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EVALUATION OF CHEMICAL AND PHYSICO-MECHANICAL PROPERTIES OF ADO-EKITI NATURAL MOULDING SANDS FOR FOUNDRY APPLICATIONS

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Abstract
Poor casting quality is associated with the use of locally available moulding sands without recourse to their suitability through adequate knowledge of their properties. The properties of some Ado-Ekiti moulding sands were therefore examined with the aim of establishing their suitability or otherwise for foundry applications. Some natural sand samples were obtained from Ureje, Omisanjana, Odo Ayo and Ogbese within Ado-Ekiti metropolis. Their chemical compositions were determined and analyzed using the X-ray fluorescence (XRF) spectrometer technique and atomic absorption spectrophotometer (AAS). The sands' physico-mechanical properties were also examined in line with American Foundry Society (AFS) guidelines. The results of the chemical analysis indicated that the sands contained silica and aluminium oxide as their major constituents with values of 63.83 – 79.23% and 12.20 – 23.76% respectively. The Ureje, Omisanjana, Odo Ayo and Ogbese sands respectively possessed American Foundry-Men's Society Grain Fineness Number (AFS-GFN): 63.27, 61.08, 66.98 and 61.12; clay content: 12, 13, 10 and 6%; moisture content: 12.04, 12.25, 12.23 and 11.92%; permeability 86.2, 87.5, 86.3 and 88.2%; flowability: 67.87, 68.50, 67.40 and 67.25%; green compression strength: 120.9, 63.6, 70.9 and 82.0 kN/m^2; dry compression strength: 203.0, 101.8, 191.0 and 76.4 kN/m^2. Each of the samples has refractoriness above 1200^oC. The sands (except that of Ogbese sand) can be used naturally as core if the core length is short due to rapid decrease in the sands' hot strength from 1100^oC. These properties were found to fall within the required values for casting of most ferrous and non-ferrous metals, except that of Ogbese sand. Comparison of the results obtained from the studied sands' properties with that of AFS mould sand properties for various types of castings revealed that the studied sands have the potential for use in sand casting process for metals like grey steel, light steels, brass, bronze and aluminum. Meanwhile, the properties of Ogbese natural sand can be improved with application of additive like bentonite to enhance its suitability for sand casting application.

Keywords: Ado-Ekiti Natural Moulding Sands, Physico-Mechanical Properties, Moulding, Foundry applications, Refractoriness

1. Introduction

In foundry technology, sand casting is one of the manufacturing processes whereby foundry sand is used to produce a mold in which molten metal is poured to produce a cast. Metal casting process is employed the in manufacturing of metallic engineering wares, tools, devices and equipment such as engine blocks, machine tool bases, cylinder heads, pump housings, and valves. In metal casting, sand casting is the most widely used (Sand Casting, 2017). Sand cast is found suitable in casting of all metals of different sizes, ranging from very small to extremely large sizes (AFS, 2017; Sand Casting, 2017).

The casting quality of moulds and hence the strength of foundry rests fundamentally on the behaviour of sands (Shuaib-Babata and Olumodeji, 2014; Nwajagu, 1994). Sand nowadays is used to cast components that have useful strengths for construction. It is therefore clearly understood that foundry sand occupies a special and non-substitute position in the foundry industry which has to be properly maintained, such properties should be well understood and put into consideration before being used.

The Raw Material Research and Development Council (RMRDC) in 1990 delved into the geological survey of Nigerian resources and found sand to be the major mineral deposits in the country (Raw Material Research and Development Council, RMRDC, 1990). Available sand in Nigeria covered an estimated proven reserve of billions of tones (Abolarin, *et al*. 2006). Out of all mineral resources in Nigeria, only the exploration of petroleum-related resources had received significant attention **(**Abolarin *et al.,* 2006; Isah, 2011; Adeoye, 2014; Ovat and Bisong, 2017). It was discovered that foundry sands were abundantly available and scattered all over the towns and villages in Nigeria which had been in use for past decades for casting of aluminum cooking utensils, decorative ornament and others, but efforts toward delving their properties and their effects sand on the product cast are limited (Shuaib-Babata and Olumodeji, 2014).

