Arid Zone Journal of Engineering, Technology and Environment. August, 2016; Vol. 12:110-121

Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

CHARACTERISATION OF NATURAL MOULDING SANDS FROM SELECTED DEPOSITS IN MAIDUGURI-NIGERIA FOR CASTING APPLICATIONS

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Abstract
Natural moulding sands consist of refractory sand grains associated with clay right from their deposit locations. In Maiduguri, there are some sand casting activities taking place. However, there seems to be no single graded source of moulding sand that the practitioners can use for producing qualitative sand castings. Therefore, this study was carried out to characterise moulding sands from five selected deposits in Maiduguri for possible use in sand casting applications. Chemical compositions of sand samples were determined using XRF Analyser while American Foundrymen's Society (AFS) standard laboratory tests were used to determine the physico-mechanical properties. The results of the characterisation revealed the following ranges of values; clay content from 21.8% to 47.2% corresponding to Pompomari and Gwange/Fori, grain fineness number from 50.94 AFS to 95.02 AFS corresponding to Pompomari and Gwange/Fori deposits.. Other physico-mechanical properties determined included; green and dry compressive strengths, permeability, loss on ignition and refractoriness. Results of chemical composition analysis show SiO_2 having dominance in all the samples (90.10 % to 66.77 %) with trace elements of CaO, Fe_2O_3, Al_2O_3, MgO, TiO_2, K_2O, NaO_2 also present within acceptable limits. The overall results show that all deposits have potential for use in sand casting applications for the casting of nonferrous metals and malleable and ductile iron. However, the clay content range given above is a major problem compared with the standards recommended by the American Foundry Society. This did not only limit their uses to low melting point alloys because of relatively lower refractoriness values but also possesses danger to their life expectancy. In conclusion, the use of the deposits characterised especially the Gwange/Fori deposit with clay content of 47.2 % should be used with caution because of the possibility of developing gas defects like blowholes and pinholes. All the other four deposits have been recommended for full exploitation for use in sand casting applications for casting of nonferrous metals as well as malleable and ductile irons. Finally, on the basis of the overall properties, the five deposits have rated in the following order of preferences; Dala Lawanti, Pompomari, Gwange/Fori, Gamboru and University of Maiduguri respectively.

Keywords: Characterisation, natural moulding sand, sand **c**asting, nonferrous metals

1. Introduction

Natural moulding sands consist of refractory sand grains associated with clay right from their deposit locations. Such sands often develop good moulding properties with the addition of water. For this reason, naturally occurring sands of this type are used "as mined" and need only be mixed with sufficient water to facilitate moulding (Yekinni *et al.*, 2015; Ihom, 2012; Ayoola *et al.*, 2010; Aweda and Jimoh, 2009; Walton and Opar, 1981). The basic ingredients of moulding sand are silica sand, clay as a binder and moisture**.** Natural moulding sand contains variable amount of clay which acts as bond between the sand grains. The use of this type of moulding sand as a green sand moulding medium is determined by type of metal being cast, economics, casting quality, and the degree of consistency demanded by the final product (Walton and Opar, 1981). There are many properties a moulding sand should have to qualify it as good. These properties include strength, refractoriness, permeability, thermal stability, flow ability, collapsibility, heat conductivity, reusability, casting finish sand preparation and control (Ayoola *et al.*, 2010; Ibhadode, 2001). One of the most important factors contributing to higher productivity in modern foundry practice is the choice of the right type of moulding and binder materials. Among the various materials employed in foundry, sand is the chief variable as it occurs in nature with considerable diversity of compositions (NMDC Jos Data Bank, 2008). For this reason, sand for foundry applications need to be evaluated to ensure that they are put into informed use.

The art of foundry has been practiced in Northern Nigeria for over 100 years (Adejuyigbe, 1998), but the country is yet to enjoy the benefits of these foundries because of lack of significant growth due partly to the traditional knowledge gap that exist with owners (Essein, 2011). Foundry practices are integral part of Nigeria's culture; therefore, it is important for the country to develop its foundry sector in order to make rapid industrial progress. It is a well-known fact that technological advancement divorced from its cultural context, is destined to grow without a soul (Essien, 2011). Foundry has been found to be an important source of industrial emancipation and economic self-reliance in Nigeria (Ademulegun, 2008, Okundaye, 2015).

