CHARACTERIZATION OF GBARA SAND FOR FOUNDRY APPLICATION

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Abstract

Assessment of moulding properties of Gbara sand deposit for casting purposes was carried out. Sand sample was collected along the river Gbara bank and characterized to ascertain its suitability for use for casting purposes. Standard foundry testing equipment were used to carry out the tests and the results obtained were compared with American Foundry Men Society (AFS) Standard. The samples were tested for the physical properties and chemical analysis of the sand. Casting was carried out using Gbara sand and Zungeru sand used in SEDI Minna foundry. The properties of the castings such as Tensile, Hardness, Impact and Microstructure were tested. The results of the tests were compared to American Foundry Men Society (AFS) Standard and it was found to be suitable for casting of non-ferrous alloy metals. The results of chemical and mechanical properties showed that Gbara river bank sand is alumina silicate with 93.2% of silicate and 1.3% of alumina which has physio-chemical properties that are suitable for non-ferrous alloy casting.

Keywords: Gbara sand, Refractoriness, Clay content, Green strength, Dry strength, chemical analysis, Foundry.

1.0 Introduction

Sand is a product of the disintegration of rocks over long periods of time. Sand is a major raw material used in construction and foundry industries. Sand casting operations are classified into green sand and dry sand. Sand moulds are designed to have good collapsibility and accommodate shrinkage of cast metal during solidification to avoid defects in the cast metal. Silica Sand is found in many natural deposits, and is suited for moulding purpose because of its ability to withstand high temperature without decomposition. Sand is resistant to high temperature, almost ancient, cheapest and most important especially in developing countries like Nigeria (Asuquo and Jama, 1991).

There have been various researches by Nigerian researchers (Ndaliman, 2002) in the area of developing local alternatives to foundry material to determine their suitability for the production of sound castings. But most of these works have been mostly on determining the refractory properties of various deposits of clays which are abundant in the country, and are used as binder in moulding sand. Akinbode (1996) carried out an investigation on the properties of termite hills as refractory material for furnace lining. In his report, he observed that the refractory properties of termite hill material which include porosity, density, dimensional change and permeability are very similar to known refractory materials for furnace lining. Abolarin, *et al* (2004) studied the characteristics of Nigerian clays and discovered that the Barkin Ladi and Alkaleri clay sample were suitable for construction of furnaces and furnace lining. Most of the sand used in foundry for moulds production or for casting must possess properties such as permeability to gases, cohesiveness or strength, and refractoriness or ability to withstand high temperature (Udeh, 2017).

Casting involves the pouring of molten metal into a mould and allowed to solidify in the mould. The items produced in this foundries are household and machine parts (cooking pots, dishes, spoons, aluminum gates decoration, machine belt pulleys, fans etc) in production capacity of 200 tons of nonferrous metal per month (Umar and Samaila, 2014).

This study therefore assesses the mechanical and thermal properties of the locally available moulding sand deposits in Gbara, Niger State, Nigeria to ascertain its suitability for use in sand casting operations.

2.0 Materials and Method

2.1 Materials Used

Natural foundry sand was collected from deposits site in river Gbara, Gbara ward in Mokwa, Niger State, Nigeria and dried to room temperature. Other materials used include ant-hill binder collected within Bida, water, aluminium scrap. The equipment used include weighing Balance, EDXRF machine, Tensometer, Computer controlled hardness testing machine, Metallurgical microscope, Sieve shaker hand rammer, small hand foundry shovel, sand rammer, flowability meter, speedy moisture tester, Carbolite machine, anvil, strength testing machine and heat treatment furnace.

The tests were carried out at Federal university of technology Minna, Ahmadu Bello University, Zaria, National geoscience survey laboratories Kaduna, and the National Metallurgical Development Centre (NMDC), Jos, Plateau State of Nigeria. The test sample were prepared in accordance with the standard specification for the preparation of moulding sand test samples using Ridsolate standard sand rammer conforming to imperial 2” diameter x 2” Height or (51mm diameter x 51mm Height).