Foundry sand is noted to be imported into the country, in spite of the fact that it is locally and abundantly available in the country. Atanda and Ibitoye (2004) revealed that almost all foundry industries in Nigeria using the sand casting technique imported 60% of the sand used. They suggested the need to domesticate the sources of these imported sand through intensive researches. Previous Researchers had discovered through their various studies that most Nigerian Moulding sands, such as Azare foundry sand, Alkaleri, Barkin-ladi, Ilorin, were suitable for foundry applications (Abolarin *et al.*, 2004, Tokan, *et al.*, 2004, Shuaib- Babata and Olumodeji, 2014). It implies that Nigeria is well blessed with sands that can effectively be used for sand casting processes that can improve the economic activities of the country, most especially during the present economic recession which require shifting attention from over dependency on oil and gas as the main economic source. Hence, it is very essential to study the properties of the available moulding sands in Ado-Ekiti to enhance its adequate and effective applications, since much study has not been done on this valuable material.

Better understanding of sand, as the most crucial factor in the practice of foundry, is very essential (Shuaib-Babata and Olumodeji, 2014). This can be achieved through adequate knowledge of its properties. According to Mechanical Engineering (2012), after the moulding sand is prepared, it should be properly tested to ensure that require properties are achieved. Tests are conducted on a sample of the standard sand. Therefore, it is very important to identify or characterise moulding sand through analysis of its chemical composition. Sand testing is significant in the control of the moulding sand properties through the control of its composition; the testing also indicate the moulding sand performance and help the foundry men in controlling the properties of moulding sands (Mechanical Engineering, 2012). Sand control testing include moisture content test, clay content test, grain fitness test, permeability test, strength test, refractoriness test, and mould hardness test

In moulding sand, the basic properties required for effective performance include dry strength, green strength, permeability, refractoriness, flowability, collapsibility, cohesiveness and adhesiveness, among others. These properties are obtained through various experimental testing of the sand. Sand testing is significant since it indicates the moulding sand performance and helps the foundry men in controlling the properties of moulding sands (Mechanical Engineering, 2012). It is thus essential that after the moulding sand has been prepared, it should be properly tested to ensure that the required properties are achieved. This study therefore aimed at examined the characteristics of the Ado Ekiti moulding sands to determine if their desirable characteristics would be suitable and effective for foundry applications, especially in producing casting materials. Through this study, information on physico-chemical properties of available natural sands in Ado-Ekiti will be provided, which in the long run enhances industrialization, job creation and also improve the nation’s economy status through reduction in importation of foundry sand into the country.

American Foundry Society’s mould sand standards for various types of castings collated from technical literature are presented in Table 1. This information will be useful to evaluate the study sands’ properties for different appplications.

Table 1: American Foundry Society's Satisfactory Mould Sand Properties for various types of Castings

Metal	Clay Content (%)	Moisture content (%)	Green Compressive Strength (kN/m^2)	Dry compressive Strength (kN/m^2)	Permeability Number	Flowability (%)
Heavy steel	10-12	4-5	70-85	1000-2000	130-300	-
Light steel	7-12	6-8	70-85	400-1000	125-200	-
Heavy grey steel	10-19	6-8	70-105	50-800	70-120	-
Aluminium	8-10	6.5-8.5	50-70	200-550	10-30	65
Brass and Bronze	10-15	5-7.5	55-85	200-800	15-40	-
Light grey iron	8-13	4-6	50-85	200-550	20-50	-
Malleable iron	8-14	5-7	45-55	210-550	20-60	-
Medium grey iron	11-15	5-8	70-105	350-800	40-50	-

Source: Dieter (1966), Mikhailov (1989) and Burns (1989)

2. Materials and Methods

2.1 Materials

The sand samples for this study were collected at the of depth of 2 meters using simple hand tools like cutlass, spade and hole with the assistance Technicians and a foundry-man at the foundry unit of the Federal Polytechnic, Ado-Ekiti from different four locations within Ado-Ekiti metropolis as mentioned below. Ado-Ekiti is located in Ekiti State, South Western Nigeria; situated in between longitude 5° 11′ and 5° 25′ and latitude 7° 11′ and 7° 37′. The sand samples were:

- Ureje river banks (Sample A)
- Omisanjana river bank (Sample B)
- Odo Ayo river bank (Sample C)
- Ogbese river bank (Sample D)

2.2 Methods

2.2.1 Preparation of Natural Moulding Sands

The sand samples collected from the above named locations were washed and sun-dried for 3 days to free water in the sand, and sieved in order to separate the debris that were collected with them. The dried samples kept in desiccators for further laboratory/experimental analysis.

