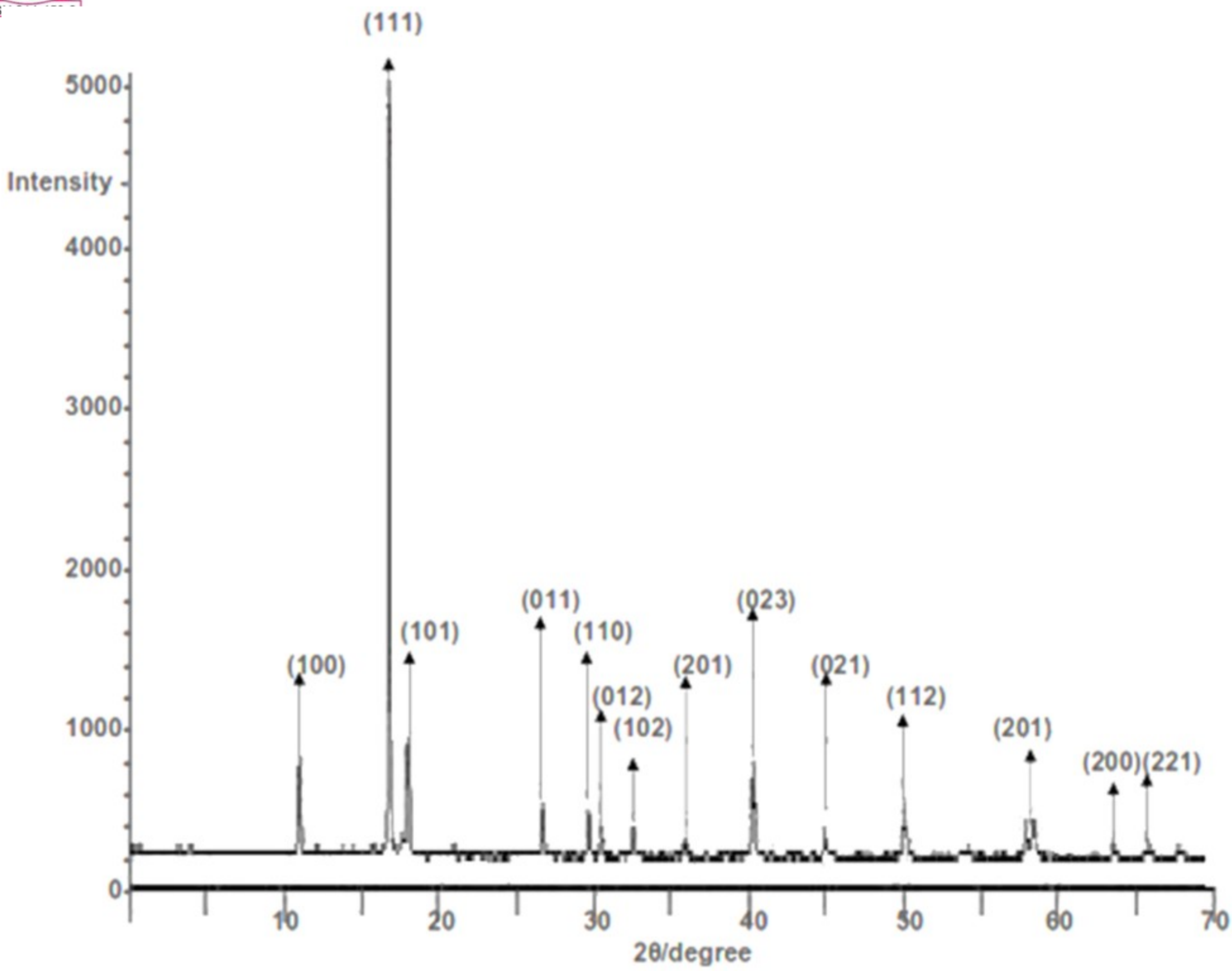

Figure 7: Diffractogram of Igbokoda Silica Sand Deposit

Table 2: Grain fineness number of silica sand deposits in the study area

Sieves (µm)		**Igbokoda**		**Ote**		**Opa**		**Osooro**	
	F_i	**A_i**	**F_iA_i**	**A_i**	**F_iA_i**	**A_i**	**F_iA_i**	**A_i**	**F_iA_i**
Pan	300	0.7	210.00	0.1	30.00	0.2	60.00	0.0	0.00
0.063	170	1.3	221.00	1.0	170.00	0.2	34.00	0.1	17.00
0.075	148	7.5	1110.00	7.4	1095.20	0.8	118.40	0.6	88.80
0.106	104	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
0.125	85	33.6	2856.00	36.7	3119.50	37.7	3204.50	23.7	2014.50
0.250	44	21.0	924.00	22.0	968.00	23.4	1029.60	36.3	1597.20
0.335	30	13.7	411.00	16.3	489.00	22.6	678.00	28.9	867.00
0.600	19	2.3	43.70	0.9	17.10	4.3	81.70	3.3	62.70
0.710	16	5.9	94.40	1.5	24.00	8.5	136.00	4.8	76.80
1.18	8	10.3	82.4	0.5	4.00	2.0	16.00	0.0	2.4
Total		96.3	5952.50	86.4	5916.80	99.7	5358.20	98	4726.40
GFN = $\sum F_iA_i/\sum A_i$		**48.23**		**53.74**		**61.82**		**68.48**	

