Characterization of Belle Natural Moulding Sand for Foundry Applications

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Abstract

There exists vast availability of natural sands which may be suitable for foundry applications in different locations Kwara State in particular and generally in Nigeria. The sands need to be identified and characterised for productive and profitable foundry practices. In this study, assessment of chemical and physico-mechanical properties of the natural moulding sand in Belle community of Kwara State, Nigeria was carried out to ascertain its suitability for foundry applications. The analysis of the sand samples' Chemical compositions were done using an XRF Analyser, while American foundry-men Society, ASTM and British standards laboratory tests procedures were adopted appropriately to determine the sand's physico-mechanical properties. The results of chemical composition analysis showed that SiO_2 have dominance proportion in the sand sample with an average value of 92.90 %, followed by Al_2O_3 (5.13%). CaO, Fe_2O_3, MgO, K_2O, Na_2O, ZnO and MnO were present within acceptable limits as trace elements. The results showed average physico-mechanical properties of the natural moulding sand sample to include grain fineness number (126), bulk density (1765 Kg/m^3), moisture contents (7.66%), specific gravity (2.64), permeability (0.1cm/s), green compressive strength (51KN/m^2), dry compressive strength (209KN/m^2), flowability (65.22%), clay content (10%) shatter index (76%) and refractoriness (>900^{o}C), which were within the required standards for casting of non-ferrous metal. Thus, Belle sand was found suitable for casting of non-ferrous metals. Though, there may be a need for the use of additives like bentonite, to enhance the sand's clay content in order to increase the sand potential for foundry applications.

Keywords: Characterisation, natural moulding sand, non-ferrous metals, sand casting.

1 Introduction and Concepts

Moulding sand is one of the most important materials used in the foundry (Nuhu, 2008), as the quality of casts largely depends on the properties of the sand used (Oke and Omidiji, 2016; Shuaib-Babata and Olumodeji, 2014). Metal casting, which is a process of pouring molten metal into moulds and allowing it to solidify is a convenient and cost-effective means of manufacturing intricate shaped objects (Desai *et al*., 2016). The solidified object is called casting. Metal casting has several advantages over other manufacturing methods. These include versatility, weight saving, size, complexity and dimensional accuracy (Oke and Omidiji, 2016). Casting could be accomplished through expendable mould processes or permanent mould processes (Ademoh and Abdullahi, 2009). However, the predominant method is an expendable mould process which involves the use of moulding sand (Oke and Omidiji, 2016).

Moulding sand is commonly used to cast both ferrous and non-ferrous metals because of its ability to withstand the temperature of the molten metal, absorb and transmit heat, and has good permeability to allow gasses generated during casting to escape without causing casting defects (Ademoh and Ahmed, 2008). The use of sand as a moulding medium is determined by the type of metal being cast, economics, casting quality required, and the degree of consistency desired in the final products (Mshelia *et al*., 2016). The major constituents of moulding sands include silica sand, clay and moisture. Each of the constituents is important in determining the characteristics of moulding sand (Nigerian Foundries Limited, 1995). Clay is responsible for bonding; moisture content determines the plasticity of the moulding sand (Steve, 1996), while silica sand impacts refractoriness, chemical resistivity and permeability (Scaffer and James, 1995; Sarka, 1967). Silica sand is specified according to its average size and shape (Aribo, 2011). The higher the sand grain fineness, the higher the cohesiveness, and the lower the permeability of the sand (Aribo *et al*., 2009). Clay is made up of two ingredients: fine silt and true clay. Fine silt is a kind of foreign matter in clay deposit and possesses no bonding power. True clay provides the necessary bonding action which it acquires in the presence of an appropriate amount of moisture (Atanda *et al*., 2012; Mechanicalinfo, 2019). However, as the quantity of the clay increases, the permeability of the moulding sand decreases (Atanda *et al*., 2012).

Moulding sand is classified as natural (green sand) and synthetic sand. Natural moulding sand is taken from the river bed or dug out from pits. Synthetic moulding sand, on the other hand, is made in the foundry by mixing a relatively clay free sand with selected clay binder like bentonite (Atanda *et al*., 2012). Water and other additives may be added as may be required. Virtually all moulding sand for ferrous castings is of the green sand type (Deepak, 2008). A green sand mould refers to the fact that the mould will contain moisture during the pouring of the molten metal (Desai *et al*., 2016).