2.2.2 Determination of Chemical Composition of the Natural Moulding Sands

The chemical constituents of the sand samples were determined using x-ray fluorescence (XRF) spectrometer and atomic absorption spectrophotometer (AAS) in line with AFS recommendations (American Foundry-Men Society Standards, AFS,1982) and in accordance with practices of earlier researchers (Ayoola, *et al.*, 2013; Mshelia, *et al.*, 2016).

2.2.3 Production of Sand Specimens for Laboratory Analyses

Samples were taken from the dried sands obtained from the earlier mentioned four selected sites to prepare specimens for laboratory analysis. The sand samples were sieved through British Standard (BS) sieve to obtain grain size required for the experiment. The sand grains pebbles were broken into pieces using foundry flat edge rammer, the powdered-moulding sand were thoroughly mixed manually in a container with clean water for about 10 minutes to have homogeneous sand water mixture and sieved with 2 mm British standard sieve.

To produce standard test specimens of 50 mm by 85 mm sizes, each of the samples were then moulded in a specimen tube using standard sand rammer.

The specimens were grouped for various foundry tests and the sands' foundry (Physico-Mechanical) properties were obtained in accordance with the American Foundry-Men Society, AFS (1989) guidelines, as successfully done by earlier researchers (Ayoola, *et al.*, 2013; Bala and Khan, 2013; Danko, *et al.*, 2014; Jimoh, *et al*., 2015; Mshelia, *et al.*, 2016) as presented below:

2.2.4 Determination Physico-Mechanical Properties

2.2.4.1 Determination of Grain Fineness

A 5.0kg weight of dried sample from each selected sand sample was taken unto a set of electrical sieve shaker of sieves using British standard sieve numbers 8 - 200 (2.06mm, 1.68 mm, 1.00 mm, 0.70 mm, 0.25 mm, 0.15 mm, 0.10 and 0.90 mm sieves). These sieves were stacked in sequence with the coarsest sieve at top and placed in a sieve shaker. The shaker was allowed to vibrate for 15 minutes. The residues on each sieve were removed and weighed. The sieve sizes were classified according to the mesh numbers as presented in Table 3. The American Foundry-Men's Society Grain Fineness Number (AFS-GFN) for each sample was calculated using Equation 1 (Burns, 1986; Elanchezhian and Vijaya Ramnath, 2006) and presented in Table 3

$$AFS\ Grain\ fineness\ No. = \frac{P}{W_S} \qquad (1)$$

Where: P = Sum of product; W_S = Weight of sample (total sum of the percentage of sand retained on pan and each sieve).

2.2.4.2 Determination of Moisture Content

In accordance with the British standard (BS 1377:1990) procedures as described by Faluyi, *et al*. (2013), Mittal and Shukla (2003) and Head (1992), the sand samples collected from selected locations were placed in an oven and heated to a temperature of 110^0C for an hour to evaporate the moisture present. Each sample was reweighed until constant weight was attained. The percentage of moisture was calculated from the differences in the weights of the original moist and the consequently dried sand samples using Equation 2 credited to Faluyi, *et al*. (2013); Mittal and Shukla (2003); and Head (1992)

$$Moisture\ Content\ percentage = \frac{M_W}{M_D} x\ 100 \qquad (2)$$

Where: M_W = Mass of water removed by drying at 110^{o}C; M_D = Mass of dried soil

2.2.4.3 Determination of Clay Content

From each of the natural moulding sand samples, 5.0 kg weight of sand was separately weighed put into a wash bottle of sand washer. A solution of 475ml distilled water and 25ml of sodium hydroxide was added as shown in Figure 1. The system was agitated for the period of 10 minutes. Some water was added and filled to cover the sand level in the measuring cylinder, stirred and allowed to settle. The liquid content was siphoned and dried the remaining wet sand in the oven at 105^{o}C. This process was repeated thrice and average value was determined for each sample. The value was converted to percentage in line with American Foundry-men Society, AFS (1989)'s recommendation.