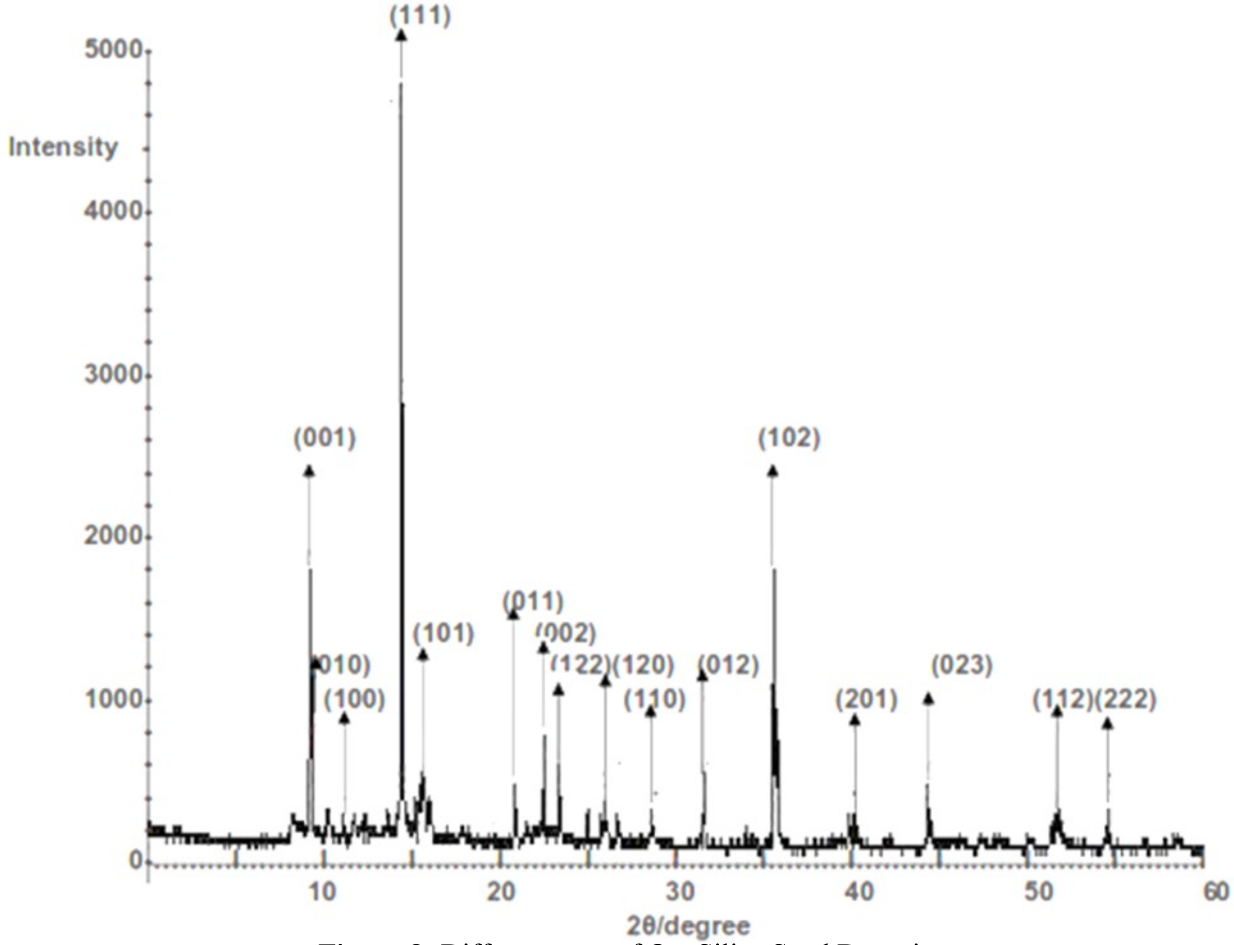

Figure 8: Diffractogram of Ote Silica Sand Deposit

Table 4: Chemical composition of silica sand deposits in the study area

S/N	Parameters	Formulae	Composition of Igbokoda Deposit (%)	Composition of Ote Deposit (%)	Composition of Opa Deposit (%)	Composition of Osooro Deposit (%)
1	Silicon Oxide	SiO_2	86.46	83.14	82.71	80.56
2	Aluminium Oxide	Al_2O_3	4.94	5.68	6.36	8.16
3	Ferric Oxide	Fe_2O_3	2.23	2.65	3.07	3.45
4	Titanium Oxide	TiO_2	1.66	1.15	1.32	1.18
5	Calcium Oxide	CaO	0.17	0.22	0.24	0.26
6	Lead Oxide	Pb_2O_5	0.02	0.02	0.03	0.04
7	Manganese Oxide	MnO	0.05	0.06	0.09	0.09
8	Magnesium Oxide	MgO	0.16	0.16	0.22	0.16
9	Sulphide	SO_3	0.02	0.04	0.11	0.04
10	Sodium Oxide	Na_2O	0.21	0.22	0.26	0.30
11	Potassium Oxide	K_2O	1.43	1.56	1.73	2.00
12	Loss of Ignition	LOI	1.48	2.08	3.68	3.89
13	Trace Elements	Pb, Cu, Cr, etc.	1.17	0.87	1.78	0.08

