

Investigation into the physical and chemical characteristics of silica sand for glass production: An analysis of Dilichim and Makera

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Abstract:

Silica sand is the primary component of all types of standard and specialty glass. It provides the SiO₂ component of glass formulation which is one of the key raw materials used for glass manufacturing. The suitability of such silica sand deposits of Dilichim and Makera in the Hong Local Government Area of Adamawa State, Nigeria, were examined based on the chemical and physical characteristics. The silica sand samples were gathered along the riverbanks. A specific gravity testing machine was used to examine the physical properties, such as particle size, grain morphology, and specific gravity. While an x-ray fluorescence spectrometer (XRFS) was used for the chemical analysis and an electronic microscope was also used to reveal the shape of the samples. The outcomes were contrasted with the industry standards for glassmaking which both the samples fall within the permissible ranges for glassmaking. Dilichim was found to have the highest percentage of silica concentration with a value of 79.81.00 % followed with that of Makera with a value of 76.50%, also it was found that both the samples had a high iron oxide level; Makera had the highest value at 1.30% and Dilichim had the lowest at 1.22%. Nevertheless, all of the samples had iron contents greater than 1%, which restricted their use to the production of amber and colored glass. The physical characteristics, including the angular grain shape and specific gravity of 2.50 for both samples, were determined to meet the standard for glassmaking. Therefore, the silica sand samples investigated are adequate for glass manufacturing and therefore, should be utilized.

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1. Introduction

Glass sand, also known as silica sand or quartz sand, is a critical raw material used in the production of glass. Chemical analysis of glass sand involves determining the composition of the sand to ensure that it meets the necessary quality and purity standards for glass production. The main components of glass sand are silica (SiO₂) and various impurities such as iron oxides, alumina, and titanium dioxide. Natural glass, which is existing for millions of years, formed when certain types of rocks melted as a result of high-temperature phenomena such as volcanic eruptions and lightning, and then cooled and solidified rapidly [1, 2]. Stone Age people may have used natural glass as tools owing to its high strength and sharpness. The oldest use of manufactured glass may have happened around 3500 BC in Egypt where colored glass was used as jewelry and as vessels to store liquids.

Manufactured glass contains considerable amounts of various metal oxides, mainly soda (Na₂O) and lime (CaO), in addition to the main constituent, silica. Therefore, it is known as 'soda-lime-silica-glass' or 'soda-lime glass'. Soda-lime glass is the most widely used silica-glass type in the world [3, 4].

Chemical analysis of glass sand is important to ensure that the sand meets the required specifications for use in the production of glass. The ASTM C146 standard outlines the procedures for determining the chemical composition of glass sand, including the amounts of various oxides and elements present. The standard involves the use of various analytical techniques, including wet chemical analysis, atomic absorption spectrometry, and X-ray fluorescence spectrometry. The specific methods used will depend on the nature of the sample being analyzed and the desired level of accuracy. The ASTM C146 standard provides detailed instructions for sample preparation, including cleaning and drying the sample, and performing the chemical analysis. The results obtained from the analysis are reported as percentages of the various oxides and elements present in the sample [5]. Following the guidelines outlined in ASTM C146, glass manufacturers can ensure that the glass sand they use meets the required specifications for composition and purity. This can have a significant impact on the quality of the finished glass products [5, 6].

Silica sand analysis for glass making focuses on ensuring the sand's suitability for producing desired types

of glass. This involves assessing its chemical composition, particularly the percentage of silicon dioxide (SiO₂), and its physical properties, including grain size distribution and shape. Iron oxide (Fe₂O₃) content is crucial as it can cause color changes in the glass [7]. The additions of other materials, such as iron, cobalt, manganese, etc., give color to the glass. All of the above mentioned glass making raw materials constitutes the principal (major) constituents for glass making. Whereas the auxiliary (minor) raw materials include, Fining agents such as As₂O₃, Sb₂O₃, ZnO, NaCl, KNO₃ and NaNO₃, Colourants such as CuO, Decolourants, Opacifiers agents [5, 8].