Sand casting which is perhaps the most versatile of the casting methods can be used for casting various articles ranging from very small size to extremely large size (Ibitoye, 2005). It is used to cast several engine components such as engine blocks, machine tool bed, cylinder heads, piston rings, wheels, pump housings, water supply pipes, mill rolls, valves etc. However, in order to produce good quality casting, the properties of the moulding sand must be at the optimum level (Mahesh *et al*., 2008). Research has shown that the quality of the casting is largely affected by moulding sand properties (Dhruval *et al*., 2015; Mishra, 2017; Saikaew and Wiengwiset, 2012), such as cohesiveness, green compressive strength, dry strength, permeability, mould hardness, compatibility and shatter index. All these properties invariably depend on such parameters as the quality of binder used, amount of water and sand grain size (AFS, 1963; Loto and Omotoso, 1999; Ayoola *et al*., 2010).

Large deposits of suitable foundry raw materials are obtainable in various parts of Nigeria. Amongst these are naturally bonded moulding sand in river Osun, Osun State (Ayoola *et al*., 2010), dolomite (Nnuka and Olanrewaju, 1999) found in Osara, Edo State, clay in Ibule (Ijagbemi, 2005) and Ijapo (Akintunde and Omole, 2008) both in Ondo State. Recently, several deposits of natural moulding sand were discovered in Ado-Ekiti, Nigeria (Shuaib-Babata *et al*., 2017a,b,c). Also, there exists vast availability of sands in Kwara State that may be suitable for foundry applications and has huge potential for the development of foundry activities (Adesina, 2005; Adesina, 2010; Adesina and Adegbite, 2013; Shuaib-Babata and Olumodeji, 2014; Shuaib-Babata *et al*., 2019). *Belle* community of Kwara State, Nigeria is not left out. However, one major challenge is the ability to ascertain the quality and suitability of the available sands. Therefore, there is a need to identify and characterise the natural moulding sands for productive and profitable foundry practices. Thus, this paper is centred on the characterization of Belle natural moulding sands, with a view to determining their chemical and physico-mechanical properties and their suitability for foundry applications.

2 Materials and Method

2.1 Materials

Samples of natural moulding sand were obtained from three different points, tagged as A, B and C (5 km apart) within *Belle* community, near river Niger in *Bacita*, Kwara State. Basic sand sample collection and preparation tools, which include pans, riddles and shovel were used in collecting and preparing the moulding sand. The natural moulding sand samples were taken at the depth of 2.54 cm deep, to obtained pure and even silica sand in line with the practice of Shuaib-Babata *et al*. (2017b).

Belle community is located in Bacita, Edu Local Government Area of Kwara State with geological coordinates 9^{o}5'0'' North, 4^{0}57'0'' East (Bacita Map, 2019). Figure 1a and 1b respectively shows the location of the natural moulding sand deposit in *Belle* community where samples were taken and map of Nigeria showing location of the study.

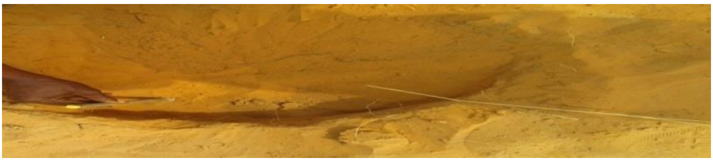

Figure 1a: *Belle* natural moulding sand deposit

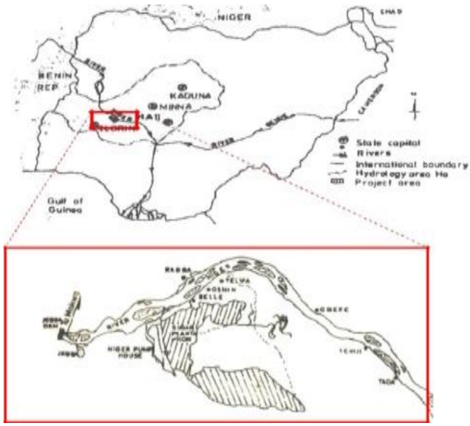

Figure 1b: Map of Nigeria showing location of the study
(Salami and Adedeji, 2014)

