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Geological and geotechnical assessment of natural sands in Ilorin, Nigeria

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The quality of the aggregates used inplastering mortar contributes to the properties of the mortar. This study evaluated the suitability of two grades of sand – sharp sand collected along active/old river courses and plastering sand collected from borrow pits – as plastering materials. X-ray diffraction and X-ray fluorescence analysis were used to study their mineralogy and major, minor and trace element components. Grain-size distribution analysis, natural moisture content, specific gravity, Atterberg limits, matric suction and permeability tests were also carried out on the sand samples. In both sands, the silica content was more than 80%. The plastering sand had a higher natural moisture content than the sharp sand. The fineness modulus ranged from 1.31 to 1.83 and 0.53 to 1.01, respectively, for the sharp sand and the plastering sand. The permeability coefficients and matric suction of the sharp sand were larger than those of the plastering sand. This implies that sharp sand will allow easier water passage through its pore spaces, therefore tending to exist in a dryer state than plastering sand. The tested sharp sand may be suitable for plastering because the test results were within the acceptable limits for good plastering materials according to national and international standards.

Keywords: aggregates/geochemistry/mineralogy

1. Introduction

Evaluation of naturally occurring construction materials is important for sustainable development. The rate of building collapse in Nigeria is on the rise (Anosike, 2021; Bamigboye *et al*., 2019; Owoyemi and Bamigboye, 2013). Additionally, buildings are experiencing the phenomenon of rising damp. According to Gentilini *et al*. (2012), one of the most severe factors leading to the deterioration and decay of buildings is rising damp. While building failures have been attributed to poor or substandard materials (Bamigboye *et al*., 2019; Tetsopgang *et al*., 2020), the presence of groundwater and the porosity of masonry sandcrete block walls are, among others, the main causes of rising damp (Oduro Asamoah *et al*., 2017).

Aggregates are hard, granular materials suitable for use in construction either on their own or with the addition of cement, lime or bituminous binder (Mitchell, 2015). Knowledge of the geology of aggregates is important because it helps to evaluate their suitability for their intended use (Langer and Knepper, 1998). Natural aggregates can be classified as either coarse or fine aggregates (BIS, 2016). Natural sand can be defined as fine aggregates resulting from the disintegration of rocks and which have been deposited by streams or glacial deposits (BIS, 2016). Plastering mortar is a composite material made up of inert materials of varying sizes, which are bound together by water and a binding medium such as cement or lime. Mortars used for rendering the outside and inside of walls in building construction are termed plasters (Caroselli *et al*., 2021).

The quality of mortar is largely influenced by the quality of aggregates used in the mix (Lanas *et al*., 2004; Pavia and Toomey, 2008; Varghese, 2015). Good-quality aggregates do not contain harmful materials such as silt, clay, shale, iron oxide, coal, mica, free lime, lignite, alkali, pyrites and so on in quantities that can affect the durability and strength of the mortar (BIS, 2016). Certain rocks and minerals such as cherts, strained quartz and certain dolomitic limestones are alkali reactive (Buck *et al*., 1984). In construction works, natural aggregates are needed in larger quantities than manufactured materials. Normally, the focus is on the evaluation of manufactured materials such as cement and steel, while evaluations of naturally occurring components such as sand and gravel can be neglected. These materials are often used for construction without recourse to their properties and suitability for their intended use.

Evaluation of the quality and suitability of construction aggregates is important because it helps to forestall issues that can negatively affect the functionality and durability of buildings or infrastructures. Fixing construction errors is costly, and structural failure poses a risk to human lives and causes loss of property (Gollu *et al*., 2016; Owoyemi and Bamigboye, 2013; Sahlol *et al*., 2021).

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Standards such as the American Society for Testing and Materials (ASTM) standard for Ottawa Sand, the European Committee for Standardisation (CEN) standard for sand, the Indian standard for quartzanium sand and the Japanese standard for Toyoura Sand have been recommended for testing concrete and mortar (Asare and Ernest, 2021; Nakamura *et al*., 2022; Ojuri and Agbolade 2017; Pratiwi *et al*., 2020; Ta *et al*., 2023). These standards are for silica (SiO_2) sands with suitable properties for the optimum performance of concrete and mortar. One report (RMRDC, 2010) showed that major silica sand deposits in Nigeria are located at Ughelli, Igbokoda, Baure, Badagry and along the sandy shoreline of the Atlantic Ocean. These sands are not accessible to many local builders because they are geographically confined to certain regions of the country and the high cost of haulage makes it difficult to transport this essential building aggregate over long distances. Therefore, there is a need to access locally available sand deposits to supply aggregates to local builders and to ascertain that their properties do not have adverse effects on infrastructure.