Figure 1: Measuring of Clay Content

2.2.4.4 Determination of Flowability

The samples of standard specimens (earlier prepared in section 2.2.1) in the tube were placed in position in rammer machine, which has an indicator (dial gauge) attached to it, to read in percentage flowability. The stem of this indicator rested on top of the plunger of the rammer, which recorded the actual movement of the plunger between one drops (blow) and the other drops (blow). Though, the movement between the fourth and fifth blow gives the value on the scale that corresponds to maximum flowability (Bergaya, *et al*., 2011). The flowability of the molding and core sand were determined by the movement of the rammer plunger between the fourth and fifth drops indicated in percentages by using a rammer of 6.35kg to give the fourth blow on the specimen, which was followed by the fifth blow as shown in Figure 2.

Figure 2: Flowability Test

Figure 3: Permeability testing apparatus (PTA)

2.2.4.5 Determination of Bulk Density

To determine the bulk density of a natural moulding sand sample, cleaned sample of measuring cylinder without lids was weighed and recorded. Each of the soil samples (wet) was placed in the cylinder, weighed and recorded. It was later placed in oven at 105°C and dried for 24 hours till the weight became constant. It was removed from oven, covered with lids and allowed to cool. Lids were removed, weighed and recorded. The volume of each of the soil samples was determined by measuring the volume of the samples with a measuring cylinder and weighed on a balance. The bulk density values for the soil samples were determined using the relationship in Equation 3 (Hassan, 2005)

$$Bulk\ Density = \frac{W_S}{V_S}\ (\text{g/cm}^3) \tag{3}$$

Where: W_S= Weight of sand, V_S = Volume of sand

2.2.4.6 Determination of Sands' Permeability

The permeability number of each of the sand samples was determined by the flow of air under standard pressure through the cylindrical specimen tube containing standard moulded green sand specimens placed in parameter of the permeability equipment (Figure 3). Each period for 2000 cm^3 of air to pass through the specimens was taken to determine permeability of each sand samples using relation in Equation 4 (Mittal and Shukla, 2003; American Foundry-Men Society Standards, AFS, 1989; and Head, 1992).

$$Permeability\ No = \frac{V.h}{p.a.t} \tag{4}$$

Where: V = Volume of air passing through the specimen cm^3, h = Height of the specimen in cm (5.0cm), p = Pressure of air (9.8×10^2 N/m^2), a = Cross-sectional area of specimen in cm^2 of water, t = Time for air to pass in minutes.

2.2.4.7 Determination of Moulding Sands' Shatter Index

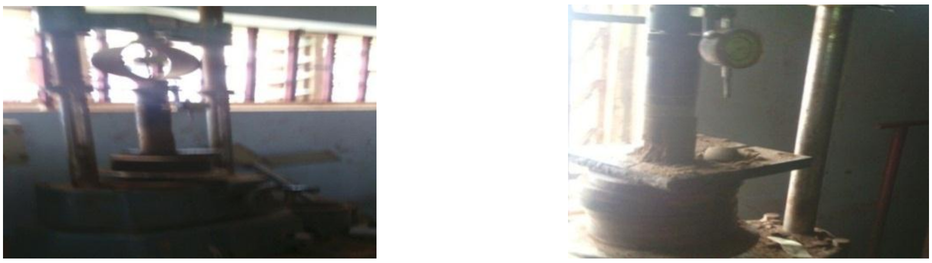
The shatter index values of the green specimens and oven dried specimens were determined using shatter tester by allowing the weigh-green specimens to fall freely from a height of 1.83m unto a steel anvil. The degree of disintegration of each specimen was measured, from which the toughness or plasticity of the sand was determined in line with the BS standard specification (Mittal and Shukla, 2003). The shatter index was determined using Equation 5 as earlier practice (Aradime, *et al*., 2011; Shuaib-Babata and Olumodeji, 2014; Bala and Olabisi, 2017).