2.2 Determination of chemical compositions and physico-mechanical properties of the natural moulding sand

2.2.1 Analysis of the sand chemical compositions

The chemical composition analysis of the *Belle* natural moulding sand was carried out using the X-Ray Fluorescence (XRF) Analyser (Shimadzu 720, Shimadzu Cooperation, United Kingdom made) at Materials Testing Laboratory, University of Lagos, Nigeria in line with the practice of Patrick *et al*. (2019). Three (3) grams of the sand sample was measured, put in a sample holder and placed inside the X-ray chamber. The setting of the oxide analyses was carried out. After 100 seconds, the result was displayed on the monitor connected to the XRF.

2.2.2 Physico-mechanical properties

In order to determine the suitability or otherwise of the moulding sand for the casting process, various physico-mechanical properties tests were carried out. The properties tested include the grain fineness number, permeability, refractoriness, green compressive strength, bulk density, dry compressive strength, specific gravity, moisture content, clay content and flowability. These tests were carried out at Soil Testing Laboratory, Department of Civil Engineering, Federal Polytechnic Ado-Ekiti, Ekiti State. The procedures used were in accordance with the American Foundry-men Society (AFS), ASTM and British standards for the determination of these properties as stipulated in technical literatures (BS1377:1990; BS 4377:1990; Head 1997 a, b; Mittal and Shukla, 2003; Faluyi *et al*., 2013).

2.2.3 Sieve analysis / Grain fineness number determination

The moulding sand was prepared by washing, drying and picking and sorting processes to remove debris and other unwanted materials from the sand. The weight of the dried cleaned sand sample was determined and recorded. The British standard set of sieves (Figure 2) was cleaned, and the weight of each sieve in the set was determined with the use of electronic weighing balance (Electronic balance Mp10001, Max: 1000 grams & Min: 2 grams) and recorded along with the bottom pan used. The sieves were then assembled in ascending order of sieve numbers (8, 10, 16, 22, 60, 100, 150 and 200) with the pan placed at the bottom. The sand sample was then carefully poured into the top sieve and covered with the cap. Subsequently, the sieve stack was then placed on the mechanical shaker (Endvolts sieve shaker, volts/220/240, single phase; Ridsdale & Co. Ltd made) and shake for 15 minutes. The stack was then removed from the shaker and carefully weighed, the weight of each sieve was recorded with its retained sand. The weight of the bottom pan was also determined and recorded also with its retained fine sand. The grain fineness number was calculated using the relation in equation 1 (Faluyi *et al*., 2013; Mittal and Shukla, 2003; Head, 1997a&b).

$$\text{Grain fineness number} = \frac{Total\ product}{Total\ \%\ retained\ by\ different\ sieves} \quad (1)$$

2.2.4 Moisture content

Three (3) aluminium cans were cleaned, dried and weighed with lid as W_1. Moulding sand sample was filled into each of the three dried cans. The cans filled with sand were covered with lid, weighed and recorded as W_2. Each of the cans was then opened with the lid placed beneath them and placed in the oven (electro-thermal oven model DHC9). The sand was allowed to dry for 24 hours in the oven at 110^{o}C. Each of the cans was brought out from the oven with the dried sand in them, weighed on the electronic weighing balance and recorded as W_3. The moisture content was calculated using equation 2 (Faluyi *et al*., 2013; Mittal and Shukla, 2003; Head, 1997a&b).

$$\boldsymbol{Moisture\ content = \frac{W_2 - W_3}{W_3 - W_1} \times 100\%} \quad (\mathbf{2})$$

where W_1 = weight of empty can, W_2 = weight of drying can + wet sand and W_3 = weight of drying can + dry sand