Although a few research studies have been conducted on the assessment of sand for use as fine aggregates in concrete production in Nigeria (Ajagbe *et al*., 2017; Ojuri and Fijabi, 2012; Olasupo and Omotoyinbo, 2009), the literature on the properties of sand for plastering mortars in Nigeria is scanty. Traditionally, in Nigeria, two common types of sand are used for plastering buildings. One is plastering sand and the other is the sharp sand/river sand. Both are unconsolidated sand deposits usually quarried from borrow pits, which are believed to be old stream channels. River sand can also be quarried from present stream channels. Plastering sand is usually finer grained and clumpy and is suspected to contain an amount of natural cement. Its primary use is for plastering. Other uses for river sand include concrete mixing and floor tile fixing. There is no research reported on the physical, mineralogical and geochemical properties of these important building aggregates in the study area. Therefore, in this study, the physical, chemical and mineralogical properties of samples of plastering sand (PL) and sharp sand/river sand (SH) were evaluated for their use in plastering.

2. Study area

The sand samples for this study were taken from locations on the outskirts of Ilorin, which is a rapidly expanding city and an administrative centre of Kwara state, Nigeria. Massive rural-to-urban migration has increased the demand for new residential and commercial buildings in the metropolis. This has given rise to an increase in demand for aggregates for building construction. Figure 1 shows the sampling locations on a geologic map of the study area. Most of the samples (SH1, SH2, SH3, PL2 and PL3) are located on migmatite, while the others (SH4, PL1 and PL4) are located on medium-to-coarse-grained biotite and hornblende granite. The sampling locations are quarry sites and old/active river courses where aggregate merchants quarry sands that they supply for construction purposes in the metropolis. The sampling points and their coordinates are shown in Table 1.

3. Methods

In total, eight bulk sand samples were taken from borrow pits and stream channels at different locations on the outskirts of Ilorin metropolis, where aggregate suppliers usually quarry sand for building projects in the city (Table 1). All the samples were checked for natural moisture content and then air dried until a constant weight was achieved. Major, minor and trace elements present in the sands were analysed by X-ray fluorescence (XRF) using Rigaku Primus IV WDXRF XRF equipment. A quantity of each sample (10 g) was heated to 110°C to dehydrate and devolatilise it. They were then heated to 1050°C to give the total loss on ignition (LOI). From each 10 g soil sample, 0.28 g was used to prepare a fusion disc by adding flux in the order: 0.2445 g of lanthanum oxide (La_2O_3), 0.705 g lithium borate ($Li_2B_4O_7$), 0.5505 g of lithium carbonate (Li_2CO_3) and 0.02 g of sodium nitrate ($NaNO_3$). The mixture was then heated to 950°C for approximately 5 min in a platinum crucible until a consistent fluid was formed. The resulting fluid was then poured into a mould and pressed to form the fusion disc, which was used for the measurement of elements in major quantities. For sodium and trace element measurements, a pressed pellet formed from 8 g of soil sample added to 3 g of Hoechst wax ($C_6H_8O_3N_2$) was used.

Mineralogical analysis was carried out using X-ray diffraction (XRD). A Panalytical Empyrean X-ray diffractometer equipped with a copper side window tube and X' Celerator detector was used. The anode of this equipment is made of copper while the cathode is made of tungsten. Its X-ray tube produces a $CuK_{\alpha 1}$ X-ray beam with a Bragg–Brentano geometry focus position and a theta–theta goniometer configuration. The soil samples were scanned between 3.5 and 70° (2θ) detector position and tube settings of 45 kV and 40 mA. Data Collector v. 3.0c software was used for data collection and Highscore v. 3.0e software equipped with the ICDD PDF-2 database was used for evaluation of the diffractograms.

Geotechnical tests such as grain-size distribution analysis, specific gravity, consistency limits, permeability and matric suction were carried out on the soil samples. Grain-size distribution analysis, including hydrometer tests, was performed following the ASTM D 422-63 standard test method for particle-size analysis of soils (ASTM, 2007). This helps to determine the distribution of coarse-grained and