2.2 Methods

The samples of sand for mould preparation for determination of green compression strength, permeability, moisture content, shatter index, green, dry and hot strength test, refractoriness and thermal linear expansion tests were prepared. Experimental trials of the following sand mixture ratio are as shown in table 2.1.

Table 2.1 Percentage and Weight Composition of Moulding Mixture

Sample	Water (%)	(g)	Additive (%)	(g)	Sand (%)	(g)
A	1	6	12	72	87	522
B	2	12	12	72	86	516
C	4	24	12	72	84	504
D	6	36	12	72	82	492
E	8	48	12	72	80	480
F	10	60	12	72	78	468

Source: (Abolarin *et al.*, 2010).

The sand additive and water mixture for each of these experiments A to F were thoroughly mixed using mixer. This was hand squeezed and the mixture oured into a tube and rammed by impact with three blows of a 6.35 kg weight to fall a distance of 5 cm one after another in accordance with the method of (Tokan *et al.,* 2004).

Sand additive and water mixture for each of the experiments 1 to 5 were thoroughly mixed using mixer. It was hand squeezed and the mixture was poured into a specimen tube and rammed by impact with three blows of a 6.35kg weight to fall a distance of 5 cm one after another to produce test pieces (Tokan *et al.,* 2004).

The following tests were conducted to determine the chemical composition, clay content, sieve analysis, green compression strength, shatter index, green shear strength, dry shear strength, permeability, moisture content, and refractoriness. The tests include foundry properties test, mechanical properties tests, chemical analysis and microstructural analysis.

2.2.1 Foundry properties test

Chemical Composition

The chemical composition of the sand sample was determined using the X-Ray Fluorescence (XRF) spectroscopy technique at the National Geoscience Research Laboratories Centre, Kaduna, Nigeria. This is a non-destructive analytical method in which X-ray tube is used to irradiate the sample with a primary beam of X-rays. Some of the impinging primary X-rays are absorbed by the sample elements in a process known as the photoelectric effect (Bala and Khan, 2013).

Clay Content

One kilogram (1kg) of the control sand was first washed with raw water, in a 53 microns sieve to remove the clay content using AFS clay content determination. Particles which fail to settle were referred to as clay content and other additives. This process was repeated twenty times until the 1kg of the control sand was fully separated from clay and 0ther undesirable impurities as described in (Ayoola *et al,* 2010).

Sieve Analysis

100g of dried specimen was sieved using 150, 300, 600, 833 and 11167 μm. Equal amount of sands was placed on top of the sieves on a mechanical vibrator and then shaken for 30 minutes after which the content of each sieve was weighed. The mass of the specimen left at each compartment of the sieve, the percentage retained and the percentage passed was calculated.

GFN = Product/% weight retained (1)

$$R = \left(\frac{M1}{Mo}\right) \times 100\% \quad (2)$$

And,

$$P = 100 - R \quad (3)$$

Where,

GFN = Grain finess number

M_o = Mass of each sample of sand (g)

M_1 = Mass of sand sample retained on the sieve (g)

R = % of sand sample retained

P = % of sand sample passing through the sieve (Ayuba *et al,* 2012).

Green Compression Strength Test

The green standard mould specimen of 50mm diameter by 50mm height was fixed on a strength testing machine using compression-holding device. A uniformly increasing load was applied on the specimen until the specimen crushed or squeezed. The point on the scale at which the specimen crushed or squeezed was recorded as the green compression strength (Tokan *et al,* 2004).

The Shatter Test

The specimen of 50mm height by 50mm diameter size was from its tabular mould by means a tripping post and allowed to fall through a height of 1800mm to a steel anvil. The fragments were collected in a 12.5 mm mesh sieve. The shatter index being that percentage of the total weight retain on the sieve was determined (Tokan *et al,* 2004).

Determination of Green Shear Strength

The Green Shear Strength (GSS) which is the measure of the shear strength of the prepared sample, when shear load is applied in its green state. The machine used for the GCS was also used for the determination of green shear strength (GSS), except that the compression head was replaced with shear head in the machine. The shear strength was recorded at the point of failures of the sample loaded.