2.2.5 Permeability

The sand sample was filled into a cylindrically shaped mould of 8.50 cm diameter and height of 12.73 cm. The filter paper was placed at both ends of the specimen and then centrally placed over the bottom saturated porous stone of the drainage base fixed to the mould (Figure 3a). The annular space between the mould and soil specimen were filled with impervious material (gravel) to avoid any leakage from the sides. The drainage cap was then fixed over the top of the mould (Figures 3b & c). The water storage was connected with the outlet of the bottom drainage base plate of the mould and the water was allowed to flow in. The whole water got saturated and 1.00 cm depth of free water was allowed to stand on the top of the sample. The flow was allowed in the specimen for 24 hours. After which the water reservoir was disconnected from the outlet at the bottom and connected to the inlet at the top plate. The stop cock at the top plate was opened and water was allowed to pass through it to remove all the air in the cylinder. The stop cock was closed after all the air has escaped. The outlet at the bottom plate was then opened and the water was allowed to flow through the soil in order to establish a steady flow. The water was collected in a graduated measuring flask for 2 minutes time interval. The collection of the water was repeated thrice and the times were noted and recorded.

The permeability was calculated using the relation in equation 3 (Faluyi *et al.*, 2013; Mittal and Shukla, 2003; Head, 1997a&b). Figure 2d shows the permeability constant falling head equipment and its mould.

$$\boldsymbol{Permeability\ (K) = 2.30 \frac{a.L}{A.t} \log\left(\frac{h_1}{h_2}\right)} \quad (3)$$

Where: K = coefficient of permeability at T ^{o}C (cm/sec), L = length of soil specimen (cm), h_1 = initial head of water at time t_1 in the pipe above the outlet (cm), h_2 = final head of water at time t_2 in the pipe above the outlet (cm), a = cross sectional area of stand pipe (cm^2), A = cross sectional area of the soil specimen (cm^2) and t = (t_1 - t_2) time interval (sec) for the head to fall from h_1 to h_2.

a b c d

Figures 3: (a, b, c) The process of loading the mould with sample sand for permeability test, and (d) Permeability constant falling head equipment

2.2.6 Specific gravity

The density bottle was washed, dried, cleaned, weighed and recorded as m_1. The soil sample was placed in the density bottle with stopper, weighed and recorded as m_2. Air free water was added to cover the soil in the bottle. This was placed without the stopper in the vacuum desiccators. The pressure was reduced to about 25 Kilopascals. The bottle was left for 1 hour. The vacuum was released and the desiccator lid was removed. The soil in the bottle was stirred. The soil particle was washed off before the stirring rod was removed. The lid of the desiccators was replaced and the vacuum procedure was repeated until there was no more air evolved from the soil. The specific gravity was then determined using equation 4 (Faluyi *et al.*, 2013; Mittal and Shukla, 2003; Head, 1997a&b).

$$\text{Specific gravity} = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \quad (4)$$

Where: m_1 = mass of empty bottle, m_2 = mass of bottle with sand sample, m_3 = mass of sand sample with water and bottle, m_4 = mass of bottle filled with water

2.2.7 Sand strengths

(a) Green compressive strength

In determining the moulding sand green compressive strength, the sand was filled into a standard mould of 50 mm in diameter and 100 mm in length (Figure 4a), and compacted using sand compaction machine where a 6.6 kg load was dropped 50 times at both ends of the mould. Thereafter the sand in the mould was removed with the use of hydraulic jack placed at the bottom of the mould. This process was repeated nine times to produce nine specimens from the sand sample. Three out of the moulded sand (3 specimens) were then placed in the sand compressive strength testing machine (California Bearing Ratio machine, model No. 212060257; ELE (Engineering Lab. Equipment Ltd., Volts: 240, Amps 3, HZ.: 50 Ph: 1) shown in Figure 4b, where they were subjected to varying degree of load to determine the maximum amount of load they can withstand before the sand collapsed. The readings on the machine indicator at different load were recorded to calculate the green compressive strength using equation 5 (Faluyi *et al*., 2013; Mittal and Shukla, 2003; Head, 1997 a & b).

$$Green\ compressive\ strength = \frac{DGR \times 0.025}{Area} \quad (5)$$

Where DGR means "Dial Gauge Reading"

a

b

Figure 4: (a) Process of loading the mould for compressive strength tests and (b) California bearing ratio compressive strength testing machine

(b) Shear strength and dry compressive strength

The shear strength was determined by filling the shear strength machine mould with the sand sample and thereafter the mould was placed in the sand shear strength testing machine as shown in Figure 3b (Shear tester T206 Electronic) and subjected to different loading and the corresponding deflections on the machine scale were recorded for each of the load for the calculation of the shear strength. The shear strength and the dry compressive strength was calculated using equation