There is huge potential for the development of the foundry sector in Maiduguri, but one major challenge is the availability of moulding sands. In the Year 2012, a field survey conducted by the authors revealed that there were 92 indigenous foundries operating in Maiduguri alone. Similarly, University of Maiduguri, Ramat Polytechnic Maiduguri, Technical Colleges and the Industrial sector in the Metropolis also need supply of cheap and readily available sources of moulding sands. Strategic location of Maiduguri as capital of Borno state which borders three Francophone Countries could also serves as a good market of cast products. Natural moulding sands from deposit locations in Maiduguri that are currently being exploited and used in foundry applications have not been characterised. Therefore, there is need to identify and characterise natural moulding sands in Maiduguri for productive and profitable foundry business in Maiduguri. In the present study, an attempt was made to characterise natural moulding sands from five selected deposits in Maiduguri. This involved the determination of chemical composition as well as physico-mechanical properties of natural moulding sands from the selected deposit sites.

2. Materials and Methods

Samples of natural moulding sands collected from five selected deposits in Maiduguri were used in the study. Basic sand sample collection and preparation tools including, pans, riddles, shovel were used in collecting and preparing moulding sands. The test equipment/tools utilised include; X-ray fluorescence (Minimate PAN analytical, made by Philips) to carry out chemical composition tests, digital electronic weighing balance ± 0.01 g, rapid sand washer, sieve shaker/standard test sieves, GPS maps, laboratory sand mixer, moisture teller, Universal sand testing machine all made by Ridsdale and Co. Ltd.UK were used to carry out basic physico-mechanical properties of the sand samples. American Foundrymens Society (AFS) standard laboratory tests were used to determine the physico-mechanical properties of the samples. In order to grade the five sand deposits, they were put into field test where blanks of trapezoid prisms were produced and evaluated on the basis of; casting yield, casting density and surface defects.

2.1 Brief Description the Study Area

Maiduguri is the capital and largest city of Borno State, North Eastern Nigeria. The State was formed in 1976 when the north east region was divided into three states. Maiduguri is located on latitude 11° 51' E and longitude 13°15' E and altitude of 354 m above sea level (Encyclopaedia Britannia visited on 12/07/2015). The population of Maiduguri as of 2015 projected from the 2006 census figures using a growth rate of (+1.51%/year) for the period 2006 - 2015, was 1,112,400. Figure 1 is the map of Maiduguri Township showing the locations of the five selected deposits.