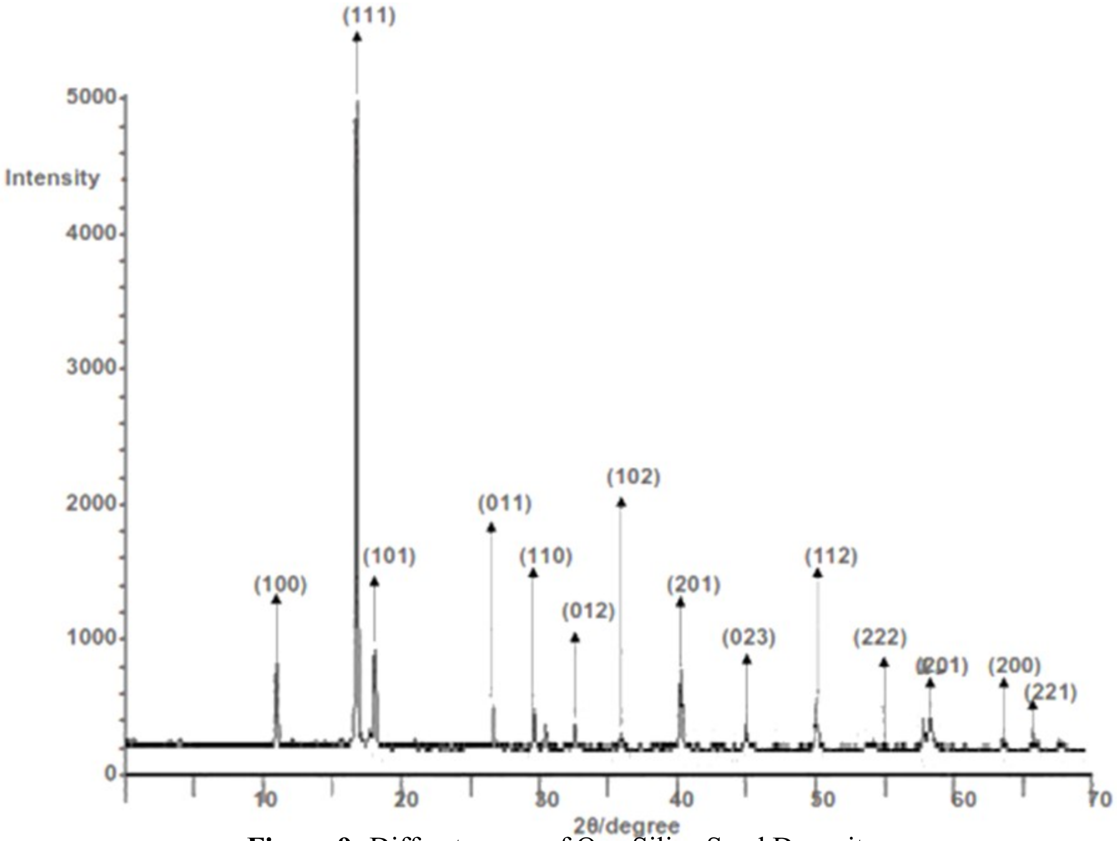

Figure 9: Diffractogram of Opa Silica Sand Deposit

Table 3: Distribution of sand in the study area

Sample	% Coarse	% Main	% Fine	No of Screens
Igbokoda	4.8	85.2	10.0	3
Ote	8.5	76.5	15.0	3
Opa	8.0	70.0	22.0	4
Osooro	8.0	74.0	18.0	4

ca sand deposits can be classified as 3-screen sand while Opa and Osooro silica sand deposits as 4-screen sand. As recommended by Jain (1995) Igbokoda and Ote sand deposits will have a good compactibility property as against Opa and Osooro deposits because their percentage main fraction is more than 75%. According to Mohammed-Noor (2004), the amount of coarse fraction and fine fraction should be less than 10%. Percentage coarse fraction in excess of this can contribute to poor surface finishing of casting because coarse particles are easily dislodged from mould cavity surface and may become dirt in the casting (Rao, 1998). Since all the tested sand deposits contain less than 10% coarse fraction it can be stated that silica sand in the study areas will enhance good casting surface finish. Fine fraction in excess of 10% can cause balling to occur during mulling and may prevent the binder from being thoroughly disseminated throughout the mass (Mohammed-Noor, 2004). All the tested sand deposits contain between 10% and 22% and hence required further processing to reduce the amount of fine fraction.

3.3 Grain Shape Analysis

Figure 6 shows the shapes of the grains of various silica sand deposits investigated. Opa and Osooro silica sand deposit has a combination of angular and sub-angular grain shapes with the latter in the larger proportion. The implication of this is that the moulding sand prepared from these deposits will have high green strength and appreciable permeability. Igbokoda and Ote silica sand deposit also has a combination of angular and sub-angular shape but the former is in the largest proportion. The process moulding sand from these deposits will have appreciable green strength and high permeability.

