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Investigation of Abuja Sands for Foundry Application

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Abstract

The investigation of the properties of sands within the Abuja metropolis of the Federal Capital Territory, Nigeria, to ascertain their suitability for foundry applications is critical considering Abuja's proximity to the Ajaokuta Steel Company, at Ajaokuta, Kogi State, Nigeria. The foundry industry in Nigeria is yet underdeveloped. However, the government's determination to reduce overdependence on foreign goods to boost its economic base and embrace agriculture as an alternative source of economic booster is a good move to setting up foundries for manufacturing spare parts for industrial machinery and equipment. The results of the mechanical properties of the investigated Ushafa sand with moisture and clay content values of 5.8 and 25 % respectively, and permeability of 72 m/sec. exhibited green and dry compressive strengths of 72 and 108 kN/m^2 while the Giri samples having moisture and clay content values of 4.2 and 14 % respectively and permeability values of 180 m/sec recorded green and dry compressive strengths of 76 and 78 kN/m^2. These results indicate that the Abuja sands are most suitable for casting heavy grey steel.

Keywords

Foundry; sand; casting; permeability; green compressive strength; dry compressive strength.

1.0 Introduction

The need for the growth of the foundry industry in Nigeria is crucial. It cannot be overemphasized considering the government's drive for the advancement of the agricultural sector to diversify its economy. Nigeria is still heavily dependent on the importation of wares, auto parts, machine parts, and agro machine implements, among other products to meet the demands of her local industries, agricultural sector, and other manufacturing sectors which has not helped in advancing the economic situation of the country [1], [2].

Strong economies of the World are driven by the foundry and steel industries which feed the manufacturing sectors for technological growth [3]. The prospects of the foundry industries in most of Africa are under-utilized unlike in the advanced countries. Most of the Nigerian foundries are operated as Small-Scale Industries thereby hindering their abilities to contribute much to the automotive industries in the country [3].

Foundry sand is a uniformly sized, high-quality silica sand to which a binder is added and used to form molds for ferrous and nonferrous castings [4]. It is obtained from a specific source used in direct production processes of foundry casting operations [5]. Atanda and Ibitoye (2004) observed that most Nigerian foundries use sand-casting techniques [6]. In the past, this technique was cost-effective only for small-volume production, presently it is also suitable for high-volume cast products as a result of the availability of automated equipment for producing molds [7]. This process is used for the manufacturing of medium to large parts such as valve bodies, crankshafts, and engine blocks. For molding sand to be suited to foundry applications, some basic requisites such as grain shape and grain size distribution (i.e sieve analysis), or grain fineness, green and dry strength, permeability, refractoriness, thermal stability, flowability, reusability, collapsibility, moisture content, and cohesiveness are required to ensure casts free of defects [6], [8], [9]. The main constituents of molding sands are the silica sand grains, binder (clay), moisture, and additives [9]. Using locally available sands for casting processes will help reduce the production cost and time for the production of castings as compared to imported sands [10].

Abuja is a promising industrial and innovation hub. With the Ajaokuta Steel Company close to Abuja, there are tendencies that related industries will be established in the Federal Capital. Therefore, the need for the establishment of foundries is crucial to driving Nigeria's economic growth. This is the motivation factor for the authors to embark on this research to determine the properties and suitability of some sands within the Federal Capital Territory (FCT) for foundry application. Though a significant number of works have been carried out to determine the properties of molding sand in various communities in Nigeria, no such works have been done on FCT sands to the best knowledge of the authors.

2.0 Materials and Methods

The materials and methods for determining the basic properties of the various sands from within the FCT are reported in sections 2.1 and 2.2 respectively.

2.1 Materials

The sand samples for the experiment were fetched from locations in Ushafa and Giri, and in Nigeria's capital Abuja. The equipment used includes an electric permeability meter, stopwatch, standard sand rammer, XRF spectrometer, specimen tube, pouring hope, specimen rammer, digital weighing balance, laboratory mixer, wash beakers, clay washer, electric permmeter, universal strength testing machine, oven.