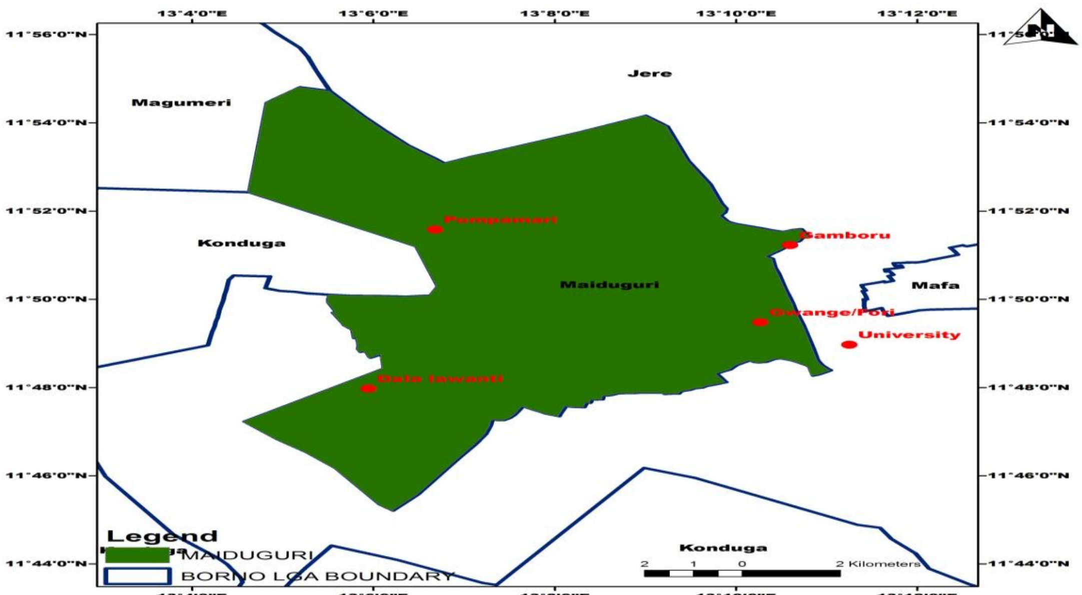

Figure 1: Map of Maiduguri showing the Five Natural Moulding Sand Deposits

2.2 Selected Natural Moulding Sand Deposits in Maiduguri

Two of the five deposits selected namely Gwange/Fori and Gamboru Customs Area bank sands are presently being exploited and used in foundry applications in Maiduguri. Three additional natural moulding sand deposits were identified these are; University of Maiduguri- outskirts of Maiduguri (behind the Faculty Engineering Teaching Workshop), Dala Lawanti (nearby a railway line) and Pompomari (Pompomari Industrial Layout Area). Five locations of natural moulding sand deposits selected and from which samples have been collected are shown in Figure 1. The GPS locations of the five locations are presented as follows:

Dala Lawanti – (alongside the Ngadda River Bank) latitude 11° 48' 0.53" N longitude 12° 5' 51.13" E, Gwnage/Fori – (by the Gwange/Fori axis) latitude 11 49° 33'.81" N longitude13° 10' 14.99" E, Gamboru- (Custom Area by the river side behind Custom Market) latitude 11° 51' 2.36 "N and longitude 13 10 23.09 E, Pompomari – (Pompomari Industrial Layout Area) latitude 11° 51' 68.86" N and longitude 11° 51' 34.00" E and University of Maiduguri–outskirts of Maiduguri (behind Faculty of Engineering Teaching Workshop) latitude 11° 48' 18.40" N and longitude 13° 12' 45.38" E.

2.3 Characterisation of Natural Moulding Sand

Standard sand tests were carried out in accordance with the AFS recommendations in characterising natural moulding sands from the five deposits selected for study. Quantities of representative samples of natural moulding sand were collected from the five selected deposits in Maiduguri, Borno state. With the assistance of a foundry artisan in the Department of Mechanical Engineering, University of Maiduguri, sand samples were collected at different depths of up to two meters from the five locations of interest. Each sample collected from the five different locations was then thoroughly mixed to have representative samples used for the study (Ayoola *et al.*, 2010). Chemical compositions of the sand samples were determined using XRF Analyser while American Foundrymen's Society (AFS) standard laboratory tests were used to determine the physico-mechanical properties. The tests were at the National Metallurgical Development Centre (NMDC), Jos, the Department of Geology, University of Maiduguri and the Department of Civil Engineering Soil Testing Laboratory, Ramat Polytechnic Maiduguri.

2.3.1 Determination of Chemical Compositions Physico-mechanical Properties of Natural Moulding Sand

Chemical compositions and physico-mechanical properties of natural moulding sands from the five selected deposits were determined at Sand Testing Laboratory of the National Development Centre, Jos and Geology Department, University of Maiduguri. Sieve analyses were carried out at the Soil Testing Laboratory of the Department of Civil Engineering, Ramat Polytechnic Maiduguri.

2.4 Evaluation of the Selected Natural Moulding Sand

The chemical compositions and physico-mechanical properties of natural moulding sands from the five selected deposits were compared with AFS standardised recommended values in order to determine their suitability for foundry applications. On the basis of the comparison between the properties of the sand samples under study and the standards, the potentials of the natural moulding sands for sand casting were evaluated. Similarly, to further evaluate the natural moulding sands from the five deposits, the physico-mechanical properties of the natural moulding sands from the five deposits were tabulated against recommended/standard values in literature.