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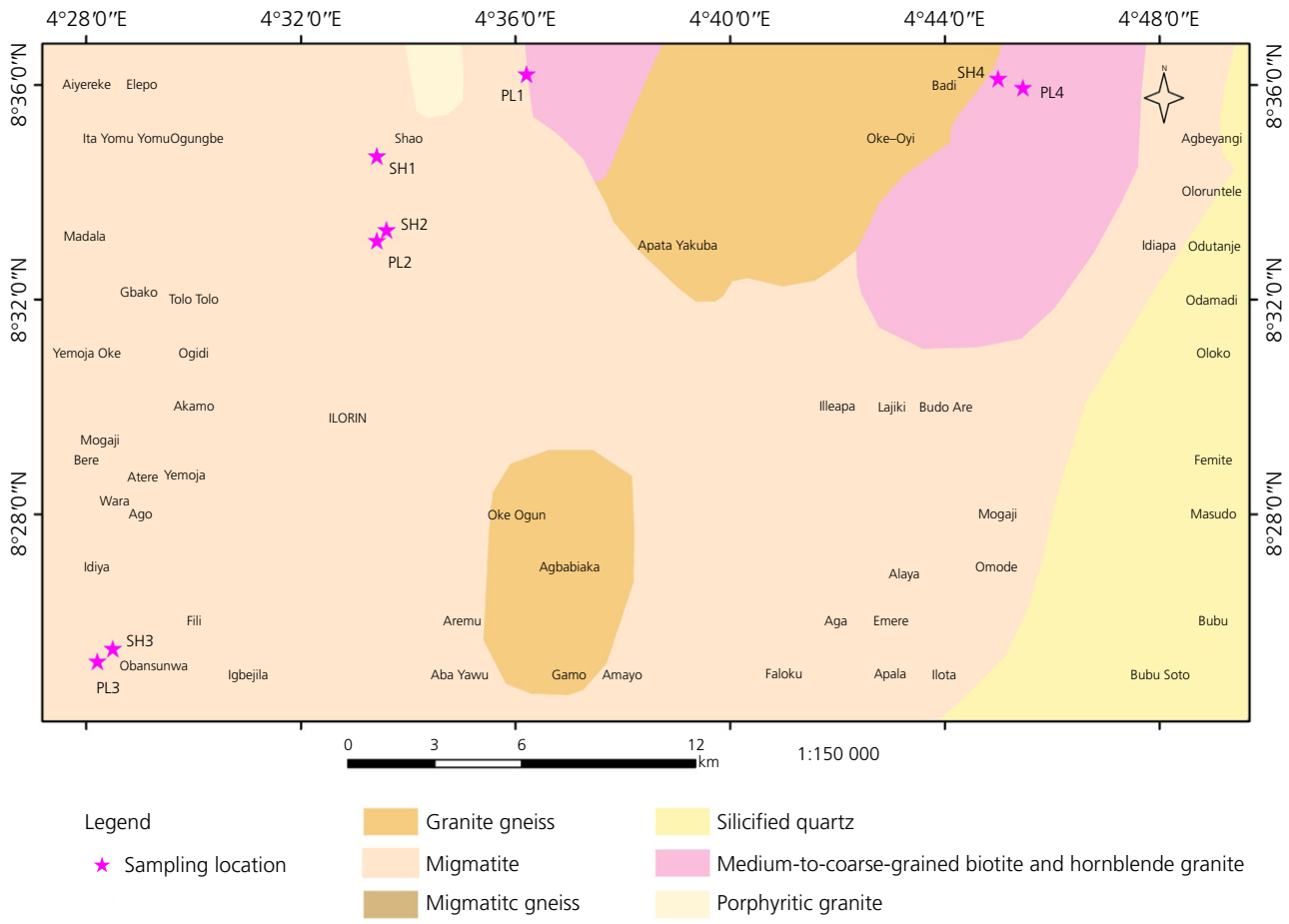


Figure 1. Geologic map showing sampling locations

Table 1. Locations of sampling sites

Plastering sand	Location	Coordinates	River sand	Location	Coordinates
PL1	Jagodo old quarry	Latitude: 8.603 Longitude: 4.517	SH1	Asa River tributary at Shao	Latitude: 8.857 Longitude: 4.557
PL2	Kangile sand quarry	Latitude: 8.553 Longitude: 4.560	SH2	Asa River tributary at Kangile	Latitude: 8.555 Longitude: 4.560
PL3	Eye Nkorin sand quarry	Latitude: 8.425 Longitude: 4.75	SH3	Eye Nkorin old stream channel	Latitude: 8.425 Longitude: 4.475
PL4	Oke–Oyi sand quarry	Latitude: 8.600 Longitude: 4.754	SH4	Oke–Oyi old stream channel	Latitude: 8.602 Longitude: 4.754

fine-grained particles in the soil samples. The fineness modulus was calculated from the grain-size distribution test results using Equation 1.