$$Shatter\ Index = \frac{M_1 - M_2}{M_1} \qquad (5)$$

Where: M_1 = Initial mass of the sand (g), M_2 = Mass of the sand in the receiver (g)

2.2.4.8 Determination of Compression Strength

This test was performed on the specimen by using Universal Sand Strength Machine also known as California bearing calibration (Model No. 212060257; ELE (Engineering Lab. Equipment Ltd; Volts: 240. Amps: 3, HZ.: 50Ph: 1) shown in Figure 4. This machine consists of a pusher arm and weight arm, both hanging from pivot bearing at the top of machine. The weight arm applied load on the specimen while the pusher arm pushed the specimen against the weight and the compression strength in Newton/mm^2 was deduced using the Equation 6.



(a) (b)

Figure 4: Universal Sand Strength Machine (California bearing calibration) (a) without specimen prior the test (b) with specimen after the test

$$\text{Compression Strength} = \frac{G_L \ x\ F_S}{A} \quad (\text{Newton/mm}^2) \quad (\text{Hassan and Bukar, 2009}) \qquad (6)$$

Where: G_L = Guage Length (mm), F_S = Factor of Safety, A = Specimen surface area (mm^2)

2.2.4.9 Determination of Green Compression Strength

The green standard specimen 50mm by 85mm (AFS) size was fixed on 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 got crushed or squeezed was read as the green compression strength and the corresponding compressive value was recorded.

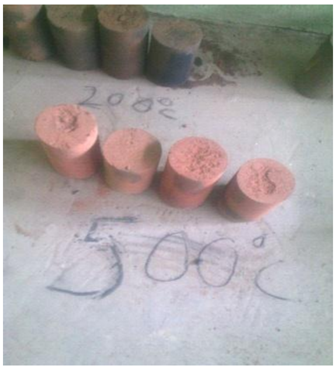
2.2.4.10 Determination of Dry Compression Strength

The AFS standard specimen was placed in the oven and dried for about two hours at 110^{o}C. the specimen was cooled and compressed on universal strength testing machine. A uniformly increasing load was applied on the specimen until the specimen got crushed or squeezed. The point on the scale at which the specimen crushed or squeezed was read as the dry compression strength values in kN/m^2 of the specimens.

2.2.4.11 Determination of Hot Compression Strength

The cylindrical test specimens of 50mm by 85mm were heated in a heating furnace to the temperatures of 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, and 1200°C separately and retained at those temperatures for 2 minutes per specimen to attain homogenous heat transformation. Each hot specimen was positioned and held on the strength holding device one after another. A uniform increasing load was applied on each specimen until the specimen got crushed or squeezed (Head, 1988; Mittal and Shukla, 2003). The points on the scale at which each specimen got crushed or squeezed were read as the compression strength for each sample (Singh, 2006; AFS 1982). Various specimens heated to different temperatures and used in hot compression strength test are shown in Figure 5.

(a) 100°C



(b) 200°C

(c) 300°C


(d) 400°C

(e) 500°C

(f) 600°C

(g) 700°C

(h) 800°C

(i) 900°C

(j) 1000°C

(k) 1100°C

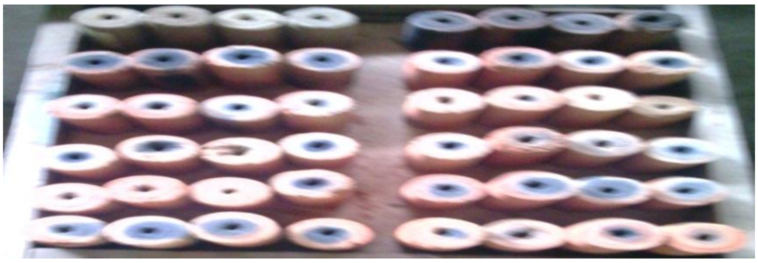
(l) 1200°C

Figure 5: Hot compression strength test specimens heated to different temperature

2.2.4.12 Determination of Refractoriness Value

The cylindrical test specimens (15 in number) were heated in heat treatment furnace one after the other up to the following temperatures 700˚C, 800˚C, 900˚C, 1000˚C, 1100˚C, 1200˚C, 1300˚C and retained at each of the temperature for 2 hours to attain homogenous heat transformation. The specimens were observed for the following signs: cracks, changes in colour, fissures and distortion. The specimens are shown in Figure 6.