6 and 7 respectively (Faluyi *et al*., 2013; Mittal and Shukla, 2003; Head, 1997 a & b).

$$Shear\ strength = \frac{DGR \times 0.0009}{Area} \quad (6)$$

$$\text{Dry compressive strength} = \text{Shear strength} - \text{Green strength} \quad (7)$$

2.2.8 Refractoriness

Three specimens of the moulded sand as described in the green compressive strength procedure (section 2.3.5) were placed in a furnace (M.L Furnace, model M5, Rating 3 kilowatts), the temperature of the furnace was set to 950^{o}C and this temperature was maintained for 3 hours. The moulded sands were then brought out of the furnace to determine any defect or otherwise in the sand appearances and sizes.

2.2.9 Shatter index

Three specimens out of the nine moulded specimens produced (described in section 2.3.5) were used for the shatter index test. The shatter index value of the moulding sand was determined by allowing the compacted moulding sand specimen to fall freely from a height of 1.83 meters unto a steel anvil. The degree of disintegration of each specimen was measured by weighing the specimen before falling (W_1) and weighing the bigger piece among the disintegrated specimen after fall (W_2), from which the toughness or plasticity of the sand was determined using equation 8 (Faluyi *et al*., 2013; Mittal and Shukla, 2003; Head, 1997 a & b).

$$Shatter\ index = \frac{W_1 - W_2}{W_2} \times 100\% \quad (8)$$

2.2.10 Clay content

A measuring cylinder of 1000 ml capacity was filled with an iodine salt of 50 g and water was added to fill the cylinder to 300 ml. Thereafter, the sand sample of 200 g was added into the cylinder. This mixture was left in the cylinder for 2 hours. The mixture then formed three layers in the measuring cylinder. These layers are water which is at the top level (V_1), followed by the silt (V_2), and the silicate sand at the bottom (V_3). Thus, the clay content was calculated between these layers using equation 9 (Faluyi *et al*., 2013; Mittal and Shukla, 2003; Head, 1997 a & b).

$$Clay\ contents = \frac{V_3 - V_2}{V_1} \quad \textbf{(9)}$$

3 Results and Discussions

3.2 Chemical compositions of the moulding sand

The chemical constituents of the sand samples are as presented in Table 1. Silica (SiO_2) constitutes the main element in the sand, with an average value of 92.90% by weight, followed by Alumina (Al_2O_3) which constituted 5.13% on average value. Thus, the sand belongs to Alumina-silicate group of sand. Most foundry sands for metal casting are highly quality silica with physical characteristics (Shuaib-Babata *et al.*, 2017c). Other elements present in the sand include CaO, MgO, Na_2O, Fe_2O_3, K_2O, MnO, and ZnO in smaller proportions as recommended (Jimoh *et al.*, 2015). The sand contained no amount of CaO and ZnO which are one of the significant constituents of the clay content in the sand (Jimoh *et al.*, 2015). However, this may have little effect on the strength of the sand because clay serves as a binder which holds the grains of the sand together (ME Mechanical Team, 2016). This deficiency can be eliminated through the addition of a binder (Mshelia *et al.*, 2016). Information on the sand chemical composition is important as it relates directly to the metal moulded at the foundry (Akinyele and Oyeyemi, 2014).

Table 1: Elemental Composition of the Moulding Sand

S/N	Constituents	Weight (%)			
		A	B	C	Average Value
1	SiO_2	92.9	92.8	93.0	92.900
2	Al_2O_3	5.0	5.1	5.3	5.1300
3	CaO	0.01	0.01	0.01	0.010
4	MgO	0.068	0.068	0.068	0.068
5	Na_2O	0.77	0.79	0.78	0.780
6	Fe_2O_3	0.029	0.031	0.030	0.030
7	K_2O	0.385	0.385	0.385	0.385
8	MnO	0.006	0.006	0.006	0.006
9	ZnO	0.300	0.300	0.300	0.300

3.3 Physico-mechanical properties of the natural moulding sand

3.2.1 Sieve analysis / Grain size distribution and Grain fineness number (GFN)

The average results of the moulding sand's grain size distributions and AFN grain fineness number are as shown in Table 2. In sand, the characteristics shape of a sand grain is an important factor (Shuaib-Babata and Olumodeji, 2014). Many of the sand's properties are affected by the grain size distribution (Richard, 2003).