The test method in BS 1377:1990 (BSI, 1990) was used for determination of the liquid limit, plastic limit and plasticity index of the soils. Consistency limits help to classify soils and

$$1.\quad \text{Fineness modulus} = \frac{\text{Cumulative per cent retained on standard ASTM sieve numbers } 4, 8, 16, 30, 50, 100}{100}$$

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Table 2. Major and minor elemental composition of the sand samples and Ottawa sand

	PL1	PL2	PL3	PL4	SH1	SH2	SH3	SH4	Ottawa sand
Silica: wt%	83.46	92.36	91.92	83.30	89.01	83.17	88.51	85.44	99.8
Titanium dioxide: wt%	0.79	0.92	0.87	0.29	0.21	0.28	0.56	0.30	0.01
Aluminium oxide: wt%	7.71	2.14	2.75	7.34	7.17	5.96	5.11	5.81	0.06
Ferric oxide: wt%	2.67	2.52	2.17	1.13	2.49	6.82	0.83	2.40	0.02
Magnesium oxide: wt%	0.01	0.17	0.00	0.00	0.18	0.00	0.09	0.07	0.01
Manganese oxide: wt%	0.02	0.04	0.03	0.02	0.03	0.08	0.02	0.04	–
Calcium oxide: wt%	0.21	0.22	0.27	0.60	0.49	0.64	0.16	0.65	0.01
Sodium oxide: wt%	0.42	0.24	0.37	1.07	1.01	0.61	0.22	0.88	0.01
Potassium oxide: wt%	2.40	0.20	0.20	3.32	1.05	1.31	1.95	2.33	0.01
Phosphorus pentoxide: wt%	0.03	0.02	0.02	0.02	0.02	0.08	0.02	0.03	0.01
LOI: wt%	1.89	1.04	1.01	1.39	0.27	2.47	0.88	0.51	
Total: wt%	99.6	99.9	99.6	98.5	101.9	101.4	98.3	98.5	

determine their ability to absorb water. The traditional plastering sand in the study area is believed to have some natural cementitious properties, hence the evaluation of its plasticity. Specific gravity is used in the computation of mixture proportions in concrete (Asare and Ernest, 2021; ASTM, 2001). The permeability of the two sands was determined using a falling head permeameter following the specification of BS 1377:1990 (BSI, 1990). This was done to determine the ease with which water would drain through these materials when used for construction. Soil suction is a measure of the free energy of soil pore water. The total matric suction of the soil samples was investigated using Whatman grade 42 filter paper enclosed in a plastic bag following ASTM D 5298-03 (ASTM, 2003). This property, expressed in kiloPascals, was determined from the amount of water absorbed after 7 days from a standard calibration curve for the Whatman grade 42 paper based on the wetting testing procedure modified after ASTM D 5298-10 (ASTM, 2010), cited by Kim *et al*. (2017). This calibration curve was originally proposed by Greacen *et al*. (1987); it has a correlation coefficient greater than 0.99 for filter paper moisture content and suction in kiloPascals. Matric suction was investigated to determine the affinity of the two types of plastering materials for water retention.

4. Results and discussion

4.1 Geochemical and mineralogical properties of the sands

Quality and gradation are two general types of requirements for plastering sand. Table 2 presents the major and minor elements present in the PL and SH samples, while Table 3 shows the trace elements present in representative samples of the two types of sands. Silica, generally above 80%, was found to be the main component of all the sand samples (Table 2). None of the samples from the two categories of sands had a silica content close to that of Ottawa Sand (99.8%). The silica content of the PL samples did not correspond to their quartz content. This implies that some of the measured silicas are from other silicate-bearing minerals such as feldspars, mica and kaolinite. Both sand types generally have major and minor elements exceeding standard recommended values as represented by Ottawa standard sand. Quartz is generally believed to be inert, but the presence of impurities such as iron oxide in sands can interfere with plaster performance. The LOI was higher in the PL samples than in the SH samples. This might indicate the presence of more volatile components such as organic matter, as indicated by the dark brown colour of the PL samples (Figure 2(a)). This is not desirable for aggregates used for plastering and mortar (BIS, 1992; BSI, 1976; FRN, 2006).

Table 3. Trace element contents (in ppm) of selected sand samples

	PL4	SH1
Scandium	<3	<3
Vanadium	23	14
Chromium	16	26
Cobalt	<3	7
Nickel	9	6
Copper	<4	4
Zinc	8	5
Arsenic	<1	4
Rubidium	99	23
Strontium	175	102
Yttrium	16	5
Zirconium	638	134
Niobium	10	2
Barium	1074	435
Lead	31	2
Thorium	5	3
Uranium	<3	<3

The PL samples were richer in trace elements than the SH samples (Table 3). The presence of barium as the highest trace element in PL4 is an advantage since research has shown that barium-containing mortars have better performance

