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Investigation Into the Morphological Characteristics of Dawakin Kudu Silica Sand for Glass-Making Applications

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Abstract- Silica sand is a critical industrial mineral widely used in glass manufacturing, ceramics, foundry molding, and advanced engineering materials. The suitability of silica sand for glass production depends largely on its chemical composition, grain morphology, particle size distribution, and impurity content. In this study, the morphological characteristics of silica sand deposits from Dawakin Kudu, Kano State, Nigeria, were systematically investigated to assess their potential for glass-making applications. Scanning Electron Microscopy (SEM) was employed to examine the grain morphology, while quantitative particle shape analysis was conducted using ImageJ software. The SEM micrographs revealed that the sand grains are predominantly angular to sub-angular with sharp edges and distinct grain boundaries. Particle shape analysis further confirmed low circularity and sphericity values, indicating non-rounded grain morphology, which is desirable for effective melting and homogeneous glass formation. The average particle size distribution was found to fall within the acceptable industrial range for soda-lime silica glass production. The results demonstrate that Dawakin Kudu silica sand possesses favorable morphological properties for glass manufacturing. This study contributes to the identification of alternative indigenous silica sand resources in Nigeria, which can reduce import dependence, stimulate local industrial development, and create employment opportunities. The findings provide a scientific basis for further beneficiation, chemical characterization, and pilot-scale glass production trials using Dawakin Kudu sand.

Keywords: Silica Sand, Grain Morphology, SEM, Imagej, Glass Making, Nigeria.

I. INTRODUCTION

Silica (SiO_2) is one of the most abundant and industrially significant minerals in the Earth's crust, constituting approximately 60–70% of the total crustal composition. It exists in both crystalline and non-crystalline forms and serves as the fundamental raw material for glass, ceramics, foundry sand, refractory materials, optical fibers, and electronic components [1], [2]. Among the various forms of silica, quartz is the most common naturally occurring crystalline phase, widely distributed in sedimentary, igneous, and metamorphic rocks [3].

The glass manufacturing industry represents one of the largest consumers of silica sand, accounting for over 70% of global silica sand production [4]. Glass is primarily produced through the melting of silica sand together with fluxing agents such as soda ash (Na_2CO_3) and stabilizers like limestone ($CaCO_3$), forming soda-lime-silica glass. The quality of the resulting glass depends heavily on the purity, particle size distribution, and morphological characteristics of the silica sand used [5].

Grain morphology plays a crucial role in determining the melting behavior, homogeneity, and optical properties of glass. Angular and sub-angular grains with sharp edges enhance packing efficiency and promote uniform melting, while rounded grains tend to trap air, leading to bubble formation and defects in the glass structure [6], [7]. In addition, grain shape affects the kinetics of chemical reactions during melting, influencing energy consumption and production efficiency [8].

The industrial suitability of silica sand is determined by three principal factors: chemical composition, physical properties (grain size and morphology), and impurity content [9]. High-quality glass sand typically contains more than 70% SiO_2, with very low concentrations of iron oxides, alumina, and alkali impurities [10]. Iron oxide, in particular, is undesirable in glass production as it imparts coloration and reduces optical transparency [11]. Therefore, beneficiation processes such as washing, attrition scrubbing, magnetic separation, and acid leaching are often employed to enhance sand quality [12].

Several studies have investigated silica sand deposits across Nigeria with the aim of identifying viable local sources for industrial glass production. Edem et al. [13] characterized silica sand from River Benue and reported promising chemical and physical properties suitable for container glass manufacturing. Sintali and Egbo [9] evaluated silica sands from Dapchi, Ngala, and Gwoza in northeastern Nigeria and found that certain deposits met industrial specifications for flat glass production after beneficiation. Similarly, Duvuna and Ayuba [14] analyzed silica sands from Yazaram and Mugulbu deposits and confirmed their suitability for glass manufacturing based on morphological and chemical assessments.