The results in Table 2 revealed high concentrated grain retained of the sand (88.6%) between sieve size BS No.100 and 150 (0.15 and 0.075 mm). This shows that the sand had a high concentration of fine structure. Fine surface finish casting is enhanced by highly concentrated small grain structure of sand (Mikhailov, 1989; Adesina, 2010). In natural sand, particle distribution and the sand's shape allow good permeability and strength (Ihom *et al.*, 2011; Turkeli, 2017).

The sand's GFN was averagely 69 which fell within the specified standard values (36 – 90) for non-ferrous metals (Burns, 1986; Mshela *et al*., 2016). The sand's average grain size will be approximately 195 µm, which are useful parameters with AFN, as the choice of sand should be based on particle size distribution (Burns, 2000). The size distribution has effects on the quality of the castings.

However, the sand has higher compatibility level, since the finer the grains of sand, the higher its level of compatibility and vice-versa (Donald, 2010), which results to good surface finishing (Ammen, 1979).

Table 2: Sieve analysis of Belle natural moulding sand

BS Sieve No	Sieve Size (Mm)	% Retained (A)	Multiplier (C)	Product (A X C)
8	9.5	0.00	0.375	0.0
10	4.75	0.00	4.000	0.0
16	2.36	0.00	8.000	0.0
22	1.18	0.05	16.000	0.8
60	0.6	10.95	22.000	240.9
100	0.3	56.40	60.000	3384.0
150	0.15	32.20	100.000	3220.0
200	0.075	0.35	150.000	52.0
Total		99.95		6897.7
GRAIN FINENESS NO		***69.01***		

Sand with higher grains fineness number has the tendency to produce a very good surface finish cast product, with low binders (Tuncer, 2017). GFN serves as a guide to determine the quantity of binding materials required to produce desirable properties in new foundry sand (Shuaib-Babata and Olumodeji, 2014).

Table 3: Physico-Mechanical properties of the moulding sand

S/N	Parameters	Sample A	Sample B	Sample C	Average Value
1	Colour	Reddish brown	Reddish brown	Reddish brown	Reddish brown
2	Moisture content (%)	7.50	7.83	7.65	7.66
3	Specific gravity	2.64	2.64	2.64	2.64
4	Bulk density (Kg/m^3)	1764.71	1766.78	1764.12	1765.20
5	Permeability (cm/sec)	0.12	0.09	0.09	0.10
6	Flowability (%)	64.71	66.67	64.29	65.22
7	Grain fineness number	69.0	69.0	69.0	69.01
8	Green compressive strength (KN/m^2)	50.8	50.9	51.3	51.0
9	Dry compressive strength (KN/m^2)	208.9	209.0	209.1	209.0
10	Clay content (%)	10.0	10.2	9.8	10.0
11	Shatter index (%)	76.0	76.0	76.0	76.0
12	Refractoriness (^0C)	>900	>900	>900	>900

The grain fineness number also affects the permeability of the sand (Mshela *et al*., 2016). Fine-grained sands yield better surface finish but need higher binder content (Burns, 2000). The results of the moulding sand samples' physico-mechanical properties are presented in Table 3.

3.3.3 Moisture content

The importance of moisture content on the moulding sand and subsequently on the casting quality cannot be underestimated. Moisture test determined the dampness of the mould. The sand has an average moisture content of 7.66%, this falls in the range of (4 – 8%) which is the recommended standard suitable for casting of light steel, heavy grey steel and medium grey iron (Burns, 1989; Mikhailov, 1989). By establishing the percentage of moisture content of the natural moulding sand, it will help in controlling the amount of water that can be added during the process of mould making (Oke and Omidiji, 2016). If the proper amount of moisture in the sand is not achieved, it can lead to some defects such as scabs and blow holes and it will also affect the strength properties of the moulding sand (Mshelia *et al*., 2016).