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(Carmona-Quiroga and Blanco-Varela, 2021). Sulfate attack is one of the causes of deterioration in Portland cement mortar. Barium can counteract sulfate attack on mortars by the formation of barium sulfate ($BaSO_4$) (Carmona-Quiroga and Blanco-Varela, 2021; Karatasios *et al.*, 2008; Wilkins *et al.*, 2001). When barium carbonate is present in the cementing material of a mortar mixture, its reaction with attacking sulfuric acid leads to the precipitation of barite (Reaction I), which is relatively insoluble. The formation of barite in mortar consolidates the aggregates in the binding material and therefore increases their resistance to chemical degradation. Barium also has radiation-resistant properties (Zezulová *et al.*, 2016)

$$\text{I.} \quad HSO^{-}_{4(aq)} + SO^{2-}_{4(aq)} + BaCO_{3(s)} \rightarrow BaSO_{4(s)} + CO_{2(aq)}$$

XRD analysis was only conducted on the PL samples because the SH samples were mostly clean sand-sized quartz grains from visual examination (Figure 2). XRD analysis showed that the kaolinite content was less than 10% and quartz was the dominant mineral (Table 4). Figures 3 and 4 show the XRD diffractograms of two PL samples.

The presence of some mica and clay minerals in the PL samples is not desirable because the British standard for building sands from natural sources (BSI, 1976: p. 1) recommends that natural sands for building 'shall be hard, durable, clean and free from adherent coatings, such as clay, and from any appreciable amount of clay in pellet form'. It further recommends that sands shall not contain harmful materials such as iron pyrites, salts, coal or other organic impurities, mica, shale or similar laminated materials, or flaky or elongated particles in such a form or in sufficient quantity to adversely affect the hardening, the strength, the durability or the appearance of the final product or any materials in contact with it.



(a) (b)

Figure 2. (a) PL sample. (b) SH sample

Nigeria's *National Building Code* (FRN, 2006) also recommends that sand for mortar, plaster, rendering or floor screeds should be reasonably clean and free from clay, organic or other deleterious matter, pass through a 5 mm mesh and be well graded. The Indian standard for plastering sand quality (BIS, 1992) recommends that sand shall not contain any harmful impurities, such as iron pyrites, alkalis, salts, coal, mica, shale or similar laminated materials, soft fragments, sea shells and organic impurities in such quantities as to adversely affect the hardening, the strength, the durability of the appearance of the plaster or apply decoration, or to cause corrosion of metal lathing or other metal in contact with the plaster. Based on these standards and comparison with the standard Ottawa Sand mineralogy, the PL samples fell short of recommended standards.

4.2 Physical properties

Table 5 shows the physical properties of both sands. The physical properties tested included natural moisture content, specific gravity and consistency limits. The PL sands were found to have specific gravities between 2.55 and 2.69, while those of the SH samples were between 2.53 and 2.7. Apart from PL2 and SH3, which had specific gravities lower than 2.6, the other samples had values close to the value of 2.65 for Ottawa standard sand. This range of specific gravities is expected to be suitable for good plastering sand. Aggregates with relatively high specific gravities are expected to be high quality because aggregates that are porous and rich in organic matter usually have low specific gravities. Ojuri and Fijabi (2012) stated that the specific gravity values somehow reflect the silica content of the sand – that is, the higher the silica content, the higher the specific gravity. This could not be established in this study as there was no correlation between silica content and the specific gravity of the sand in question. Also, the standard value of 2.65 for Ottawa Sand corresponds to the specific gravity of pure silica (Lambe and Whitman, 1969). In addition, other silicate-bearing minerals can also contribute to

Table 4. Mineral components of the sand samples

	Quartz: wt%	Plagioclase: wt%	K-feldspar: wt%	Mica: wt%	Kaolinite: wt%
PL1	62	6	17	8	7
PL2	64	5	20	6	5
PL3	82	6	6	—	6
PL4	60	8	26	—	6
Ottawa standard sand	99.8	0.01		0	0.01

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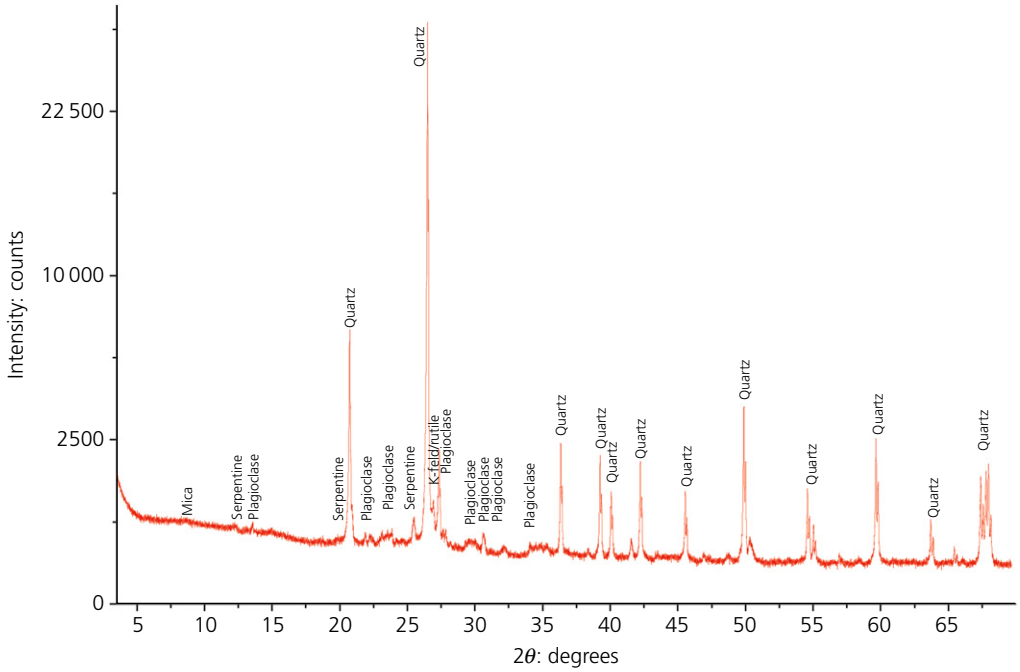


