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Investigation of Fori natural sand as foundry moulding material

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Abstract

An investigation into the application of Fori natural sand as foundry moulding material was conducted. Chemical analysis, sieve analysis, refractoriness and clay content test of the sand was conducted. The samples were tested for mouldability, shatter index, dry and green compressive strength and permeability with different moisture content of 4.7%, 3.6%, 2.8%, 2.2% and 1.9%. The research indicated that the moulding sand have 68.98% silica contain, sub-angular grain shape, a refractoriness value of 1370^{0}C, a clay content of 19.2% and a satisfactory green compressive strength of 57.26KN/m^2 at moisture content less than 3%. This makes it suitable for a wide range of casting of some metals and its alloys such as light steel, bronze, brass and aluminium in accordance to AFS standard.

Keywords

Foundry; Moulding; Permeability; Refractoriness; Clay Content; Moisture; Green Compressive Strength

Introduction

Sand moulding (casting) is one of the most versatile of metal-forming processes, providing tremendous freedom of design in terms of size, shape, and product quality. The use of sand in foundry industry is indispensable as it applicability to all type of castings with exception of few types. Sand moulding processes are classified according to the way in which the sand is held (bonded). These include resin binder processes, bonded sand moulds and unbounded sand moulds [1].

Basically there are two types of sands the natural sand and the synthetic sands. Natural sand has enough clay content for moulding. During mulling of natural sands they only need moisture and other additives to improve the quality of the casting [2, 4]. Synthetic sands require clay binders, moisture and other additives before they can be moulded. Natural sands are more economical and easy to use. They however, in most cases lack the high refractoriness that is commonly associated with synthetic sands. The properties of synthetic sands can also be adjusted with ease [3, 4].

Shuaib and Yusuf [4] carried out an analysis of Ilorin sand moulding properties for foundry application. The results indicated that the natural sands within Ilorin metropolis exhibit appropriate casting properties for non-ferrous and ferrous metals, which can facilitate the establishment of small and medium castings industries within the locality in accordance with American-men’s Foundry Society (AFN) standards and specifications.

Paul *et al* [5] investigated the effects of moisture content on the foundry properties of Yola natural sand. They found out that for optimum green compression strength, the moisture content should be 5% while for high dry compression strength, moisture contents between 5-9% should be used. The authors concluded that the moisture content of 5% produce a quality casting of aluminium using aluminium alloy scraps.

Katsina and Reyazul [6] determined the characterization of Beach/River sand for foundry application. The analyses showed that samples from Ughelli River, Warri River and Ethiope River could be used effectively in the foundry while Lagos bar beach requires to be sieved properly to remove the coarse fractions in order to make it suitable for foundry use.

Guma [7] carried out the characteristic foundry properties of Kaduna River sand. He found out that the sand is weak in strength and does not meet the practical value for casting heavy metals.

Mbishida and Audu [12] investigated the suitability of Lere river bank sand for green sand casting. Their investigation revealed that the river bank sand is alumino-silicate with physico-chemical properties that are suitable for non-ferrous alloy casting. It responded well to bentonite clay binder that gave good mechanical properties to sand mould specimens. The result of the mechanical properties analysis of the sand was compared to existing foundry standard and it was discovered to be very suitable to all types of nonferrous alloy castings.

The Fori natural moulding sand is located at the Fori community of Borno State, Nigeria on latitude 11°49'33.81" N and longitude13°10'14.99" E. The local foundries within and around the Fori community are already using this natural foundry sand for aluminium casting, though nothing or less is known about the characterization of this sand. As such, this paper is centred on the investigating the Fori natural sand as foundry moulding material. It is limited to characterization of the sand with its chemical composition and investigation of its effect of moisture content with a view of determining the grain shape, AFS grain fineness number, clay content as well as the refractoriness, permeability, green and dry compression strength at a varying percentage of moisture content. This research is to provide the foundries with relevant information on the chemical composition of the sand and the appropriate amount of moisture to be used while moulding so as to enhance their production quality.

Material and method

The foundry sand (Fori natural sand) required for the work was sourced from the Fori community of the present Borno State of Nigeria at a depth of 2, 4, 5 and 6 meters. The apparatus used in the entire research include: laboratory sand mixer, sand rammer, quick moisture teller, dry oven, universal strength test machine, permeability-meter, shatter index machine and mouldability machine.