Determination of Dry Compression Strength

Standard sample of 50mm diameter x 50mm height was prepared and dried in an oven at a temperature of 1100 ºC for a period of 30 minutes and then removed and allowed to cool in the air to ambient temperature. After cooling, the sample was fixed into the universal sand-testing machine with the compression head in place. The compressive load was applied and the samples failed at the ultimate compressive strength of the sample. The point at which the failure occurs was recorded at DCS (Abolarin *et al,* 2010).

Determination of Dry Shear Strength

The prepared standard sample of 50mm diameter x 50mm height was dried in an oven at a temperature of 1100 ºC for 30 minutes and then removed from the oven to cool in an air to ambient temperature. The same universal testing machine was used for dry compression strength. In this case, the shear head was replaced for the compression head. The shear strength was recorded at the point of failures of the standard test sample.

Determination of Permeability

The permeability test was carried out on the standard sample specimen of 50mm diameter x 50mm height. The specimen, while still in the tube, was mounted on permeability meter. The permeability meter is an electrical perimeter and it employed the orifice method for rapid determination of sand permeability. Air at a constant pressure was applied to the standard sample specimen, immediately after producing the sample and the drop in pressure was measured on the pressure gauge, which is calibrated directly in permeability numbers (Tokan *et al.,* 2004).

Moisture Content

The speedy moisture tester was used for the test. Sand sample was weighed on a speedy moisture testers weighing balance. The sample and a small quantity of calcium carbide will be placed in a calibrated container and shaken for 2 minutes, and later for 1 minute. A measurable amount of acetylene gas proportional to the amount of sand moisture was produced. The moisture content was read directly from the calibrated scale on the instrument.

Refractoriness

The dried sand sample was fired to a temperature of 900 ºC in a Muffler furnace. Pyrometric cones design to deform at 1300 ºC, 1400 ºC, 1500 ºC, 1700 ºC was placed round the samples and the temperature was rise to above 1000 ºC at 10 ºC/min. The heating was then discontinued when the test cone bend over and level with the base of the disc. The pyrometric cone equivalent (P.C.E) of the samples were recorded as the number of standard pyrometric cone corresponding in terms of softening to the test cone (Ayuba *et al.*, 2012).

Experimental Comparison of Gbara Sand and Zungeru Sand

To be able to compare the properties of Gbara sand and existing standard properties of Zungeru sand, two moulds with bentonite and ant-hill as binder were prepared for the casting. The first mould was prepared using 80% Zungeru sand (25kg), 13% bentonite (4.06kg) and 7% moisture (2.19kg) while the second mould was prepared using 50 % Gbara sand (15.63kg), 43% ant-hill (13.44kg) and 7% moisture (2.19kg).

2.2.2 Mechanical properties test

To carry out the mechanical properties test, specimens were cast.

The casting was carried out using the prepared sand samples and mechanical properties tests were carried out on the cast. Aluminium scrap was charge into a red-hot crucible pot on a charcoal-fired crucible furnace and allowed to melt at 660 ºC. The molten metal was then poured into a prepared cylindrical mould and allowed to cool. The cast samples were removed from the mould and machine to sample sizes for mechanical tests produced. The mechanical properties tests include hardness, tensile and impact tests.

Hardness Test

Hardness test was carried out on the samples according to ASTM E384-11 using standard computerized Vickers Hardness Testing Machine, Model MV1-PC serial No: 07/2012-1329, with a load of 0.3 kgf, max/min limit of 150/050 HV.

Tensile Test

The ultimate tensile strength test was conducted in accordance with ASTM E 8M using the Monsanto Tensometer, type W Serial No. 9875. The samples were gripped in the chucks of the Tensometer and load was applied by with the aid of load handle until the samples fracture.

Impact Test

The impact test was conducted in accordance with ASTM E 602-91 Standard Method and Definitions for Mechanical Testing of Steel Products. A V-notches of 0.5mm depth were made on the samples each and the impact strength was carried out using Honsfield Balance Impact Machine, serial No: 3203.