3. Results and Discussion

3.1 Chemical Compositions of Natural Moulding Sands

The results of the chemical compositions of the natural moulding sands from the five selected deposits are presented in Table 1. The Table shows silicon dioxide (SiO_2) as the major constituent with values ranging from 66.77 % - 90.10 % across the samples from the five selected deposits. Silica grains are very important in moulding as they impact refractoriness, chemical resistivity and permeability to the sand (Ihom and Offiong, 2014). The higher the percentages of silica sand the better the refractoriness of the sand. Samples with 66.77 % (Gwange/Fori) and 77.63 % (Gamboru) are already being used in indigenous foundries in Maiduguri to cast aluminium alloys and other low melting point metals like brass and bronzes. These figures point to the fact that while their use in casting aluminium alloys is appropriate, however, they are not suitable for casting higher temperature metals like iron and steel (Ademoh, 2008).

Table 1: Analysis of Chemical Compositions of Natural Moulding Sand in Maiduguri

Constituents	Dala- Lawanti	Gwange/Fori	Gamboru	Pompomari	University
SiO_2	90.10	66.77	77.63	80.76	76.86
Al_2O3	1.40	20.72	3.97	2.98	12.20
Fe_2O3	4.78	0.76	1.69	5.67	1.06
TiO_2	0.21	1.21	3.10	0.75	0.52
CaO	0.30	2.07	2.37	1.89	1.61
MgO	1.20	2.01	2.11	3.23	3.20
K_2O	0.48	3.87	2.31	0.56	2.50
NaO_2	0.41	2.16	5.40	2.76	1.70

Other constituents of the samples included small amounts of iron oxide, alumina, lime, soda, magnesia, manganese oxide also present as impurities. The values of the specimens' chemical constituents are in line with the recommended mould sand chemical compositions in literature (Ademulegun, 2008). 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 (Sinha and Goel, 1991). From the chemical composition determined it can be concluded that all the deposits are safe for use in sand casting, however, the deposits with silica content below 80 % should be limited to nonferrous alloys. The deposits affected are; Gwange/Fori, University and Gamboru while Dala Lawanti and Pompomari can be used to produce ferrous castings.

3.2 Physico-mechanical Properties of the Natural Moulding Sand from Deposits in Maiduguri

The results of the physico-mechanical properties of the natural moulding sand determined are presented in Table 2.

Table 2: Physico-mechanical Properties of Natural Moulding Sand from Deposits in Maiduguri

Parameter	Dala Lawanti	Gwange/Fori	Gamboru	Pompomari	University
Colour	Dark Grey	Light brown	Dark Grey	Light brown	Dark brown
*AFS G F N	85.77	95.02	61.69	49.33	72.0
Clay Content (%)	32.6	47.2	37.4	21.8	34.0
Moisture Content (%)	3.11	4.31	4.67	2.74	4.07
Permeability No.	184.0	169.0	172.3	190.7	178.4
*LOI (%)	2.00	2.00	1.50	2.50	2.53
*G CS (kN/m^2)	90.5	76.5	68.2	65,8	61.3
*DCS (kN/m^2)	644	547.8	443.7	412.6	644.2
Refractoriness(^0C)	1500	1400	1500	1500	1500

***Key:** AFS = American Foundrymens Society; GFN = Grain Fineness Number; LOI= Loss on Ignition; GCS= Green Compressive Strength; DCS= Dry Compressive Strength

Each physico-mechanical property evaluated using AFS standardised procedures for the samples collected from the five deposit locations were discussed as follows.

3.2.1 Clay Content

The amount of clay content in the samples collected from the five selected natural sand deposits are presented in Table 2. It varies from the minimum 21.8 % to a maximum of 47.2 % for Pompomari and Gwange/Fori natural sand deposits respectively. From the standard requirement for casting of aluminium alloys, these values are above the recommended standard values of 10-12 % making the natural sands sampled from these deposits unsuitable for ferrous alloy castings (NMDC Data Bank, 2008)). The sand from these deposits can however be used for nonferrous casting with close sand control in order to minimise the production of defective castings. Permeability decreases with increase in clay content; with the potential of castings produced developing gas defects like blow holes.