The most familiar type of glass used for centuries as windows and container glass is the Soda-Lime Silica Glass with a typical composition of about 75% silica (SiO₂) from quartz or sandstone, soda (Na₂O) from soda ash (Na₂CO₃), lime (CaO) from limestone (CaCO₃) and several other additives. Silica (SiO₂) is an acidic oxide, that is, it provides the acidic oxide in the glass. It is the fundamental constituent of all oxide glasses such as soda-lime silica glass, borosilicate glass, alumino silicates glass, lead silicate glass and vitreous or fused silica glass. It occurs in nature both in its free state in form of quartz and in combined form [9, 10].

Sillimanite, kyanite, andalusite, zircon, spinel, garnet, and other heavy minerals are included in the final glass. These particles can withstand the melting of glass and emerge as solid inclusions or flaws in the stone. These kinds of minerals have a specific gravity higher than 2.65. Accordingly, any sample with a specific gravity higher than 2.65 is undesirable for use in the production of glass [4, 11]. Finally, the aim of the research is to evaluate the two sand samples for glassmaking in terms of their physical and chemical characteristics.

2. Materials and Methods

Two silica sand samples were gathered from Dilichim and Makera, two streams on opposite sides of Hong Local Government in Adamawa State. The National Metallurgical Development Centre (NMDC) [18] in Jos, Plateau State, Nigeria, conducted tests on the silica sand samples' chemical and physical characteristics in 2024. The chemical analysis was conducted using an X-ray fluorescence spectrometer (XRFS). The standard method was followed based on BS2975: 2024 [4], finally the sand samples were calibrated to identify the anticipated chemicals or components within the sand samples. For the particles size analysis, dry sieving method was used followed by an oven drying process, and after the total percentage of particles that passed through each sieve was then computed and noted. For the grain morphology, electronic microscope was used for the two sand samples. For the specific gravity analysis, gravity tester was used in which the two sand samples were introduced directly and automatically and digitally the tester presented the specific gravity values on a visual display unit.

3. Results and Discussion

The silica sand samples of Dilichim and Makera with regard to chemical and physical characteristics, and

computed cumulative percentage weight values are presented in Tables 1, 2 and 3 respectively.

Table 1: Chemical properties of Dilichim and Makera silica sand samples

S/No	Composition	Dilichim % by Weight	Makera % by Weight
1	Na ₂ O	3.02	5.28
2	SiO ₂	79.81	76.50
3	ZrO ₂	0.04	0.03
4	MnO	0.04	0.02
5	Al ₂ O ₃	7.10	7.92
6	K ₂ O	7.00	7.23
7	TiO ₂	0.22	0.04
8	Cr ₂ O ₂	0.10	0.13
9	Fe ₂ O ₃	1.22	1.30
10	RB ₂ O	0.04	0.04
11	NiO	0.02	0.005
12	CUO	0.04	0.04
13	CaO	0.10	0.10
14	ZnO	0.05	ND
15	MgO	0.15	0.11
16	Ga ₂ O ₃	ND	0.03
17	SrO	0.02	0.01
18	BaO	0.22	0.14
19	Nb ₂ O ₅	0.03	0.04
20	Na ₂ O	2.01	3.05
21	AU	0.02	0.02