Despite Nigeria's vast silica sand resources, industrial glass production remains heavily dependent on imported raw materials, largely due to inadequate characterization of local deposits and limited beneficiation infrastructure [15]. Kano State, located in northwestern Nigeria, is endowed with extensive alluvial and riverine sand deposits, particularly along major water bodies such as River Challawa, River Kano, and River Yanbarau. Dawakin Kudu Local Government Area, situated within this geological zone, hosts significant sand deposits that are currently exploited mainly for construction, pottery, and basic ceramic applications. However, their suitability for high-value industrial glass production has not been sufficiently investigated.

Previous research on Nigerian silica sands has largely focused on chemical composition and beneficiation methods, with relatively limited emphasis on detailed morphological characterization using advanced microscopy techniques such as Scanning Electron Microscopy (SEM). SEM provides high-resolution visualization of grain shape, surface texture, and microstructural features, enabling more precise assessment of industrial suitability [16]. Furthermore, quantitative image analysis software such as ImageJ enables accurate measurement of particle shape parameters including circularity, roundness, Feret diameter, and aspect ratio, offering objective criteria for evaluating grain morphology [17].

Recent advancements in materials processing have highlighted the importance of microstructural optimization in glass manufacturing. Morphological characteristics influence melting efficiency, batch homogeneity, and defect minimization, thereby affecting production cost and glass quality [18]. However, existing studies on Nigerian silica sands often rely on qualitative morphological descriptions without comprehensive quantitative analysis. This limitation hinders reliable industrial decision-making and large-scale resource development.

Research Gap

A critical review of existing literature reveals a significant research gap in the detailed morphological and quantitative particle shape characterization of silica sands from Dawakin Kudu, Kano State. While several Nigerian deposits have been chemically and physically evaluated, no comprehensive SEM-based morphological study combined with quantitative ImageJ particle analysis has been reported for Dawakin Kudu sand. Moreover, the relationship between grain morphology and glass-making suitability for this specific deposit remains unexplored.

This study addresses this gap by conducting a systematic morphological investigation using SEM and advanced image processing techniques, providing scientific data necessary for industrial assessment and policy formulation.

Aim and Objectives

The primary aim of this study is to investigate the morphological characteristics of Dawakin Kudu silica sand and evaluate its suitability for glass manufacturing applications.

The specific objectives are to:

1. Examine the grain morphology using Scanning Electron Microscopy (SEM).

2. Perform quantitative particle shape analysis using ImageJ software.
3. Determine the angularity, circularity, and grain size distribution of the sand.
4. Assess the suitability of the sand for soda-lime-silica glass production.

II. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

Silica sand samples were collected from River Yanbarau in Dawakin Kudu Local Government Area of Kano State, Nigeria. Representative bulk samples were obtained from multiple points along the riverbank to ensure compositional uniformity. The samples were thoroughly washed with distilled water to remove clay, silt, and organic impurities, followed by oven drying at 60°C for 3 hours.

2.2 Equipment and Materials

The experimental equipment included:

- Scanning Electron Microscope (SEM) – Phenom ProX model
- Electric oven (DHG-9053A, capacity: 900°C)
- Analytical weighing balance
- Computer system with ImageJ software
- Specimen holders and conductive carbon tape

2.3 Scanning Electron Microscopy (SEM) Analysis

The dried sand samples were mounted on aluminum specimen stubs using conductive adhesive tape. SEM analysis was conducted at Umaru Musa Yar'adua University Laboratory, Katsina, using an accelerating voltage of 30 kV. The sample was oven dried at 60^{o}C for at least 3 hours, it was then loaded into the SEM holder and the SEM was turned ON, also the monitor was ON. The sample was then bombarded with a beam of hot tungsten filament electron at an acceleration potential of 30 kV, which emit electrons that pass through a series of electromagnetic lenses. Magnification was chosen starting from lower 100X and TV scan mode was also chosen. The sample was found using trackball, slow scan mode was used to increase the magnification slowly up to 370X and 500X. Variable button was pressed were it opened small window on the monitor screen, the size of the screen was adjusted and overlaid it on the region of interest, then the image was focused within the small screen using outer focus ring followed by using inner focus ring which looked more fine than using outer focus ring. The spirit icon in the computer was double clicked and the image was saved by clicking file menu, sample name and photo I.D was imported as shown in Plate I

Images were captured at magnifications of 370× and 500× to observe surface texture, grain boundaries, and morphological features.