3.2.2 Grain Fineness Number (GFN)

The AFS grain fineness numbers for the samples from the five selected natural sand deposits are summarised in Tables 2. The minimum GFN was 50 94 AFS for Pompomori and the highest GFN value of 95.2 AFS for Gwange/Fori. By these GFN values it shows that Gwange/Fori deposits consist of finer aggregates sand and Pompomari deposit consist of coarser aggregate sand. The finer the sand, the higher is the compatibility and vice versa (Yekinni and Bello, 2013). Coarse sand has the tendency to produce rough surface finish on castings due to penetration defects while fine sand produce good surface finishes but with the possibility of having lower permeability which can lead to gas defects.

3.2.3 Moisture Content

From Table 2, the moisture content of natural moulding sand varies from 2.74 % to 4.67 %. It should be noted that moisture content is extremely critical and can affect nearly all the physical properties that are measured in a foundry (Strobl, 2000). Knowing the moisture content of the natural sand will help in guiding the amount of water to be added during the mould making processes. If the right moisture content (5 - 7 %) is not achieved it can lead to several defects like scabs and blows holes and it will also affect the strength properties of the moulding sand (NMDC, Jos Data Bank, 2008).

3.2.4 Green and Dry Compressive Strength

The green compressive strength (GCS) determined as shown in Table 2 ranges from 61.3 kN /m^2 to 90.5 kN/m^2 for University of Maiduguri and Dala Lawanti sands respectively. On the other hand, the dry compressive strength (DCS) determined ranges from 412.6 kN/m^2 to 644.2 kN /m^2 for Pompomari and University respectively. Green strength is the strength of sand in the wet state and is required for making possible to prepare and handle the mould. If the metal is poured into a green mould the sand adjacent to the metal dries and in the dry state it should have strength to resist erosion and the pressure of metal. The strength of the sand that has been dried or baked is called dry strength. At the time of pouring the molten metal the mould must be able to withstand flow and pressure of the metal at high temperature otherwise the mould may enlarge, crack, get washed or break. Strength of the moulding sand depends on; grain size and shape, moisture content, density of sand after ramming. The strength of the mould increases with a decrease of grain size and an increase of clay content (above 12 %) and density after ramming. The strength also goes down if moisture content is higher than an optimum value (i.e. 5 - 7 %).

3.2.5 Permeability

The permeability values determined for the five samples shown in Table 2 ranges from 169.0 for Gwange/Fori to 190.7 for Pompomari. The permeability and moisture content (MC) of the natural moulding sand need to be determined because both of them affect the quality of castings produced using the green sand process. In addition, the relationships between the two are such that moulding sand with high moisture content (above 8 %) will have a poor permeability and vice-versa. For these reasons their values need to be determined in order to enable proper control of the moulding sand properties (Ihom and Offiong, 2014). Permeability decreases with increase in clay content; the relationship is inversely proportional, however under the presence of ample moisture this relationship may not be drastic as when the moisture is low (Ihom and Offiong, 2014). The influence of moisture on permeability is such that as moisture is increased permeability also increases until an optimum point or peak is reached, thereafter any increase in moisture results in decrease in permeability, this relationship was confirmed for both round and angular shaped sands (Jain, 2009). Clay content increase brings about decrease in green permeability while moisture content increase, initially leads to increase in green permeability, but further increase however, brings about decrease in green permeability. The implication is that as moisture content increases, the green permeability decreases. While this is the case, in later stages of the relationship it shows a direct relationship until the optimum point is reached (Jain, 2009). Green permeability is controlled by a number of factors which include; sand particle size and shape, water content of the moulding sand mixture and clay content of the moulding mixture (Ihom and Offiong, 2014). Insufficient porosity (poor permeability) of moulding sand leads to casting defects such as holes and pores.