2.2 Methods

2.2.1 Sample Preparation

To remove free water, sands from the various chosen sites were cleaned and dried in an oven at 110°C. To obtain the desired grain size, a portion of the sand was sieved through a 2 mm British Standard (BS) sieve. To ensure a homogenous sand-water mixture, the sand grains were thoroughly mixed with clean water in a laboratory sand mixer for around 10 minutes. Using a standard sand rammer that gave a compaction blow of 6.4 kg three times from a height of 5.0 cm, the samples were then molded to create standard test specimens measuring 5.0 cm by 5.0 cm. The samples were divided into groups for different foundry tests.

2.2.2 Chemical Composition

The chemical composition of the sand samples was determined with an X-ray fluorescence (XRF) spectrometer.

2.2.3 Refractoriness

This refers to the sand's resistance to melting and softening at high operating temperatures. It is the highest temperature that a substance can withstand before failing (break). The sands' refractoriness was assessed using a pyrometer and the results were reported in pyrometric cone equivalents (PCEs).

2.2.4 Permeability

The electric permmeter was used to determine the permeability of the specimen after ramming with the specimen rammer. The specimen tube containing a standard specimen was mounted on the electric permmeter and switch-on and the test lever was adjusted to "test.'' Standard molded green sand specimens were inserted in the permmeter, and a standard air pressure of 9.8×10^2 N/m^2 was conducted through the cylindrical specimen tube. 2000 cm^3 of air is passed through the specimens during each measurement time. The permeability of each sand sample was determined using Equation 1 below [9]:.

$$Permeability = \frac{Vxh}{PxAxt} \quad (1)$$

Where:

V is the volume of air passing through the specimen in cm^3, h is the height of the specimen in (5.0cm), p is the pressure of air (9.8×10^2 N/m^2), A is the cross-sectional area of the specimen (20.26 cm^2 adopted standard volume), and t is the time for air to pass in minutes.

2.2.5 Grain Size and Particle Distribution

Each sieve's residual sand is weighed before being utilized to create the American Foundry Society (AFS) grain fineness index (GFI). From each chosen sand sample, 5.0 kg of a naturally dried sample was obtained and placed in a set of electrical sieve shakers with sieves of various diameters. For fifteen minutes, the shaker was allowed to vibrate. Each sieve's leftovers were taken off and weighed. The mesh numbers were used to categorize the sieve sizes. The sample's American Foundry-Society Men's Grain Fineness Number (AFS GFN) was used to determine using Equation 2 [11].

$$AFN\ Grain\ Fineness\ Number = \frac{Total\ Product}{Total\ \%\ retained\ by\ different\ sieves} \qquad 2$$

2.2.6 Clay Content

Whether they are clay particles, silt, or organic debris, all particles less than 20 microns are considered as the AFS clay content [12]. Washing a 50g sample of molding sand in a jar with 475 cm^3 of water and 25 cm^3 of standard sodium hydroxide (NaOH) revealed the entire content of clay in the sand. Several agitations and washings were carried out to remove the clay. The remaining sand was dried and weighed to establish the quantity of clay removed from the initial sample.

2.2.7 Compactability

The molding mixture was prepared, then poured into a plastic bucket, covered with a lid, and sealed. The precise amount needed to prepare the standard specimen was determined using a computerized weighing balance and the specimen rammer. The quantity was then weighed using the pouring hopper into the specimen tube. The compaction/ramming test is then started after moving the specimen tube to the specimen rammer. The range of rams produced by the specimen rammer is from 1 to 6. The specimen will be examined for bulk density, green permeability, and green and dry compression strength in each case.