3.3.4 Specific gravity

The average specific gravity of the sand was discovered to be 2.64 which fall between the 2.5 – 2.8 acceptable ASTM standard (D854) for foundry sand with clay (5%) and foundry sand without clay. Foundry sand with lower specific gravity has been discovered to contain more impurities and inorganic materials that could fuse during molten metal pouring process which might lead to casting defect (Bala and Olabisi, 2017). The sand has a high specific gravity which signifies that the level of impurities in the sand is quite low and thus will not fuse with the cast at a higher temperature (Jimoh *et al*., 2015).

3.3.5 Bulk density

The average bulk density was found to be approximately 1765 Kg/m^3 which fall within the AFS standard of 1100 Kg/m^3 to 1800 Kg/m^3 for sand casting process (Bala and Olabisi, 2017). The bulk density has been discovered to be increasing with increasing moisture content. At very high moisture content, the highest bulk density can be obtained when the sand is adequately rammed to drive off all the air in the mould (Mshelia *et al*., 2016).

3.3.6 Permeability

The sand has a permeability of approximately 0.10 cm/sec which is within the standard of 10^{-3} cm/sec and above for foundry sand (Technology, 2016). Although the sand has fine grains low clay content in the sand can also be attributed to high permeability exhibited by the sand (Mshelia *et al*., 2016). However, it has been established that the finer the sand grains, the lower the permeability and vice versa. Lower permeability can be attributed to one of the major cause of porosity defect in the casting process. Hence it is an important factor that can influence the property of moulding sand and the property of the cast (Jimoh *et al*., 2015).

3.3.7 Flowability

The average flowability of the sand is 65.22%. The value is within the standard value of flowability for moulding sand by AFS which is 65% and above (Burns, 1989; Shuaib-Babata *et al*., 2017c). This can be attributed to higher SiO_2 in the sand. Flowability of the sand increases with a decrease in the green strength and vice versa. It also increases with the decrease in grain size of sand (ME Mechanical Team, 2016). This also corresponds to the sand has a higher grain fineness number which shows a decrease in the grain size particles. Flowability is also influenced by clay content and moisture content (Desai *et al*., 2016).

3.3.8 Green compressive strength

The average Green compressive strength of the sand was 51 KN/m^2 which is within the recommended standard (50–70 KN/m^2) for non-ferrous metals (Mshelia *et al*., 2016). However, this strength can be improved upon with the addition of binders and some other additives such as clay, bentonite, corn flour and others so that its strength and toughness can be increased and thus enhanced the handling and making of the mould (ME Mechanical Team, 2016). The strength of the sand is also the compression strength that allows it to hold geometric shapes and grains together under the conditions of stresses that will be imposed on it during the sand casting process. Thus, this result shows that the sand is suitable for casting aluminium and other non-ferrous metals.

3.3.9 Dry compressive strength

The average dry compressive strength of the sand was found to be 169 KN/m^2. This is quite lower in comparison with the standard value (200-550 KN/m^2) (Mshelia *et al*., 2016). Thus, the sand does not have sufficient strength in its dry form i.e. it will lack appropriate strength in its dry form. The low dry compressive strength is due to the low clay content in the sand as the clay content was found to be 10%. However, this value can be improved with the addition of binder and some other additives such as clay, bentonite, corn flour and others.

3.3.10 Clay content

The average clay content of the sand was found to be 10% which is in agreement with the standard recommended value (10-12%) (Mshelia *et al*., 2016). The low clay content in the sand has both advantages and disadvantages. Part of the advantages is that it gives the sand high permeability and thus, minimise the probability of porosity defect in the final cast. On the other hand, the moulding sand will have low compaction strength, which has reflected in the sand's strength (51 KN/m^2). Another disadvantage is that the sand may not be used for casting of objects with intricate shapes but for simple objects such as round bar, rectangular bar and so on (Mshelia *et al*., 2016). However, these disadvantages can be adequately taken care of by simple addition of binder which includes natural clay, bentonite and other additives to impart adequate compaction strength to the sand (ME Mechanical Team, 2016).