A B C D A B C D



Column Profile
A = Ureje
B = Omisanjana
C = Odo Ayo
D = Ogbese

Figure 6: Refractoriness test of natural moulding sand

3. Results and Discussion

3.1 Chemical Composition of Natural Moulding Sands

The results of chemical composition analysis for the selected moulding sands in Ado-Ekiti are as presented in Table 2. This result is important since at the foundry, the chemical composition of the foundry sand relates directly to the metal moulded at the foundry (Akinyele and Oyeyemi, 2014). Since sand testing controls the moulding sand properties through the control of its composition, it is therefore very important to identify or characterise moulding sand through analysis of its chemical composition (Mechanical Engineering, 2012).

Table 2: Chemical Composition of Natural Moulding Sand

Element	Composition by Weight (%)			
	A	B	C	D
SiO_2	78.67	75.22	79.23	63.83
Al_2O_3	12.2	16.03	12.2	23.76
CaO	0.35	3.7	0.35	0.88
MgO	0.4	1.54	0.4	1.03
Na_2O	1.87	1.14	1.8	0.18
Fe_2O_3	1.69	0.64	1.66	2.98
TiO_2	1.76	0.23	1.75	3.62
K_2O	0.17	0.22	0.13	1.26
MnO	1.89	0.15	1.72	0.89
LOI	0.81	0.76	0.75	1.0

The major constituents of the specimens are oxide of silicon (silica) and aluminum with values ranging between 63.83-79.23 % and 12.20 – 23.76 % respectively. Other substances such as oxides of calcium, magnesium, sodium, iron, titanium, potassium, manganese and others were in small proportions. According to American Foundry Society, AFS (2017), "most metal casting sand (foundry sand) is high quality silica sand with uniform physical characteristics". High proportion of silica in the tested moulding sands, except sample D (Ogbese moulding sand) is in line with the AFS standard. Meanwhile, sample D (Ogbese moulding sand) with less value of silica (63.79%) and high value of aluminum oxide (23.76%) can still be used as moulding sand with application of additive such as bentonite.

3.2 Physico-mechanical properties of the natural moulding sands

3.2.1 Sieve Analysis

The results of the sieve analysis of the selected natural moulding sands in Ado-Ekiti are presented in Table 3. Apparently there was variation in the grain sizes of the sands. The distribution of sand affects the quality of castings (Ihom, *et al.*, 2011).

Table 3: Sieve Analysis of Natural Moulding Sand

S/N	Sieve No (BSS)	Sieve Size (mm)	Percentage of weight of sand retainedRETAINED A	B	C	D
1	8	2.06	0.0	0.0	0.0	0.0
2	10	1.68	0.6	0.4	0.4	1.0
3	16	1.00	1.5	1.1	1.2	2.0
4	22	0.70	2.0	5.3	4.7	3.6
5	60	0.25	4.8	3.2	2.0	3.2
6	100	0.15	8.4	5.4	11.4	13.3
7	150	0.10	54.7	56.3	45.3	48.5
8	200	0.09	24.2	27.0	30.1	25.0
9	Pan-clay	≥	3.8	1.3	4.9	3.4
	Total		100	100	100	100

The analysis of the results in Table 3 shows a high concentration of grains retained that ranged between 45.3 to 56.3% with sieves sizes ranging between 0.10mm to 9.5mm (i.e. BS No. 200 – 01). The samples had well defined grading with Sample A (Ureje) had high concentration of fine structure, while sample D (Ogbese) had the least concentration at sieve size of 0.15mm (BS100). A highly concentrated small grain structure enhances fine surface finish casting (Adesina, 2010), while the shape of sand and particle size distribution of the sand allows good permeability and strength in natural sand (Turkeli, 2017; Ihom, *et al.*, 2011).