Figure 3. XRD diffractogram of PL2

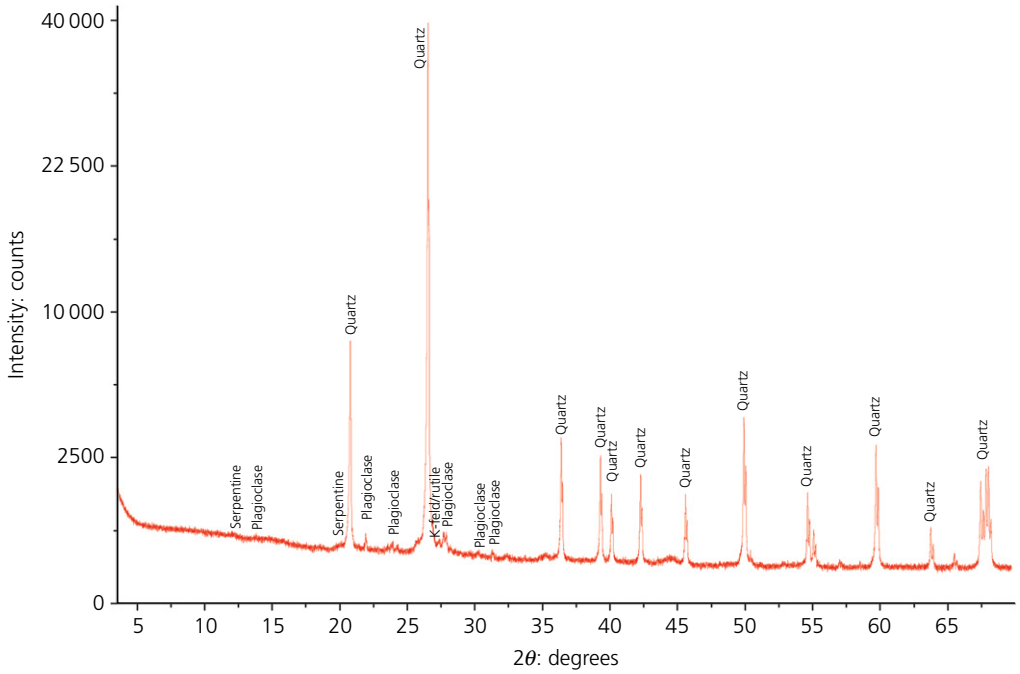


Figure 4. XRD diffractogram of PL3

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Table 5. Physical properties of the sand samples

Sample	Specific gravity	Natural moisture content: %	Liquid limit: %	Plastic limit: %	Plasticity index: %	Shrinkage limit: %
PL1	2.69	15.38	8	NP	NP	0.88
PL2	2.55	13.16	11	NP	NP	0.58
PL3	2.64	10.20	8	NP	NP	0.70
PL4	2.62	17.50	22	17.2	4.8	0.32
SH1	2.66	7.89	NP	NP	NP	NP
SH2	2.70	7.50	NP	NP	NP	NP
SH3	2.53	4.23	NP	NP	NP	NP
SH4	2.63	4.14	NP	NP	NP	NP

NP, non plastic

Table 6. Grain-size composition of the two grades of sand

	SH1	SH2	SH3	SH4
Silt: %	0.4	1	1.9	0.5
Sand: %	99.5	82.2	94.6	89.8
Gravel: %	0.1	16.8	3.5	9.7
USCS class	Well-graded sand (SW)	Well-graded sand (SW)	Well-graded sand (SW)	Well-graded sand (SW)
	PL1	PL2	PL3	PL4
Clay: %	0	10.0	4.2	14.0
Silt: %	67.0	55.0	53.4	62.4
Sand: %	30.0	25.0	42.0	22.4
Gravel: %	3	10.0	0.4	1.2
USCS class	Sandy silt (ML)	Sandy silt (ML)	Sandy silt (ML)	Sandy silt (ML)