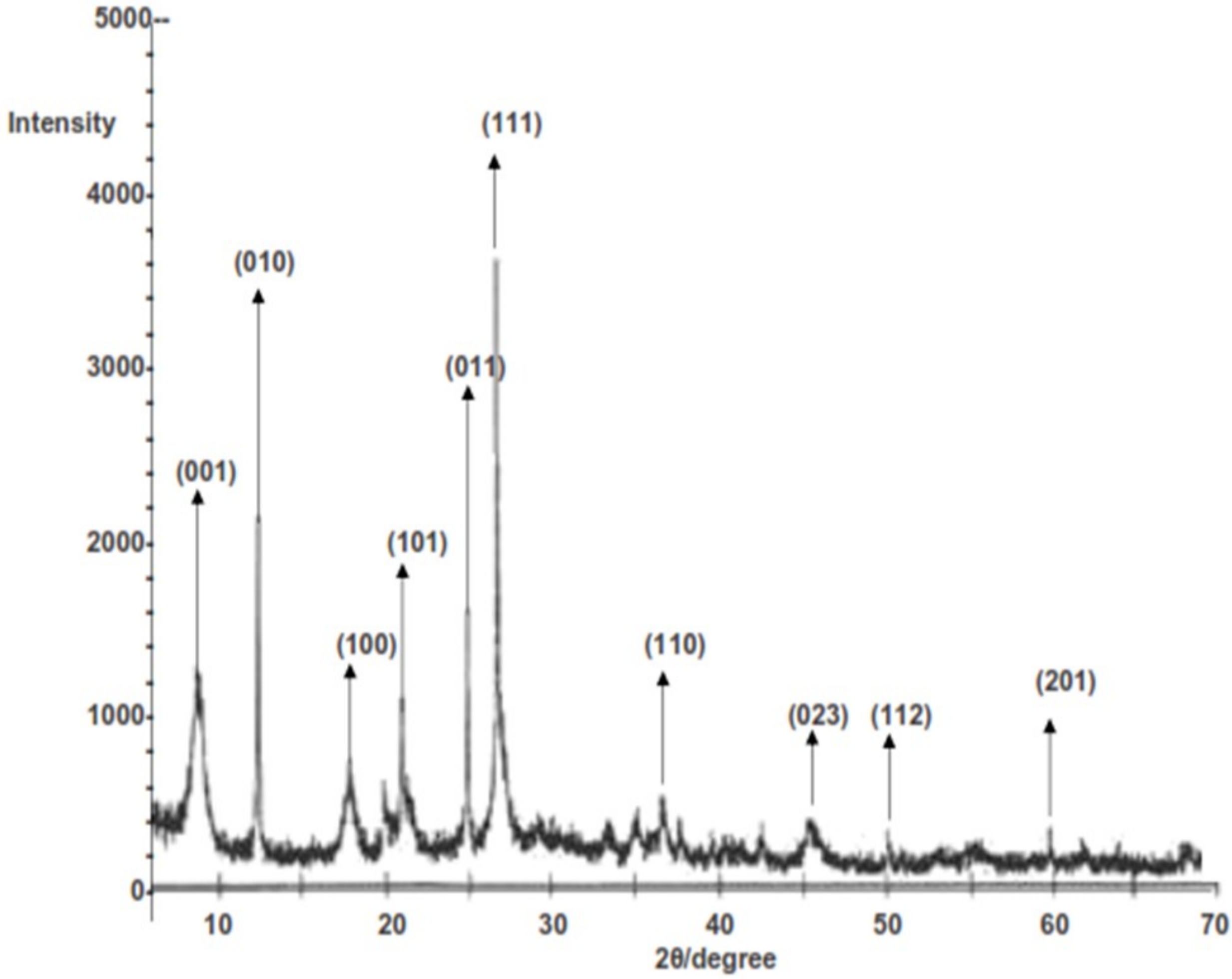

Figure 10: Diffractogram of Osooro Silica Sand Deposit

3.4 Phase Composition Analysis

The results of chemical analysis of various sand deposits are as presented in Table 4. The results show that silicon dioxide (SiO_2) is the major constituent of all sand deposits investigated with values ranging from 80.56 % - 86.46%. Silica grains are very important in moulding as they impact refractoriness, strength, and permeability to the sand (Ihom and Offiong, 2014). The higher the percentages of silica sand the better the refractoriness of the sand. Also, the presence of metallic oxides such as alumina and magnesia are important factors to be considered in silica sand as they render it cohesive and plastic, since magnesia binds the sand thoroughly together, the amount should be very small, else it will reduce the porosity; likewise the alumina as it tends to melt at the molten metal temperature. Iron oxide acts the same way as long as its total amount together with alumina is small (Richards, 1910). Thus, the more the metallic oxide present, the lower the silica content, making the sand not suitable for ferrous casting. Jain (1995) categorized silica sand as grade A, B, C, and D according to their percentage silica content and percentage total minerals and alkalis. They are respectively 98% and 2% for grade A, 95 – 98% and 2 – 5% for grade B, 90 – 95% and 5 – 10% for grade C, and less than 90% and more than 10% for grade D. Hence, all the silica sand deposit can be categorized as grade D.

Loss on ignition (LOI) ranges from 1.48 % for Igbokoda deposit to 3.89% for Osooro deposit. When these values are compared with the values of 0.5 % recommended by NMDC Jos Data Bank (2008), it shows that values of LOI for all the deposits exceed 0.5% which may be an indication of high organic matter present in the samples as impurities and therefore lowers the refractoriness of the sand by reducing the silica content. This means the lower the LOI the higher the silica content. Loss on ignition, minerals and alkalis can be reduced by thorough washing and hence increasing the percentage silica content.