In this research, the chemical analysis, sieve analysis and physical observation of the grain shape of the sand were first conducted, followed by the clay content test and refractoriness value test of the foundry sand. Thereafter, the moulding properties of the sand namely green compressive strength, dry compressive strength, permeability and shatter index were determined at different moisture content of 1.9%, 2.2%, 2.8%, 3.6% and 4.7%. The entire tests conducted were in accordance with the American Foundry Men Society Standards [8].

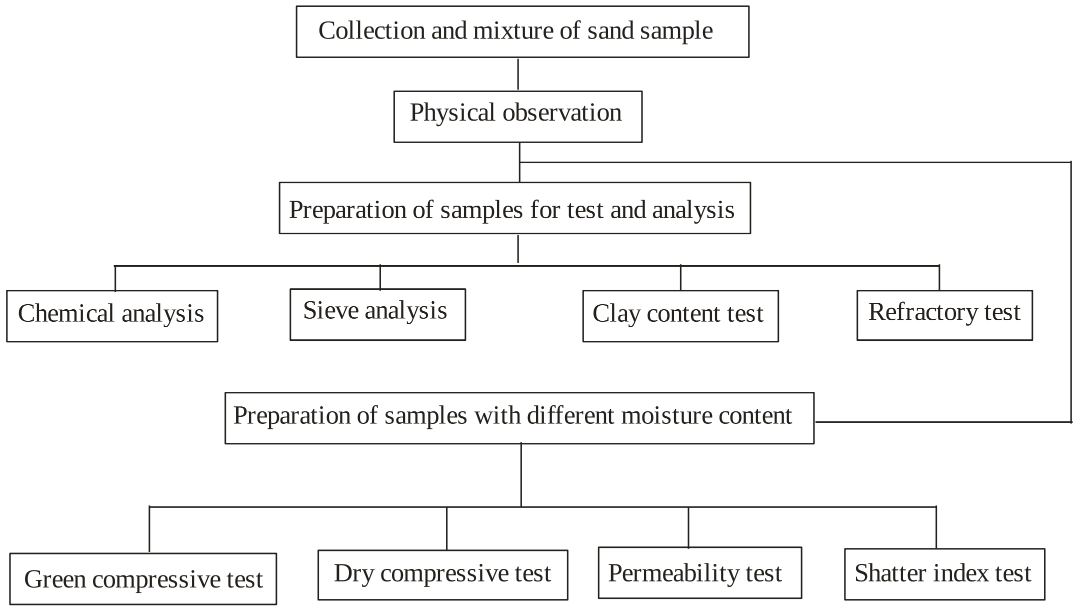

Figure 1. Flow chart for the determination of Fori natural sand properties

Preparation of moulding mixture and test specimen

In order to find the green compressive strength, dry compressive strength, permeability, mouldability and shatter index at different percentage of moisture content, the sand was moulded using laboratory size muller made by Ridsdale and Co. Ltd with serial No. 845. For each batch, 1 kg of the foundry sand and water was used to prepared a standard test specimen of 50mmx50mm using a sand rammer and weighting balance.

Determination of Chemical Composition

The chemical composition of the sand sample was determined using the X-Ray Fluorescence (XRF) at the National Geoscience Research Laboratories Centre, Kaduna, Nigeria. The result is shown in Table 1.

Sieve Analysis

The particle size analysis was carried out to measure the grain fineness of the sand using American Foundry Men Society (AFS) Grain Fineness Number (GFN). 300g of the Fori natural sand was weighed and dried to a constant weight using an oven. Then 100g of the natural sand was weighed and introduced into the topmost sieve of the nest of sieves arranged from the largest aperture (1400 microns) to the smallest (63 microns). The nest of sieve was mounted on a sieve shaker and vibrated for 15 minutes. The result was tabulated and used in calculating the grain fineness number of the foundry sand as shown in Table 2 using Eq. (1) [4].

$$AFS\ Grain\ Fineness\ Number = \frac{Total\ Product}{Total\ Sum\ of\ \%\ Weight\ Retained} \quad (1)$$

Refractory property

Refractoriness is the ability to withstand high temperature i.e. the ability for the moulding sand to withstand high temperature fusing or breaking down. The refractoriness value of the moulding sand was determined using Pyrometric Cone Equivalents (PCE) in a Furnace (model: NETZSCH 428 PCE Furnace). This is the most widely used method of measuring the softening behaviour of moulding sand at high temperature. The test pieces mounted on a refractory plaque along with some standard cones whose melting point are slightly above or slightly below that expected of the test cones were placed in the furnace. The temperature of the furnace was raised at a rate of 100^0C per minute until the tip of the test cone (Fori Sand) bent over level with the base. At the end of the experiment, the final temperature was recorded [11].