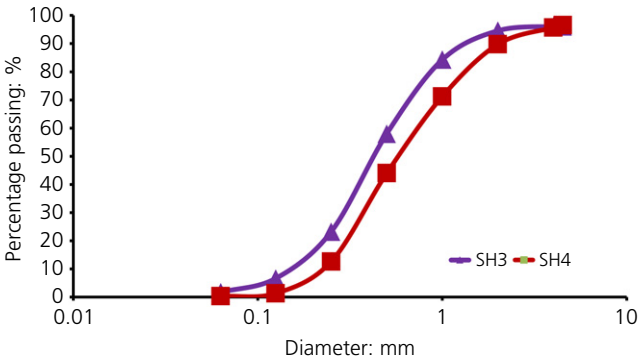


Figure 5. Grain-size distribution curve of samples SH3 and SH4

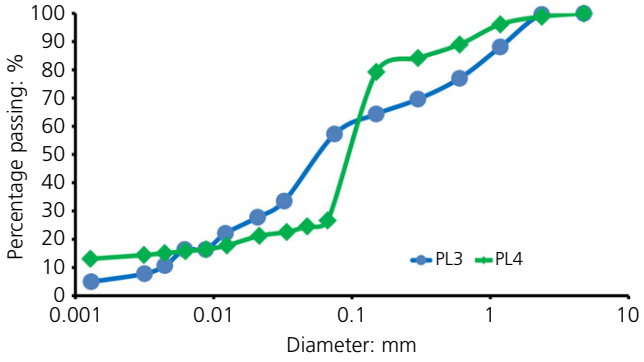


Figure 6. Grain-size distribution curve of samples PL3 and PL4

the silica measured in compositional analysis (Owoyemi and Adeyemi 2021). Therefore, mineral analysis might be an essential part of sand characterisation, as opposed to the recommendation of Raveia *et al.* (2008).

The PL samples were found to have a higher natural moisture content than the SH samples. ASTM C 70 (ASTM, 2013) recommends that fine aggregates should have a moisture content of about 3–8%. All the SH samples met this requirement, as shown in Table 5, but none of the PL samples had a moisture content less than 8%. The PL samples had a higher moisture content due to the presence of significant clay and silt particles (Table 6). These fine-grained soil grains act as narrow conduits for water, hence leading to higher capillarity and water-retention capacity. This is not desirable for good plastering sand because the resulting plaster might exhibit water-retaining ability after construction. This can lead to wall dampness and premature ageing of buildings plastered with this kind of sand.

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Plasticity is the property of soils that allows them to deform without cracking. It describes their ease of moulding. All the SH samples were non-plastic while the PL samples had a liquid limit of 8–22% with negligible shrinkage limit. Only PL4 was slightly plastic, having a plasticity index of 4.5%. This might be due to the presence of significant clay-sized fragments in this sample (Table 5). This sample also had the lowest quartz and silica contents. The granular nature of the SH samples reflects their mineral composition. Since plasticity is usually imparted by clay minerals, the quartz grains in the SH samples did not exhibit any plasticity. The presence of trace plasticity in the PL samples can be attributed to the presence of other hydrophilic minerals like mica, feldspars and clay. The PL samples were also expected to be slightly more water absorbent than the SH samples due to their liquid limits. The assumption by local builders that the plastering sand in the area has natural plasticity properties that are expected to be transmitted to the plastering mortar is therefore unfounded.

4.3 Grading

The main component of all the SH samples was found to be sand, with some gravel and negligible silt (Table 6). The grain-size distribution curves (Figures 5 and 6) show that the SH samples were well-graded sand. They are classified as SW (well-graded sand), with one sample containing a significant amount of gravel. The PL samples are classified as ML (sandy silt). These samples were

Table 7. Fineness modulus of the sand samples

Grain diameter in mm/sieve number	Percentage retained on sieve							
	SH1	SH2	SH3	SH4	PL1	PL2	PL3	PL4
4.75/no. 4	0	0	0	0	0	0	0	0
2.36/no. 8	0	19	5	8	0.48	8.04	0.36	1.142
1.18/no. 16	20	7	7	18	12.26	13.12	11.92	3.862
0.6/no. 30	26	57	27	30	19.84	18.8	23.02	10.972
0.3/no. 50	53	36.6	42	50	25.18	25.28	30.4	15.818
0.15/no. 100	43	63.2	50	48	29.14	31.82	35.66	20.724
Σ	142	182.8	131	154	86.90	97.06	101.36	52.52
Fineness modulus	1.42	1.83	1.31	1.54	0.87	0.97	1.01	0.53