The result of XRD is as presented in Table 5. From this result the phases present in the samples includes: quartz, kaolinite, illite, hematite, feldspar, aragonite and calcite. Quartz being the major constituent while kaolinite, illite, hematite, feldspar, aragonite and calcite the minor constituents. The XRD patterns of the samples under investi-

Table 5: Phases in silica sand deposits in the study area

Sand Location	Opa		Ote		Igbokoda		Osooro	
S/N	Plane	Minerals	Plane	Miner-als	Plane	Miner-als	Plane	Minerals
1	100	Quartz	001	Quartz	100	Quartz	001	Quartz
2	111	Quartz	010	Kaolin-	111	Quartz	010	Quartz
3	101	Feldspar	100	Calcite	101	Feldspar	100	Quartz
4	011	Quartz	111	Quartz	011	Quartz	101	Feldspar
5	110	Quartz	101	Illite	010	Quartz	011	Kaolinite
6	012	Quartz	011	Quartz	012	Quartz	111	Quartz
7	102	Kaolinite	202	Feldspar	102	Illite	110	Quartz
8	201	Illite	122	Kaolin-	201	Quartz	023	Calcite
9	023	Quartz	120	Hemattit e	023	Quartz	112	Illite
10	112	Quartz	100	Hemattit e	021	Kaolin-ite	201	Aragonite
11	222	Arago-	012	Quartz	112	Calcite		
12	201	Quartz	102	Quartz	201	Quartz		
13	200	Hemattit e	201	Quartz	200	Hemattit e		
14	221	Calcite	023	Quartz	221	Arago-		
15			112	Feldspar				
16			222	Arago-				

gation were analyzed at 2θ" values and compared with standard values from JCPDS data. The overlaps of XRD patterns are given in the diffractogram as shown in Figures 7 to 10. Comparing the XRD pattern with JCPDS data; quartz, kaolinite, hematite, calcite, aragonite, feldspar and illite were identified with hexagonal, anorthic, rhombohedral, orthorhombic, anorthic and monoclinic crystal structure respectively. From the pattern the peaks were predominantly quartz identified on planes (001), (010), (011), (012), (023), (100), (110), (112), and (201). Quartz phase and other phases identified on the XRD patterns depict the minerals and alkalis present in the chemical compositions.

In summary, Igbokoda silica sand deposit has clay content (2.17%), coarse grain size (48.23%), main fractions (85.2%), coarse fraction (4.8%), fine fraction (10%), silica content (86.46%), and total minerals and alkalis (13.54%). This deposit has adequate clay content, coarse grain, and the grains are well distributed. However, it will have poor chemical resistivity because of high total minerals and alkalis that lowers the fusion point of silica sand. According to Jain (1995) the total minerals and alkalis in high silica sand must be less than 2%. A coarse grain well distributed but poor chemical resistivity silica sand like this will be suitable for various sizes of cast iron and non-ferrous castings but needs to be upgraded for steel and high alloys castings.

Ote silica sand deposit has clay content (2.4%), coarse grain (53.74%), main fractions (76.5%), coarse fraction (8.5%), fine fraction (15%), silica content (83.14%), and total minerals and alkalis (16.86%). This deposit has coarse grain that is not well distributed because the percentage fine fraction is more than 10%. It also has poor chemical resistivity and high clay content. The silica sand from this deposit will be suitable for medium cast iron, small cast iron and non-ferrous castings. After upgrading it can be used for various sizes of cast iron and small size steel castings.

Opa silica sand deposit has clay content (3.44%), fine grain (61.28%), main fractions (70%), coarse fraction (8%), fine fraction (22%), silica content (82.71%), and total minerals and alkalis (17.29%). This deposit has fine grain that is not well distributed, poor chemical resistivity and high clay content. The silica sand from this deposit will be suitable for small cast iron and non-ferrous castings but can be upgraded for various sizes of cast iron castings. However, it cannot be used for steel and high alloys castings even in upgraded form because of its fineness.

Osooro silica sand deposit has clay content (6.96%), fine grain (68.48%), main fractions (74%), coarse fraction (8%), fine fraction (18%), silica content (80.56%), and total minerals and alkalis (19.44%). The silica sand from this deposit will be suitable for only non-ferrous castings but can be upgraded for medium and small cast iron castings. However, it cannot be used for big cast iron, steel and high alloys castings even in upgraded form because of its fineness.

4. CONCLUSION

The following conclusions could be drawn from this research work:

i. All the silica sand deposit in the study area can be categorized as grade.
ii. Igbokoda silica sand deposit will be suitable for various sizes of cast iron and non-ferrous castings in its natural forms.
iii. Ote silica sand deposit will be suitable for medium cast iron, small cast iron and non-ferrous castings in its natural forms.
iv. Opa silica sand deposit will be suitable for small cast iron and non-ferrous castings in its natural forms.
v. Osooro silica sand deposit will be suitable for only non-ferrous castings.

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