Clay content

The total clay content in sand was determined by washing 50 g sample of moulding sand using 475cm^3 of water and 25cm^3 of standard sodium hydroxide (NaOH) in a jar. Several agitation and washing is required to fully remove the clay. Hence, the washing of the sand was continued with fresh water until the water was clear. The remaining sand was then dried in the oven after drained of water. It was weighed to determine the amount of clay removed from the original sample using the formula in the Eq. (2) [9].

$$Percentage\ of\ clay\ content = \frac{(W_1 - W_2)}{W_1}\ x\ 100 \quad (2)$$

Where: W_1 - weight of the sand before drying, W_2 - weight of the sand after drying.

Permeability

The permeability meter was used to carry out the permeability test measuring the rate of flow of air through the AFS standard rammed specimen of 5cm height and 5cm diameter under a standard pressure of $9.8x10^2$ N/m^2 with the descent of the air drum timed between the zero and the 2000 cm^2 marched with a stop watch. The pressure indicated on the manometer was then recorded [12]. The general formula for the calculation of permeability is expressed as Eq. (3):

$$P = \frac{v\,x\,h}{p\,x\,a\,x\,t} \tag{3}$$

Where: P - permeability number, v - volume of air in ml passing through the specimen, h - height of test specimen in cm, p - pressure of air in cm of water, a - area of cross-section of specimen in cm^2, t - time in seconds.

Dry and Green compressive strength

A universal strength testing machine (Ridsdale Dieter T & Co Ltd Middles Brough England, Serial number-M8415) was used for the dry and green compressive strength tests. For the green compressive strength, the prepared specimens were tested using the compression head accessory on the machine and the result registered on the green compression scale was recorded. While for the dry compressive strength, the specimens were first oven dried at 110^{o}C for one hour and allowed to cool with the oven before the test was conducted. Steady increase in compressive force was applied on test specimen until failure occurred and strength in KN/m^2 was recorded instantaneously [10]. Both the green and dry compressive strength are determined from the formula below.

$$Green\ or\ dry\ compressive\ strength = \frac{F}{A} \tag{4}$$

Where: F - load at rupture in KN, A - cross-sectional area of the test specimen in m^2.

Shatter index

A shatter test apparatus (Ridsdale Dieter T & Co Ltd Middles Brough England Serial No: 8451) was used to measure shatter index of the specimens [11]. The index value of the

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specimen was determined by allowing the specimen to fall freely from a height of 1.83 meters unto a steel anvil. The degree of disintegration of each specimen was measured [1].

$$Shatter\ index = \frac{W_1}{W} \tag{5}$$

Where: W_1 - weight of sand remaining on 12.5 mm mesh B.S. sieve, W - total weight of sand specimen.

Results and discussion

Table 1 shows the result of the chemical analysis conducted on the natural foundry sand.

Table 1. Chemical composition of Fori natural sand

Constituent	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**TiO_2**	**CaO**	**MgO**	**K_2O**	**NaO_2**
Weight (%)	68.98	19.52	0.76	1.21	2.78	2.02	2.17	2.15

Table 1 above shows silicon dioxide (SiO_2) as the major constituent of the Fori natural moulding sand with a value of 68.98 %. This is lower than the silica content of Lere river foundry sand (71.66%) as stated by Mbishida and Audu, but almost the same with that of Garagu Offa natural moulding sand (68.83%) as submitted by Shaib, *et al* [12], [5]. Silica grains are very important in moulding as they impact refractoriness, chemical resistivity and permeability to the sand. The higher the percentages of silica sand the better the refractoriness of the sand [3]. The chemical composition result of this natural sand point to the fact that it is quite suitable to cast low melting points metals like aluminium alloys, brasses and bronzes, but not suitable for casting of higher temperature melting metals like iron and steel [12], [8]. The sample contains other small amount constituents like iron oxide, alumina, lime, soda, magnesia, manganese oxide. These can be tag as impurities as the presence of excessive amounts of iron oxide, alkalis oxides and lime can lower the fusion point to a considerable extent which is not desired [3].