2.2.3. Microstructural analysis

Prior to the metallography and surface morphology examination, the surface of the samples was ground successively using grit papers of different grades of 120C, 180C, 320C, 400C, 600C, 800C and 1200C, with the application of lubricant intermittently to prevent overheating and provides a rinsing action that flushed away the particles been removed from the surface. They were subsequently polished with the aid of a polishing machine using Alumina to remove the scratches left during grinding. Etching was then carried out on the polished surface using “Keller’s reagent (solution of 1ml distilled water, 5ml nitric acid and 2 ml hydrofluoric acid).

A computer control photographic visual metallurgical microscope MODEL NJF-120A, Rating- 230V-5V/60Hz was then used to view the microstructures of the polished samples

2.2.4 Chemical analysis

The chemical composition of the sand sample was determined using the X-Ray Fluorescence (XRF) spectroscopy technique at the National Geoscience Research Laboratories Centre, Kaduna, Nigeria. This is a non-destructive analytical method in which x-ray tube is used to irradiate the sample with a primary beam of x-rays. Some of the impinging primary x-rays are absorbed by the sample elements in a process known as the photoelectric effect (Bala and Khan, 2013).

3.0 RESULTS AND DISCUSSION

3.1 Results

3.1.1 Chemical Composition

The result of the chemical composition of the sand sample is presented in Table 3.1. The Table shows the results of the chemical composition analysis of Gbara sand. The major constituents of the sample are silica (93.2%) and alumina (1.3%) with other substances such as oxides of iron, sodium, titanium, and calcium among others which are in small proportions. The values of the specimens' chemical constituents are in line with the recommended mould sand chemical compositions in literature (Bala and Khan, 2013).

Table 3.1: Chemical Composition Analysis of Gbara sand

Elements	Si_2O	Al_2O_3	K_2O	CaO	TiO_2	V_2O_5	MnO	Fe_2O_3	CuO	AS_2O_3	SrO	CeO_2	PbO
Composition (%)	93.2	1.3	1.02	1.08	0.74	0.012	0.03	1.66	0.017	0.011	0.06	0.05	0.01

Table 3.2: Mechanical Sieve Analysis of Gbara sand

S/N	**Sieve Aperture (mm)**	**BSS NO**	**Weight Retained (g)**	**Weight Retained (%)**	**Cumulative Weight Retained (%)**	**Multiplier**	**Product**
1	1.18	10.00	0.30	0.35	0.30	6.00	2.10
2	0.83	22.00	1.03	1.03	1.33	9.00	9.27
3	0.60	2.00	6.95	6.95	8.28	15.00	104.25
4	0.30	30.00	12.10	12.13	20.38	25.00	303.25
5	0.15	44.00	24.90	24.90	45.28	35.00	871.50

The AFS fineness number which is the standard for reporting the grain size and distribution of sand was used to assess the particles. This was applied to the sieve result as in Table 3.2 to obtain the AFS number. From the table:

$$Grain\ fineness = Total\ product \div \%\ weight\ retained$$

$$= 4491.51 \div 99.99 = 44.92$$

The sieve analysis of the samples gave AFS numbers 44.9. This value is in accordance with the grain fineness number used by most foundries, which is expected to be between 40 and 220 (Oke and Omidiji, 2016; Udeh *et al*., 2017).

Table 3.3: Composition and Results of the various Properties of Gbara sand Test sample

Sample	Water (g)	Additive (g)	Sand (g)	GC (kN/m^2)	GS (kN/m^2)	DC (kN/m^2)	DS (kN/m^2)	P (No)	MC (%)	SI (No)
A	6.00	72.00	522.00	N.S	N.S	N.S	N.S	N.R	3.20	59.00
B	12.00	72.00	516.00	26.20	31.03	172.37	51.71	3.80	4.00	66.00
C	24.00	72.00	504.00	17.24	24.13	258.55	137.89	3.50	5.30	75.00
D	36.00	72.00	492.00	31.72	31.03	116.52	72.50	3.20	5.50	84.00
E	48.00	72.00	480.00	28.96	22.41	189.61	103.42	2.90	5.80	85.00
F	60.00	72.00	468.00	29.37	27.56	143.82	100.36	2.70	6.40	88.00

Where, GC: Green Compression, GS: Green Strength, DC: Dry Compression, DS: Dry Strength, P: Permeability, MC: Moisture Content, SI: Shatter Index.