2.2.8 Green and Dry Compressive Strength

For green and dry compression strength tests, a Standard Universal Sand Strength Test Machine with a specimen grasping attachment and a meter to read strength (kN/m^2) instantly was employed. The samples were loaded on the testing machine. The machine's lever was turned counterclockwise until the specimen was crushed by an evenly increasing load. The specimen's green compression strength was determined by reading the scale point at which the sample was crushed and recording that value. To assess the dry compressive strength, the same process was utilized, the AFS sand sample was baked at 110°C to 120°C for 1-3 hours and chilled in desiccators before the test. For the additional sand samples, the same process was used, and the results were tabulated.

2.2.9 Shatter Index

The specimen's shatter index value was calculated by letting it fall freely to a steel anvil from a height of 1.83 meters. A 12.5 mm mesh sieve was used to gather the pieces. The proportion of the total weight maintained on the sieve, known as the shatter index, was calculated [13].

2.2.10 Moisture Content

The test was conducted using a speedy moisture tester. A weighing balance was used to weigh the sample of sand. The sample was put in a calibrated container with a small amount of calcium carbide and agitated for about three minutes. A quantifiable amount of acetylene gas was created, proportionate to the moisture content of the sand. The moisture content was read from the instrument's calibrated scale.

2.2.11 Flowability

The tube used for this test measures 140 mm in height and 80 mm in diameter. Two sensors are housed in an insert that fits within the tube. The lower-level and the upper-level sensors are separated by 30 mm. The tube is filled with the sample and then put into a press. The sample is then crushed by the release of a plunger after scraping off any excess. A control program can change the values of time and pressure. By using pressure and direction measuring equipment, respectively, the drop in height is measured.

3.0 Results and Discussions

The results and discussions of the various tests carried out on both Ushafa and Giri sand samples are presented in this section.

3.1 Chemical Composition

The elemental chemical compositions of Ushafa and Giri sands are presented in **Table 1**. The fundamental constituents are silica and aluminium. The chemical compositions of silica in Ushafa and Giri samples are 95.60 and 79.10 % respectively, while those for aluminium are 4.30 and 16.85 % respectively. Brown (1994) reported that the minimum composition of silicon oxide should be between 95 and 96 %. Only the composition of silica sand from Ushafa falls within this range. Other constituents which include oxides of iron, magnesium, calcium, and sodium, are in insignificant proportions in all the sands from the two deposits.

Table 1: Chemical composition of sand samples

Location	Chemical compounds					
	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	CaO (%)	Na_2O (%)
Ushafa	95.6	4.30	0.065%			
Giri	79.5	15.21	0.67	1.35	2.4	1.00

3.2 Moisture Content

The suitability of any molding sand for casting purposes must consider its moisture content. It guarantees straightforward molding, high-quality molds, and casting. The moisture content of the samples is presented in **Table 2**. Ushafa and Giri sands have moisture contents of 5.8 and 4.2 % respectively. Considering only moisture content, the Ushafa sand falls within a permissible moisture range of 5 – 7.5 % which shows that it can be employed for various castings except for light steel and heavy grey steel, which require moisture contents of between 4 – 5 % and 6 – 8 % respectively. However, the measured moisture content of the Giri sand indicates that it can be used to cast heavy steel and light grey iron [11]. However, other properties are needed to ascertain the place of application of a foundry sand.

Table 2: Moisture content (%)

S/N	Samples	Values (%)
1	Ushafa	5.8
2	Giri	4.2

3.3 Refractoriness

The refractoriness of the samples is given in **Table 3**. Refractoriness refers to the ability of a material to withstand high firing temperatures without deterioration of its physical and mechanical properties. The refractoriness of Ushafa and Giri samples are 1550 °C and 1300 °C, respectively. Giri sand does not meet the AFS refractory standard, because it falls short of the ASF range of 1400 – 1800 °C.

Table 3: Refractoriness (°C)

S/N	Samples	Values (^{0}C)
1	Ushafa	1550
2	Giri	1300

Ushafa sand with a refractoriness value of 1550^{o}C correlates with the AFS refractory standard of 1400 – 1800 ^{o}C. The low refractoriness of the Giri sample is attributed to the low percentage composition of its SiO_2.