The sieve analysis of the Fori natural sand was conducted to determine the Grain Fineness Number (GFN) as shown in Table 2. Table 3 shows some of the properties of the sand that were determined. These include the grain shape, clay content and refractoriness of the foundry sand.

Table 2. Grain Fineness Number (GFN)

S/No	ISO/R.565 series Aperture (Microns)	AFS	Weight Retained (%)	Multiplier (Previous sieve no.)	Product (Weight x Multiplier)
1	1400	10	2.27	-	0
2	1000	16	2.75	10	27.5
3	710	22	3.40	16	54.4
4	500	30	2.88	22	63.36
5	355	44	3.17	30	95.1
6	250	60	4.97	44	218.68
7	180	100	6.67	60	400.2
8	125	150	22.5	100	2250
9	90	200	22.26	150	3339
10	63	300	18.93	200	3786
11	Pan	350	10.25	300	3075
Total			99.70		13309.24

From equation 2, AFS Grain Fineness Number = $\frac{\text{Total Product}}{\text{Total weight retained}}$

$$\text{AFS Grain Fineness Number} = \frac{13309.24}{99.70}$$

AFS Grain Fineness Number = 133.49

The sieve analysis carried out on the material as shown on Table 2 shows that the Fori natural moulding sand has the grain fineness number (GFN) of 133.49 AFS standard. The GFN (grain fineness number) which is the ratio of the product to the cumulative weight retained has a significant role in terms of the passage of gasses generated on introduction of the molten metal to the mould cavity [12]. Hence, the result obtained is within the recommended range of AFS Standard [8].

Table 3. Some properties of Fori natural sand

Sample Properties	GFN	Grain Shape	Clay Content	Refractorines s Value
Results	133.49AFS	sub-angular	19.2%	1370^0C

Fori natural moulding sand has sub-angular grain shape and 19.2% natural clay as can be seen from Table 3. The refractoriness value of moulding sand is 1370^0C. This implies that the material can be used for aluminium, brass, bronze, malleable cast iron and light grey cast iron products according to AFS standard [8].

Table 4. Effect of moisture content on some foundry properties

Properties	Samples				
	E	D	C	B	A
Moisture Content (%)	4.7	3.6	2.8	2.2	1.9
Green Compressive Strength (KN/m^2)	33.94	43.46	51.81	57.26	57.05
Dry Compressive Strength (KN/m^2)	94.5	95.5	105.5	136.5	146.5
Permeability (mmWs)	330	380	400	440	450
Mouldability (%)	93.00	95.40	97.40	99.80	99.70
Shatter Index	87.0	80.0	74.0	64.0	61.0

From Table 4, the effect of moisture content on Fori natural sand revealed that as the moisture content reduces the green and dry compressive strength of the material increases. The green compression strength of sand shows a high value of 57.26KN/m^2 at moisture content of 2.2% and a low value of 33.94KN/m^2 at the moisture content of 4.7% (see Table 4). The lower the moisture content, the higher the value of green and dry compressive strength. From the result obtained when compared with the recommended AFS standard, it indicates that metals, such as, aluminium, brass, bronze, malleable iron and light grey iron can be cast with Fori natural moulding sand, as the green compression strength at the maximum falls within the acceptable range [8, 7]. This is above Lere river sand (22 KN/m^2), but quite far below Yola natural foundry sand (118.6KN/m^2) at 5% moisture content, Asa Dam foundry sand (290 KN/m^2), Ita-Amo moulding sand (350KN/m^2) and Okelele foundry sand (298 KN/m^2) [4, 5, 8, 12].