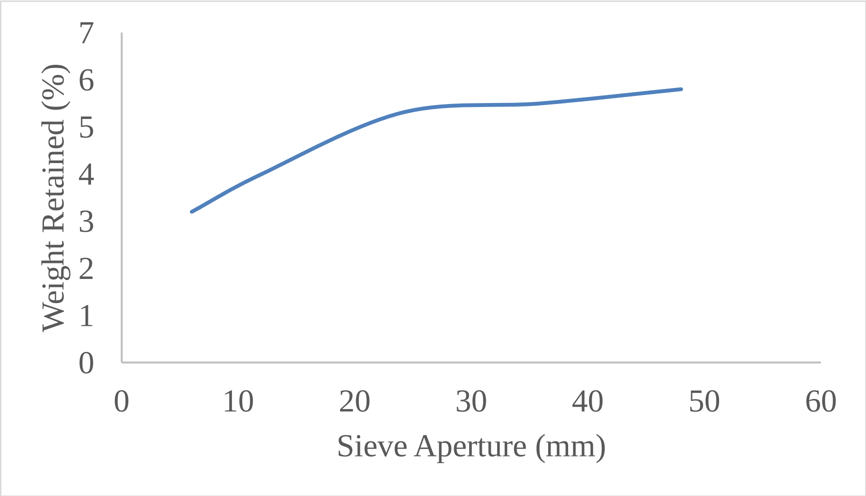


Figure 3.1: Grain size distribution

Figure 3.1 shows grain distribution curve of the various sample mixture. It can be seen from the figure that increase in sieve aperture increases the weight retained of the samples. Figure 3.2 shows variation of some physico-mechanical properties with addition of water for various prepared samples. It can be seen from the figure that increase in water addition increases the physico-mechanical properties of all the prepared sand samples, with the dry compression (DC) reaching the highest (258.55 KN/m^2). As the water addition increases at a point, the physico-mechanical properties of the samples decreases. Permeability and moisture content samples exhibited lowest values of 2.7No and 6.4% respectively. This result agrees with the results put forward by several authors (Ayoola *et al.*, 2013; Abolarin *et al.*, 2010; Aweda and Jimoh, 2009).

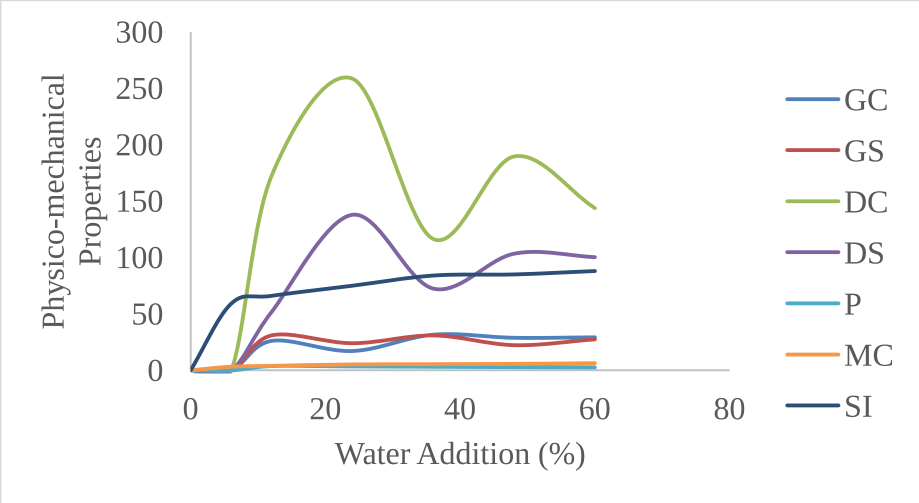
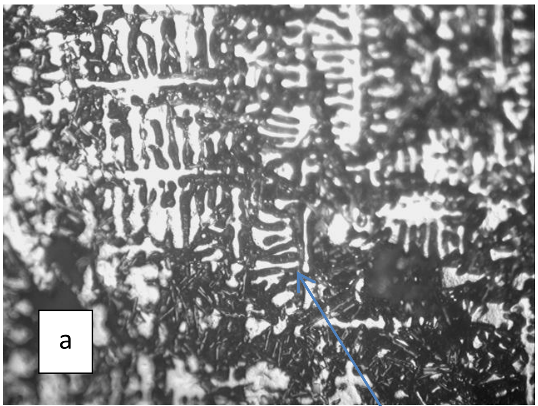