3.2.6 Refractoriness

The refractoriness of the natural sand samples from the five deposits ranges from 1400^oC for Gwange/Fori to 1500^oC for the other four deposits as presented in Table 3.2. Refractoriness is the ability of moulding sand to withstand high temperatures without breaking down or fusing thus facilitating a sound casting. It is a highly important characteristic of moulding sands. Moulding sand with poor refractoriness may burn on to the casting surface and no smooth casting surface can be obtained. The degree of refractoriness depended on the SiO_2 i.e. quartz content, the shape and grain size of the particle. From table, 4.2, it can be notice that even though the silica content for Dala Lawanti, Pompomari, University and Gamboru are different they all turn out to have the same value of refractoriness of 1400^oC . This may be due to the influence of the trace elements of CaO and MgO which have the tendency of reducing the refractoriness (fusion point) of any sand sample drastically (NMDC, Jos Data Bank, 2008).

3.3 As-mined Natural Moulding Sand

Table 3 shows comparisons between physico-mechanical properties determined for samples from the five deposits and recommended/standard values for casting aluminium alloys obtained from available literature.

Table 3: As-mined Sand Properties and Standard/Recommended Properties for Casting Aluminium Alloys

Parameter Name	Deposit Names					Standard/ Recommended Values
	DL*	GF*	GM*	PM*	UM*	
GCS (kN/m^2)	90.5	76.5	68.2	68.8	61.3	50-70 (Dietert, 1966)
DCS (kN/m^2)	644	547.8	443.7	412.6	644.2	200-550 (Dietert, 1966)
Permeability No.	184	169	172.3	190.7	178.4	80-110 (Ihom, 2012; Muhammad *et al.*, 2003)
Refractoriness (^{o}C)	1500	1400	1500	1500	1500	1100-1450 (IS, 1965; R2004) 1050-1150 (Ihom, 2012)
Moisture Content (%)	3.11	4.30	4.67	2.74	4.07	5-7 (NMDC,Jos Data Bank, 2008)
Clay Content (%)	32.6	47.2	37.4	21.8	34.0	10-12 (NMDC,Jos Data Bank, 2008)
GFN AFS	85.77	95.02	61.69	50.94	72.0	50-60 (Clark *et al.*, 1994)
LOI (%)	2.00	2.00	1.50	2.50	2.53	0.5 (NMDC,Jos Data Bank, 2008)

Key: GL= Dala Lawanti, GF= Gwange/Fori, GM= Gamboru, PM= Pompomari and UM= University

From Table 3 it can be seen that green compressive strength and dry compressive strength for all deposit fell within the recommended range of values for casting aluminium alloys as given by Dietert (1966). This means that as far as the strength property requirements of the natural moulding sands from the five deposits are concerned, they are all suitable for casting aluminium alloys. Not only are they suitable for casting aluminium alloys but also other nonferrous alloys like brass and bronze. According to the range given by Dietert (1966), they are also suitable for casting malleable iron, light grey iron and medium grey iron.

The permeability values when compared with the recommended values given by Ihom (2012) and Muhammad *et al.* (2003) are on the high side. This is however not a big threat to the utilisation of the natural moulding sands from the five deposits for use in casting aluminium alloys. There is need however for caution to minimise gas defects especially with the University and Gwange/Fori which has clay contents of 34.0 % and 47.2 % respectively.

Refractoriness of the natural moulding sand from all the deposits are suitable for casting not only aluminium alloys but also other nonferrous alloys like brass, bronze, malleable iron and light grey iron.

Moisture content of all the samples ranges between 2.74 % for Pompomari to 4.67 % for Gamboru. Comparing these values with the range of 5 % to 7 % recommended by NMDC Jos Data Bank (2008), it follows that all the deposits will still require the addition of minimum of 0.33 % to 2.66 % and maximum of 2.33 % to 4.26 % of moisture considering the lower and upper limits of the recommended ranges to make them suitable for aluminium alloy castings. This means that all the deposits are suitable for casting aluminium alloys. The moisture content determines the dampness of the mould specimen (Yekinni *et al.*, 2015).