3.3.11 Shatter index

The average shatter index of the sand was found to be 76% which is within the AFS standard requirement (65%) (Shuaib-Babata *et al*., 2017a). This indicated that the sand sample after compaction lacks sufficient toughness to help satisfactory lift during the withdrawal of the pattern (Jimoh *et al*., 2015). This high shatter index also indicates that the sand has high collapsibility which is more desired after the withdrawal of the cast from the mould (Sheidi and Ajuwa, 2008). However, high shatter index can be attributed to the low clay content in the sand which will bond the sand grains together and prevent them from easily broken into pieces (ME Mechanical Team, 2016). The shatter index can be improved with the addition of a binder.

3.3.12 Refractoriness

After the sand was subjected to a temperature above 900°C inside the furnace and removed, the sand retained its shape, size and colour. However, there was a decrease in the compaction strength of the sand physically. This can be attributed to the low clay content in the sand which should have sufficiently bonded the sand grains together and prevent them from separating from each other easily by impacting sufficient strength in the sand grains (ME Mechanical Team, 2016). However, this can also be improved with the addition of a binder to impart sufficient strength in the sand both at low and high temperature (ME Mechanical Team).

3.3 Evaluation of the Selected Natural Moulding Sand

The chemical composition and physico-mechanical properties of the natural moulding sand from *Belle* community were compared with the AFS standard recommended values. On this basis, the potentials of the natural moulding sand for foundry application was evaluated. Similarly, the physico-mechanical properties of the sand were tabulated against recommended/standard values from literature in Table 4, which reveals the suitability of Belle moulding sand for various castings of metals, most especially non-ferrous metals.

Table 4: Physico-mechanical properties of the sand against recommended/standard values

S/N	Parameter	Average obtained Values	Recommended Standard Values
1	Moisture content	7.66%	5 – 8% [for the casting of Aluminium, brass & bronze, malleable iron and medium grey iron] (Burns, 1989; Mshelia *et al*., 2016)
2	Specific gravity	2.64	2.6 – 2.8 (Technology, 2016)
3	Bulk density	1765.2Kg/m^3	1100 Kg/m^3 to 1800 Kg/m^3 as AFS standard for sand casting process (Bala and Olabisi, 2017)
4	Permeability	0.10cm/sec	0.001cm/sec and above (Technology, 2016)

5	Flowability	65.22%	65% [for casting of Aluminium] (Burns, 1989)
6	Grain fineness number	69.01	36 – 90 [for non-ferrous metals] (Burns, 1986; Mshela *et al*., 2016)
7	Green compressive strength	$51KN/m^2$	$50 – 70KN/m^2$ and above [for the casting of Aluminium, brass & bronze, light grey iron and malleable iron] (Burns, 1989; Mshelia *et al*., 2016)
8	Dry compressive strength	$209\ KN/m^2$	$200 – 500KN/m^2$ [for casting of Aluminium, brass & bronze and light grey iron] (Burns, 1989; Mshelia *et al*., 2016)
9	Clay content	10%	10 – 12% [for the casting of Aluminium, brass & bronze, light grey iron, malleable iron, heavy steel, light steel and heavy grey steel] (Burns, 1989; Mshelia *et al*., 2016)
10	Shatter index	79%	12% and above (Mshelia *et al*., 2016)
11	Refractoriness	$>900^0 c$	1100^oC and above (Mshelia *et al*., 2016)

4. Conclusions

From this study, the following conclusions were drawn:

1. *Belle* moulding sand belongs to high-quality silica sand; having SiO_2 has its dominance element (92.93 %) with other trace elements like Al_20_3, CaO, Fe_2O_3, MgO, ZnO, MnO, K_2O and Na_2O. The sand chemical compositions determined when compared with the standard recommended properties of natural moulding sands showed that the sand sample characterised does not possess the right properties for sound sand castings in its natural form. This does not, however, make it totally unsuitable for non-ferrous applications but it implies that its reusability has to be closely monitored to ensure timely reconditioning to guard against the production of defective castings.
2. The *Belle* natural sand has very fine grains and considerably sufficient clay content (10%) but only suitable for the casting of non-ferrous metals such as aluminium, brass and bronze in its natural form.

3. The sand has considerably low dry strength for the casting of ferrous metals and thus requires the addition of clay or binders but however, it is sufficient for casting object with no intricate shape in its natural form.

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