3.2.2 The AFS - GFN Analysis

The results of AFS-GFN analysis for the various specimens are presented in Table 4. This result is very important in the choice of sand. Ihom, *et al.* (2011), Edoziuno, *et al*. (2017a) and Edoziuno, *et al*., (2017b) are of the views that "average grain size and AFS grain fineness number are useful parameters; choices of sand should be based on particle size distribution", as the size distribution affects the quality and properties of casting produced (Edoziuno, *et al*., 2017a**;** Edoziuno, *et al*., 2017b). The results of the sand samples' AFS –GFN analysis are presented in Table 4.

Table 4: AFS-GFN of Natural moulding sand

SN	Multiplier (Previous B.S. Sieve Nos.	Products (% sand retained X multiplier) A	B	C	D
1	8	-	-	-	-
2	10	0.6	0.4	0.44	1
3	16	10.5	3.3	3.6	6
4	22	14	37.1	32.9	25.2
5	60	67.2	44.8	28	44.8
6	100	210	135	285	332.5
7	150	2844.4	2927.6	2355.6	2522

8	200	2420	2700	3000	2500
9	Clay pan	760	260	992	680
10	Total	6326.7	6108.2	6697.54	6111.5
	$AFSGFN = \frac{product}{100}$	63.27	61.08	66.98	61.12

From Table 4, the grain fineness number (AFS-GFN) for the sand sample A, B, C and D are respectively 63.27, 61.08, 66.98 and 61.62, which are within the standard range values of 35 to 90 fineness number for non-ferrous metal (Shuaib-Babata and Olumodeji, 2014). Tuncer (2017) was also of the opinion that sand with AFN 50 – 60 with average grain size of 220 – 250 microns and fines content (below 20 microns), 2% maximum yields good surface finish at low binder levels; allows low binder level to be used; and allows low binder levels.

Table 5 presents some of the properties of the selected Ado-Ekiti natural moulding sand. These properties include clay content, moisture content, bulk density, green strength, compression strength, permeability, shatter index and flowability. The results in Table 5 were compared with the satisfactory mould sand properties for various types of castings in the Table 1 to evaluate the studied sands' suitability for foundry applications, precisely for sand casting process.

Table 5: Some Properties of Natural Moulding Sand

Sample	Clay content (%)	Bulk density (g/cm^2)	Moisture content (%)	Permeability (%)	Green strength (kN/m^2)	Dry compression strength (kN/m^2)	Green shatter index (g)	Dry shatter index (g)	Refractoriness (°C)	Flowability (%)
Ureje	12	12.04	7.36	86.2	120.9	203.0	0.50	0.22	>1200	67.8
Omisanjanaa	13	12.25	5.75	87.5	63.6	101.8	0.03	0.05	>1200	68.5
Odo Ayo	10	12.23	6.79	86.3	70.9	191.0	0.12	0.30	>1200	67.4
Ogbese	6	11.92	5.52	88.2	82.0	76.4	0.03	0.03	>1200	67.2

3.2.3 Clay Contents

The samples' clay contents ranged between 6 and 13%, with Ogbese moulding sand and Omisanjana moulding sand had the least and highest clay contents respectively. The higher the clay contents, the lower the binder required and vice-visa. Foundry sands with 0.5% maximum (below 200 mesh) clay contents allows low binder level (Tuncer, 2017). The specified clay content for moulding sand is between 10 - 12%; while the American Foundry Men's Association Satisfactory proved values for aluminum, brass and bronze, iron and steel castings is between 12 and 18% clay contents (Burns, 1989). With these values, the natural moulding sand is expected to contain sufficient amount of binder material (ME Mechanical, 2016). The samples' clay contents fall within the required values, except specimen D (Ogbese moulding sand), which requires more binder than other samples.

Comparing the samples' clay contents with that of the required clay content value for casting applications in Table 1, the moulding sands from Odo Ayo and Ureje; Odo Ayo, Ureje and Omisanjana moulding sands, and Odo Ayo are found to be suitable for casting of heavy steel, heavy grey steel, light steel and Aluminum respectively. Ogbese moulding sand with low clay content (6%) meets the 4 – 10% clay contents requirement for casting grey iron, medium and synthetic sand (Burns, 1989). The soil (Ogbese)'s clay content can still be enhanced with addition of synthetic binder like bentonite to be suitable for casting of light and heavy steel, aluminum, brass, and bronze with a little higher clay content value requirements (7- 14%) in moulding sand (Ademoh and Abdullahi, 2009).