Plate I. Scanning Electron Microscope

2.4 Particle Shape Analysis Using ImageJ

Captured SEM micrographs were imported into ImageJ software for quantitative analysis. Image processing involved grayscale conversion, thresholding, and binary segmentation. Particle parameters measured included:

- Circularity
- Roundness
- Feret diameter
- Aspect ratio
- Solidity

Statistical analysis was performed to obtain average values and distribution characteristics.

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III. RESULTS AND DISCUSSION

3.1 SEM Morphological Analysis

SEM micrographs revealed that Dawakin Kudu sand grains exhibit predominantly angular to sub-angular shapes with sharp edges and well-defined grain boundaries. This morphology is favorable for glass production because angular grains enhance packing density and facilitate uniform melting [14], [18].

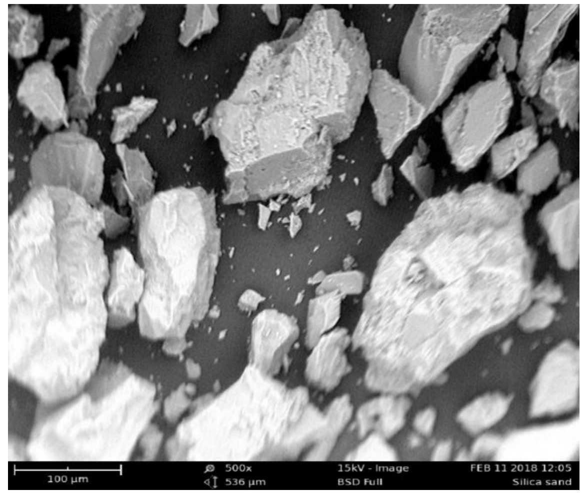

Plate II Dawakin Kudu Sand Morphology at Magnification 500x

3.2 Particle Shape Quantification

ImageJ analysis confirmed low circularity values (< 0.6), indicating non-rounded particle morphology. The average particle size was approximately 0.595 mm, which falls within the acceptable range for soda-lime glass manufacturing [9], [17]. The combined morphological and quantitative results confirm the industrial potential of Dawakin Kudu sand.

Table: 1. Dawakin Kudu Sand Particle Shape Analysis Result.

S/N	Area	BX	BY	Width	Height	Circ.	Feret	FeretX	FeretY	FeretAngle	MinFeret	AR	Round	Solidity
1	7	422	2	3	5	0.496	5.831	422	7	59.036	2.849	2.499	0.4	0.609
2	14	264	9	5	8	0.333	9.434	264	9	122.005	3.8	3.312	0.302	0.519
3	15	243	26	8	6	0.255	8.544	243	32	20.556	6	1.456	0.687	0.429
4	21	241	34	8	9	0.271	10.817	242	34	123.69	5.662	2.094	0.478	0.452
5	263	399	50	20	30	0.195	30.265	415	50	97.595	20	1.492	0.67	0.597
6	9	167	58	5	6	0.344	7.211	168	64	56.31	3.536	2.677	0.373	0.545