Table 8. British standard (BSI, 1976) specifications for plastering internal and external walls compared with the properties of the soils studied

British standard			Fraction passing: %							
	Fraction passing: %		Plastering sand				Sharp sand			
Sieve size	Type A	Type B	PL1	PL2	PL3	PL4	SH1	SH2	SH3	SH 4
100 mm	100	100	100	100	100	100	100	100	100	100
5 mm	95–100	95–100	100	98.8	100	100	100	89.1	96.6	100
2.36 mm	60–100	80–100	99.5	90.7	99.6	98.8	100	81	95	92
1.18 mm	30–100	70–100	87.7	85.7	88.08	96.1	80	74	88	74
0.600 μm	15–80	55–100	80.2	80.0	77.0	77.0	0.3	0.9	1.7	0.3
0.300 μm	5–50	5–75	74.8	73.5	69.6	69.6	0	0	0	0
0.150 μm	0–15	0–20	70.9	67.0	64.3	64.3	0	0	0	0
0.075 μm	≤5	≤5	68.0	63.8	57.2	57.2	0	0	0	0

Table 9. Coefficients of permeability of sand samples

Sample	Coefficient of permeability × 10^{-3}	Sample	Coefficient of permeability × 10^{-3}
SH1	8.72	PL1	2.75
SH2	8.06	PL2	1.47
SH3	6.56	PL3	3.79
SH4	6.62	PL4	3.86

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Table 10. Matric suction of sand samples

Sharp sand		Plastering sand	
Sample	Matric suction: kPa	Sample	Matric suction: kPa
SH1	20.0	PL1	12.6
SH2	31.6	PL2	7.9
SH3	22.4	PL3	6.0
SH4	39.8	PL4	15.8

mostly fine-grained soil with more silt content than sand content. Three of the PL samples also contained significant clay-sized grains (Table 6). This is not desirable for good plastering sand because fine-grained materials can retain water and thus keep plastered walls wet. Although the PL samples met the Nigerian building code in terms of grading, they fell short of this standard due to the presence of significant clay and mica. The Indian standard IS 2386 (part 2) (BIS, 1963) specifies that clay, silt and dust should not be more than 5% weight of plastering sand. All the PL samples had more fine-grained components than the recommended maximum value of 5% fineness. This is not desirable as the cracking of plasterwork intensifies with increasing fineness content (Soroka and Korin, 1969).

IS 2386 (part 2) (BIS, 1963) also stipulates that the fineness modulus of naturally occurring plastering sands should not be less than 1.5. Table 7 shows that the SH samples had a fineness modulus ranging between 1.31 and 1.83, while the fineness modulus of the PL samples was between 0.53 and 1.01. None of the PL samples had a fineness modulus that met the recommended value of 1.5. All the SH samples had a fineness modulus higher than 1.5. Table 8 shows the British standard provisions for sands for plastering internal and external walls compared with the grading properties of the SH and PL samples. None of the samples perfectly fitted the grading requirements of the code. This might be due to differences in climate and other local soil-forming factors in the tropics compared with the UK.

4.4 Matric suction and permeability

Matric suction is a soil parameter that influences the behaviour of unsaturated soils in terms of both shear strength and permeability. It is necessary for the determination of unsaturated soil shear strength, bearing capacity, permeability and effective stress in the unsaturated soil zone (Fredlund *et al.*, 2012; Lu and Likos, 2004). Tables 9 and 10 show that the permeability coefficients and matric suction of the SH samples were larger than those of the PL samples. This implies that the SH would allow water to pass through its pore spaces more easily, therefore having the tendency to exist in a higher matric suction state (dryer) than the PL. The PL tends to remain in a wet state in its unsaturated state; hence, the lower matric suction. This is also evident in the higher natural moisture content of all the PL samples (Table 5).

5. Conclusion

Two types of sands used for plastering in Ilorin and its environs were evaluated for their suitability as plastering sand. Samples were evaluated in terms of their quality and grading. The silica content in both types was generally above 80%. Although this content can be considered high, it does not meet the code-recommended value. The concentration of other elements in the soils studied also exceeded the standard values. The PL samples were determined to be silty sands while the SH samples were mainly clean sand with some gravel and negligible silt. The PL soils contained some organic materials like clay and mica, which should not be present in good plastering sand according to national and international recommendations. In the PL samples, the natural moisture content was higher than the recommended standard, and low matric suction and permeability were observed. These are indications that walls plastered with mortar made from PL might exhibit high water-retention capacity, contribute to rising damp phenomena and do not dry easily once wet. This is not aesthetically pleasing and might lead to faster degradation of plastered walls.

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