3.4 Permeability

According to Ademulegun (2008), the degree of fineness and moisture content of foundry sand affect its permeability number. Explosions and other damaging casting flaws are frequently the result of insufficient sand permeability. The permeability for the Ushafa and Giri samples are 72 and 180 m/sec, respectively, as indicated in **Table 4**. According to Shuaib-Babata and Olumodeji [11], these values are within the range of sand's permissible permeability for heavy grey steel, malleable iron, and medium grey iron.

Table 4: Permeability (m/sec)

S/N	Samples	Values (m/s)
1	Ushafa	72
2	Giri	180

3.5 Grain Size and Particle Distribution

Particle size, gradation, and shape are essential characteristics of sandy granular materials [14]. The examination of the grain size distribution and the calculation of the AFN grain fines number are presented in **Table 5**. The grain fineness number is a method of indicating the average grain sizes of a particular foundry sand. It helps to determine the quantity of the bonding material essential to produce the desirable properties in a foundry sand [11]. Ushafa and Giri samples have GFN of 76 and 69 respectively. The standard grain fineness number is 35 – 90 [11]. The investigated sands fall within these standards. The higher the fineness of a sand the greater its suitability for foundry use [11]. The sand from these locations may therefore be suitable for both medium and heavy steel casting and dry sand castings [11].

Table 5: Sieve analysis result and ASF GFN

S/N	Sieve size (mm)	Sieve Nos (BS)	Weight retained (g)		% weight retained		Cumulative % weight retained		Product (%weight retained x multiplier)		AFS (Grain Finness No)	
			Ushafa	Giri	Ushafa	Giri	Ushafa	Giri	Ushafa	Giri	Ushafa	Giri
1	1.400	-	6.09	6.01	6.09	6.01	6.09	6.01	-	-	76	69
2	1.000	16	7.41	6.14	7.41	6.14	13.5	12.15	118.56	98.24		
3	0.710	22	8.32	7.52	8.32	7.52	21.82	19.67	183.04	165.44		
4	0.500	30	9.19	10.75	9.19	10.75	31.01	30.42	275.7	322.5		
5	0.355	44	11.01	7.50	11.01	7.50	42.02	37.92	484.44	330		
6	0.250	60	5.67	30.82	5.67	30.82	47.69	68.74	340.2	1849.2		
7	0.180	72	28.71	10.74	28.71	10.74	76.4	79.48	2047.12	773.28		
8	0.125	100	7.63	6.87	7.63	6.87	84.03	86.35	763	687		
9	0.090	150	5.03	5.08	5.03	5.08	89.06	91.43	754.5	762		
10	0.063	200	6.21	4.72	6.21	4.72	95.27	96.15	1242	944		
11	0.00063 Pan	300	4.56	3.20	4.56	3.20	99.83	99.35	1368	960		
	Total		99.83	99.35					7,576.56	6,891.66		

3.6 Clay Content

The clay content values of the Ushafa and Giri samples are 25 and 14 %, respectively (**Table 6**). The clay content of the Giri sample falls within the acceptable range of 10 – 19 and it is suitable for use as a molding sand for the casting of Brass and Bronze, Light grey iron, malleable iron, Medium grey iron, and heavy grey steel [11].

Table 6: Clay Content

S/N	Samples	Clay content (%)
1	Ushafa	25
2	Giri	14

3.7 Bulk Density

The bulk densities of Ushafa and Giri, sands are 2.46 and 2.98 kg/m^3 respectively (**Table 7**). They all are within the suggested AFS criterion of 2.65 kg/m^3. According to Ihom et al. [15], green molding sand should have a bulk density of 1.49 g/cm^3 or higher.