Key: ND = not detected

For Dilichim, the proportion of the silica sand is 79.81% and 76.50% for Makera as can be seen in Table 1. Both the two silica sand samples were found to be high and adequate for glass manufacture [12]. With the high proportion of iron oxide that was obtained, it show clearly that the two silica sand samples are good for colored and amber glass manufacturing [9, 13]. This is as a result of the iron concentration exceeding 1% for both the Dilichim and Makera silica sand samples. The corresponding MgO percentages were 0.15 and 0.11, respectively. For Dilichim and Makera, the corresponding CaO percentages were 0.10 and 0.10, respectively. The percentages of Al₂O₃ obtained for the two samples were 7.10 and 7.92 for Dilichim and Makera respectively. All the values obtained when compared to the standard percentage composition requirements of 4-5% of CaO and MgO were required for the manufacturing of sodalime and lead glasses [8, 10, 14]. The percentages of the entire main ingredient mentioned above (MgO, CaO, and Al₂O₃) obtained in the silica sand samples shown in Table 1 were extremely low for glass making. However, the percentages of Na₂O and K₂O in the two samples with regard to the standard percentage required for different glass formulations, the two samples were found to be sufficient. Therefore, the two samples can be used for borosilicate glasses, lead glasses, fiber-glasses, and to a lesser extent, alumina silicate glasses, as the requirement falls between 2 and 9 percent by weight [10, 15, 16].

Table 2 displays the two samples' angular grain morphology. As presented by BS2975: 2024 [4] and Waudby [17], the grain shape or morphology must be angular rather than rounded. Also the specific gravity for the two samples was found to be 2.50. Grain morphology

or shape, specific gravity (SPG), and the grain fitness number (GFN) are the physical properties of silica sand that determine the suitability of silica sand for glass making. As presented by David and Mashar [14], and Tooley [11], for silica sand with a specific gravity above 2.65 automatically not suitable for glass making. Thus, all the two samples are suitable for glass making when compared with the standard requirements for glass making.

Table 2: Dilichim and Makera Physical Properties of the Silica Sand Samples

S/No	Composition	Dilichim	Makera
1	Specific gravity (SPG)	2.50	2.50
2	Grain fitness number (GFN)	21.12	14.21
3	Grain morphology	Angular	Angular

Table 3: Calculated cumulative percentage by weight of the silica sand particles passing each sieve aperture for the two samples (Dilichim and Makera)

Sieve Aperture	Mesh Number	Dilichim % by weight	Product	Makera % by weight	Product
1.40	14	18.22	-	28.34	-
1.00	18	13.11	183.54	21.32	298.48
0.71	25	19.29	347.22	22.32	401.76
0.50	35	21.06	526.50	15.41	385.25
0.355	45	15.94	557.90	8.45	295.75
0.250	60	8.55	384.75	3.07	138.15
0.180	80	2.23	133.80	0.49	29.40
0.125	120	0.97	77.60	0.25	20.00
0.090	170	0.25	30.00	0.08	9.60
0.063	230	0.10	17.00	0.07	11.90
0.063	-230	0.24	55.20	0.12	27.60
		99.96	2313.51	99.92	1617.89

Table 3 shows the particle size distribution in which sieve aperture 1.40 to 0.063 and mesh number of 14 to -230 were used to obtain the percentage by weight of the two silica sand samples, with sieve aperture of 1.40 and mesh number of 14 the percentage by weight of Dilichim and Makera were obtained as 18.22 and 28.34 respectively and it subsequently follows as shown in the Table. The results show that both the two samples were found to be suitable for glass making, this is because over 90% of the particle sizes lies within 15-100 mesh BS sieve number which is in line with the British Standard Methods for Sampling and Analysis of Glass-Making Sands [4].

4. Conclusion

Dilichim and Makera, the two main glass-forming oxides in the two samples, had silica contents of 79.81% and 76.50%, respectively. These percentages were deemed sufficient for glassmaking because they fall inside the 70% minimum standard requirements. Since the grain morphology of both silica sand samples was angular rather than spherical, it was determined that they all possessed the physical characteristics needed to make glass. Because the iron oxide content of the silica sand samples-1.22% and 1.30% for Dilichim and Makera, respectively- was somewhat more than 1%, its uses are restricted to the

manufacturing of colored and amber glass. All the silica sand samples analyzed have additional chemicals or compounds that could be added to improve the quality of the glass produced. Therefore, the silica sand samples investigated are adequate for glass manufacturing and therefore, should be utilized.

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