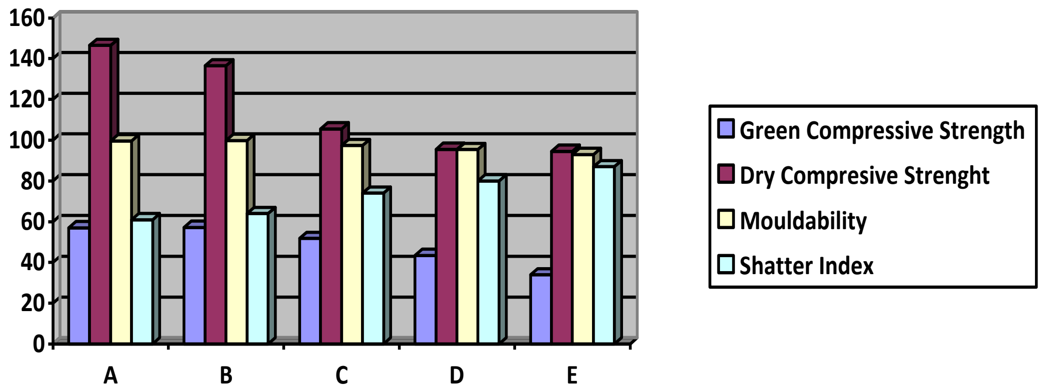

Figure 1. Samples of different moisture contents with some properties of the natural sand

From Figure 1, it can be seen that the results of the mouldability test carried out indicated that at various moisture contents, excellent mouldability of almost 100% were achieved. However, the shatter index property of the sand tends to decrease as the moisture content reduces. The result of the shatter index tests revealed that the higher the moisture content, the higher the shatter index number as shown (see table 4). The shatter index can be defined as the ability of the mould to collapse after casting [12].

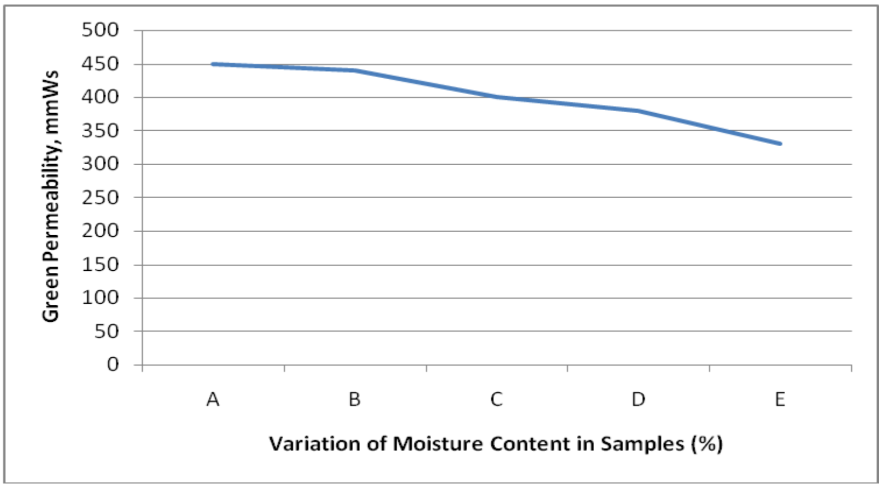

Figure 2. Samples of different moisture content with the permeability value

Figure 2 shows an increase in the permeability number with decrease in moisture content with a value of 450 mmWs at 1.9% moisture content and 330 mmWs at 4.7% (see Table 4). According to Ihom *et al*, [4] the permeability increases as the moisture content increases in a nearly linear manner due to the swelling action of the clay particles, thereby pushing the sand particles further apart and making more room for air passages just as in the case of this natural sand as it can be seen in Figure 2. With the high permeability value of 450 mmWs at the lowest moisture content of 1.9%, this revealed that the moulding sand when used for casting, the cast component(s) will be free from major and minor defects, such as, blown holes, porosity, scars, etc [6].

From the results obtained, it is obvious that high percentage of moisture in the moulding sand is not advisable, as the resultant effect will causes temperature reduction when pouring in the molten metal in the mould. High moisture content tents to affects the flow of molten metal in the mould as large volume of gasses will be produced which equally facilitates the rate of cooling and at the same time obstruct the flow of the molten metal [4].

Conclusions

Foundry laboratory tests conducted on the Fori natural sand indicated its potential to be used as foundry sand in green state. The research revealed that the quantity of moisture and clay contents has major effect on the foundry properties of the moulding sand. The moulding sand has about 19.2% clay content with a satisfactory green compressive strength of 57.26KN/m^2 at moisture content less than 3%. From the results obtained for chemical composition, compression strength, permeability, mouldability and refractoriness values, Fori natural sand can be used as natural moulding sand suitable for casting of some metals components (brass, bronze, aluminum, malleable cast iron and as well as light grey cast iron) and its alloys at a lower moisture content, but not suitable for casting of higher temperature melting metals like iron and steel.

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