Going by the clay content of the five deposits which ranges from 21 - 8 wt % to 47.2 wt % , and comparing them with the recommended values of 10 - 12 wt % by NMDC Jos Data Bank (2008), it can be concluded that their use in casting aluminium alloys will have be done with caution. The high wt % of clay content will lower the life expectancy of the sands as well as their reusability and will also have negative impact on the permeability of the sands from the five deposits with the consequences for the formation of gas defects of blow holes and pinholes.

Grain fineness number (GFN) of the as-mined natural moulding sand ranges from 50.94 to 85 77 AFS. When these values are compared with the standard values of 50 - 60 AFS recommended by Clark *et al.* (1994), then it can be concluded that the Gamboru and Pompomari deposits with 61.69 AFS and 50 94 AFS are more suitable for casting aluminium alloys compared to Gwange/Fori, Dala Lawanti and University with values of 90.02, 85.77 and 72.0 AFS respectively. The GFN affects the level of permeability of the sand and coupled with the fact that high wt % CC for all the deposits, means products being produced will have porosity defects.

Loss on ignition (LOI) ranges from 1.50 % for Gamboru to 2.53 % for University. When these values are compared with the values of 0.5 % recommended by NMDC Jos Data Bank (2008) show that values of LOI for all the deposits may be an indication of organic matter in the samples. This can however be corrected by taking samples at a higher depth and protecting the samples from being contaminated.

4. Conclusion

From this study, the following conclusions can be drawn:

1. The chemical compositions shows SiO_2 having dominance in all the samples (90.10 % to 66.77 %) with trace elements of CaO (2.37 % - 0.30 %), Fe_2O_3 (5.67 % - 0.76 %), Al_20_3 (20.72 % - 1.40 %), MgO (3.23 % – 1.20 %) TiO_2 (3.10 % - 0.21 %), K_2O (3.87 % - 0.48 %) and NaO_2 (5.40 -0.41 %), which are within acceptable limits (Brown, 1994). The chemical compositions determined when compared with the standard recommended properties of natural moulding sands showed that not one of the deposits characterised possessed the right properties for sound sand castings. This does not however make them totally unsuitable for nonferrous applications but it implies that their reusability has to be closely monitored to ensure timely reconditioning to guard against the production of defective castings.

2. The results of the physico-mechanical properties revealed the following in respect of the five deposits sampled for the study; clay content for the five deposits ranges from 21.8 % to 47.2 % which is far above the standard range of 10-12 % recommended for natural moulding sands required for

producing good quality aluminium castings (Ihom, 2012). Similarly, the grain fineness number of the 'as mined' natural moulding sands ranges from 49.33 to 95.02 AFS while the recommended range is 50-60 (Clark *et al.,* 1994). Other physico-mechanical properties of natural moulding sands evaluated include moisture content (2.74-4.67 %), green compressive strength (61.3-90.5 kN/m^2), dry compressive strength (412.6-644.2 kN/m^2), permeability No. (169.0-190.7), refractoriness (1400 -1500 ^{o}C) and Loss on ignition (1.50-2.50 %). The results of the physico-mechanical properties overall show that all the natural sand deposits are suitable for casting aluminium alloys and other nonferrous alloys like bronze and brass, however their reusability should be closely monitored because of the high clay content compared to the recommended range of 10-12 %.

Finally, on the basis of the overall properties of the five deposits studied, they have been rated in the following order of preferences; Dala Lawanti, Pompomari, Gwange/Fori, Gamboru and University of Maiduguri respectively.

Acknowledgement

The authors hereby extend their sincere appreciation to the staff of the Sand Testing Laboratory of NMDC Jos who assisted with the generation of these data. We also acknowledge the efforts of Umar Mohammed Faculty of Engineering Teaching Workshop, University of Maiduguri and Ahmed Jiddah and Ahmed G. Hassan, Department of Civil Engineering, Ramat Polytechnic Maiduguri for their roles in performing the sample collection and sieve analysis tests respectively.

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