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7	22	171	58	7	10	0.239	10.444	175	58	106.699	6.753	1.673	0.598	0.44
8	18	163	68	6	6	0.38	7.81	163	74	39.806	6	1.199	0.834	0.6
9	19	155	76	10	8	0.286	12.207	155	84	34.992	4.418	4.351	0.23	0.475
10	22	210	76	7	9	0.465	10.817	211	85	56.31	4.537	3.399	0.294	0.595
11	112	552	100	18	21	0.375	23.431	555	100	129.806	8.751	3.705	0.27	0.624
12	180	122	101	41	53	0.073	62.482	122	149	50.194	11.404	8.578	0.117	0.289
13	29	207	111	9	17	0.212	19.235	207	128	62.103	4.715	5.478	0.183	0.45
14	92	173	123	14	25	0.148	25.962	174	148	74.358	10.27	3.099	0.323	0.443
15	36	196	128	11	10	0.257	12.083	196	135	24.444	9.068	1.271	0.787	0.468
16	181	25	129	19	26	0.361	27.514	29	155	70.907	13.621	2.216	0.451	0.633
17	33	165	129	5	15	0.256	15.133	168	129	97.595	5	3.992	0.25	0.589
18	9	191	129	2	8	0.331	8.246	191	137	75.964	2	4.974	0.201	0.692
19	33	383	134	11	8	0.236	12.083	383	141	24.444	7.034	1.754	0.57	0.55
20	5	378	137	5	4	0.388	6.403	378	141	38.66	1.947	5	0.2	0.526
21	9	387	147	6	5	0.393	7.071	388	147	135	3.905	2.175	0.46	0.5
22	8	167	171	4	6	0.335	6.325	167	171	108.435	4	1.935	0.517	0.485
23	6	196	188	3	5	0.484	5.831	196	193	59.036	2.239	3.374	0.296	0.667

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24	6	325	203	2	6	0.404	6.325	325	209	71.565	1.902	4.833	0.207	0.667
25	46	262	209	17	7	0.287	17.263	262	212	10.008	6.886	3.577	0.28	0.532
26	79	121	211	11	17	0.38	17.464	127	211	103.241	10.29	1.946	0.514	0.65
27	51	237	214	15	6	0.314	15.524	237	215	165.069	5.916	2.626	0.381	0.638
28	12	279	222	5	10	0.259	11.18	279	232	63.435	2.346	6.976	0.143	0.533
29	7	224	225	2	6	0.472	6.325	224	231	71.565	2	3.982	0.251	0.737
30	298	564	255	19	40	0.215	40.608	567	295	80.074	18.598	2.266	0.441	0.57
31	13	132	264	5	10	0.28	11.18	132	264	116.565	2.69	5.906	0.169	0.553
32	6	581	280	4	5	0.425	6.403	581	285	51.34	2.121	4.116	0.243	0.571
33	21	562	282	5	10	0.225	10.296	562	291	60.945	5	2.294	0.436	0.506
34	8	583	284	3	6	0.429	6.083	584	284	99.462	3	2.467	0.405	0.593
35	158	348	312	24	34	0.098	37.162	348	346	66.194	17.665	2.612	0.383	0.378

Table 2: Summary Result Table for Particle Size Analysis.

Slice	Count	Total Area	Average Size	%Area	Circ.	Solidity	Feret	FeretX	FeretY	FeretAngle	MinFeret
Silica Sand	35	1848	52.8	0.622	0.311	0.546	15.171	281.143	155.6	75.069	6.455

IV. CONCLUSION

This study demonstrates that Dawakin Kudu silica sand possesses favorable morphological characteristics suitable for glass-making applications. SEM and quantitative image analysis confirmed predominantly angular grain morphology with sharp edges and appropriate particle size distribution. These properties indicate strong potential for soda-lime-silica glass production. The findings provide scientific evidence supporting the utilization of Dawakin Kudu sand as a local industrial raw material, promoting economic development and import substitution in Nigeria.

V. RECOMMENDATIONS

1. Chemical composition and impurity profiling should be conducted to confirm industrial-grade purity.
2. Pilot-scale melting trials should be undertaken to validate glass quality.
3. Beneficiation studies should be performed to enhance silica purity.
4. Government and private sector collaboration should support industrial exploitation of the deposit.

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