Table 7: Bulk Density

S/N	Samples	Values
1	Ushafa	P_b = 2.46kg/m³; Particle density = 0.6 g/cm³; Total density = 0.45 g/cm³
2	Giri	P_b = 2.98 kg/m³; Particle density = 1.17 g/cm³; Total density = 0.9 g/cm³

3.8 Shatter Index

The shatter index results for Ushafa and Giri, sands are 0.55 to 0.69 and 0.66 to 0.79 respectively (**Table 8**). The high shatter index values of the Ushafa and Giri samples show that they are strong enough to support adequate lift during pattern withdrawal. The high values are attributable to the clay content and associated moisture content [13].

Table 8: Shatter Index

S/N	Samples	Values
1	Ushafa	0.55 - 0.69
2	Giri	0.66 - 0.79

3.9 Green and Dry Compressive Strength

The Ushafa and Giri sand samples have green compressive strengths of 61.88 and 78.0 kN/m^2 and dry compression strengths of 108.18 and 76.40 kN/m^2 respectively (**Table 9**). This is consistent with the idea that the samples' dry compression strength rises proportionally to moisture content. These results are comparable to the AFS standard of 45 – 105 kN/m^2 [16]. This suggests the sand samples have sufficient green strength to maintain their shape without collapsing [15].

Table 9: Green and dry compressive strength

S/N	Samples	Compressive Strength (kN/m^2)		Sand grains based on green strength
		Green	Dry	
1	Ushafa	61.88	108	Clay fine-grained sand
2	Giri	76.4	78	Coarse sand

3.10 Compactability

The compactability values of 58 and 49 % for the Ushafa and Giri samples respectively are presented in **Table 10**. The standard compactability values are 38 – 52 % [16]. This suggests that the 49 % value for Giri sand is optimal.

Table 10: Compactability

S/N	Samples	Compactability (%)
1	Ushafa	58%
2	Giri	49%

3.11 Flowability

This test assessed the sand's ability to flow and properly fill a mold cavity. The results of the flowability test (**Table 11**) indicate that these Abuja sands exhibit t*he ability of foundry sands to act like a fluid when it is rammed.* Judging from the work of Rana et al., [17], there seem to be no optimal standard values for the flowability of green sands. However, according to Shuaib-Babata et al., [16] the AFS standard value for casting aluminium is 65 %. Though the flowability index values of 65 and 67 % suggest good flowability characteristics of both sand samples, additional comprehensive testing and evaluation would be needed to make definitive conclusions about their suitability for foundry use.

Table 11: Flowability

S/N	Samples	Flowability, %
1	Ushafa	65
2	Giri	67

3.12 Results of the foundry properties of Ushafa and Giri sands

The results of the foundry properties of Ushafa and Giri sands are presented in **Table 12**.

Table 12: Flowability

Properties	**Ushafa Sand**	**Giri Sand**
Moisture content (%)	5.8	4.2
Clay content (%)	25	14
Permeability (m/sec)	72	180
Green compression strength (kN/m^2)	72	76
Dry compression strength (kN/m^2)	108	78
Shatter index	0.55 – 0.69	0.66 – 0.79

4.0 Conclusion

The investigative work on the mold properties of the two sand samples from the FCT's Ushafa and Giri, areas has provided valuable insights into their properties and suitability for foundry applications. Judging from the various test results these sands possess several desirable characteristics, such as high silica content, optimum clay and silt content, and good thermal stability. These properties make them suitable for application in foundry processes, particularly in the production of molds and cores. The particle size distribution analysis revealed that Abuja sand has a relatively uniform grain size distribution, which is crucial for ensuring proper compaction and permeability in foundry molds. The chemical composition analysis confirmed their high silica content, indicating their potential for efficient binding with other materials and good refractoriness.

Furthermore, the moisture content and permeability tests demonstrated that Abuja sand has favorable moisture retention and permeability characteristics, which are important for achieving proper molding and casting processes. These properties contribute to the ability of the sand to withstand the high temperatures and pressures involved in metal casting.

Taking into consideration the following properties: moisture content, clay content, permeability, and green and dry compression strength (Table 3.12), both the Ushafa and Giri sands are most suitable for the casting of heavy grey steel [8].

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