Figure 3.2: Variation of Water Addition on Physico-mechanical Properties

3.2 Cast Samples

The cast samples cylindrical shaped (20mm diameter by 350mm length) were machine into standard test specimen for Tensile, Hardness and Impact tests. The microstructure of the samples cast using Gbara sand and Zungeru sand viewed under metallurgical microscope are presented in Plate 3.1



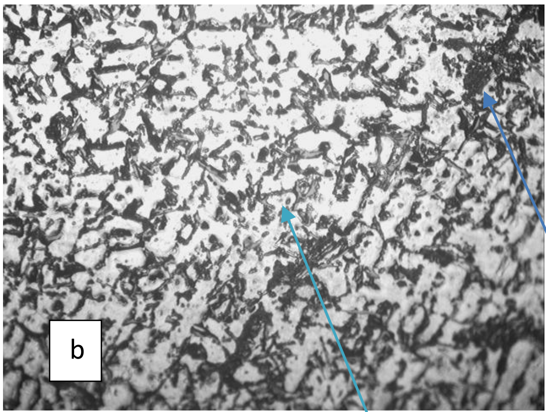


Plate 3.1: Microstructural view of the cast samples using (a) Gbara sand and (b) Zungeru sand (x100).

Plate 3.1 shows optical micrograph of the cast samples using Gbara and Zungeru sand. Zungeru sand casting show refined microstructures than Gbara sand castings; this might be due to the presence of faster solidification rates in the moulds (Murthy *et al.*, 2018). Zungeru sand products cools more quickly, resulting in microstructure with small size grains. The microstructure mainly consists of soft and ductile α - aluminum dendrite phase containing hard and brittle eutectic phase (α-Al+Si) in the inter-dendrite region, as shown in plate 3.1 (a and b)

Sieve analysis

The AFS fineness number which is the standard for reporting the grain size and distribution of sand was used to assess the particles. This was applied to the sieve result as in Table 3.2 to obtain the AFS number. From the table:

$$Grain\ fineness\ = Total\ product\ \div \%\ weight\ retained$$

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The sieve analysis of the samples gave AFS numbers 44.9. This value is in accordance with the grain fineness number used by most foundries, which is expected to be between 40 and 220 (Oke and Omidiji, 2016; Udeh *et al*., 2017).

4.0 CONCLUSION

An investigation of the chemical and mechanical properties of Gbara sand were determined for foundry application and the results of the study showed that the Gbara sand exhibit good properties for casting of non-ferrous metals such as aluminum. The chemical and physical analysis showed presence of elements such as Si, Al. XRF analysis confirmed that SiO_2 (93.2%), Al_2O_3 (1.3%) were found to be major constituents of the sand. Fe_2O_3 (1.66%), TiO_2 (0.743%) were also found to be present in traces. The sand good green shear strength, green and dry compression strength, adequate permeability, and shatter index. The mechanical properties of the cast samples produced showed high tensile strength of 110.61N/m^2 in the sample cast using Gbara sand compared to 101.28N/m^2 obtained for sample cast using Zungeru sand. Low hardness value of 85.93HRB was obtained from sample cast using Gbara sand compared to 111.33HRB obtained from sample cast using Zungeru sand. Equal value of impact energy (2.38J) was recorded for the both samples.

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