3.2.4 Moisture Contents

As presented in Table 5, the percentage of the moisture contents of the specimens fall between 5.52 and 7.36 %. The moisture content value of the studied moulding sand is in descending order of Ureje (7.36%), Odo Ayo (6.79%), Omisanjana (5.75%) and Ogbese (5.52%). The samples' moisture contents are within satisfactory AFS moulding sand moisture content for various types of castings as shown in Table 1.

3.2.5 Flowabilty

The ability of the sand mixture to flow over and fill the sand casting pattern during the impression making phase of the manufacturing process, more flowability is useful for a more detailed casting (Sand Casting, 2017). Flowabilty, being the ability of the moulding sand to get compacted to a uniform density assists moulding sand to flow and park all-around the pattern and take up the required shape (Mechanical Booster, 2017).

The specimens had flowability range between 67.25 to 68.50% as shown in Table 5, but it varies with moisture and clay contents (ME Mechanical, 2016). The AFS satisfactory mould sand percentage flowability for casting aluminium is 67 (Table 1). The high flowability value in the sands is as a result of rounded grains nature of the sand, which enhances the ease compaction of the sand (Casting and Welding, 2017). Flowability increases with decrease in grain size of sand (ME Mechanical, 2016).

3.2.6 Permeability

Permeability is that property of moulding sand which permits the escape of steam and other gases generated in the mould during hot metal pouring. The permeability test results recorded for the tested natural moulding sands ranged between 86.2 and 88.2. The experimental results of the green permeability for the specimens in Table 5 indicates that the sand samples had good natural green permeability for casting a good number of ferrous and non-ferrous metals (Burns, 1989). According to Ihom *et al*. (2011), the recommended green permeability number for green sand is within 80 – 110. This implies that the studied sands' green permeability values are within the stated standard ranges. The samples' permeability numbers also fall within the values in Table 1 for casting of metals, except for heavy and light steel. The high permeability of the sand samples is due the amount of well spread grain distribution and rounded-grains of the sand. The permeability depends on grain size, grain shape, grain distribution, binder and its content, degree of ramming and water content of the moulding sand (ME Mechanical, 2016; Aweda and Jimoh, 2009; Sharma, 2007; Elanchezhian and Vijaya Ramnath, 2006).

The Ureje sand with the highest moisture of 7.36% had the lowest permeability number (86.2), while the Ogbese sand sample with the lowest moisture content had the highest value of permeability number of 88.2. This is in line with the principle that high moisture content (MC) decreases permeability (Mechanical Engineering, 2012).

3.2.7 Shatter Index

The green and dried shatter index of the specimens ranged between 0.51-0.66 and 0.73-0.89 as shown in Table 5. The high shatter index values indicate that the sand in Ado-Ekiti is tough enough to aid satisfactory lift during pattern withdrawal. The content of clay and corresponding moisture content are attributed to this high value (Tokan, *et al.*, 2004).

3.2.8 Bulk Density

The result of bulk density of sand ranged from11.2 to 12.22g/cm^3 which are within the recommended AFS specification (Tokan, *et al.*, 2004). Ihom *et al.* (2011) also gave recommended bulk density for green moulding sand as 1.49 g/cm^3 and above. Similarly, Tuncer (2017) reported that the AASHTO and ASTM standards or design parameter for foundry sand performance is 2.563 g/cm^3 (160 ib/ft^3).

3.2.9 Dry Compression Strength

The Ureje, Omisanjana, Odo-Ayo, and Ogbese sand samples exhibited dry compression strength values of 203 kN/m^2, 101.8 kN/m^2, 191 kN/m^{2}and 76.4 kN/m^2 respectively. The results in Table 5 show that the higher the MC, the higher the dry compression strength. This is in line with the assumption that dry compression strength increases with the MC of sand (Ihom *et al.*, 2011).

3.2.10 Green Compression Strength

The Ureje, Omisanjana, Odo-Ayo, and Ogbese sand samples exhibited green compression strength values of 120.9, 63.6, 70.9 and 82.0 kN/m^2 respectively (Table 5). The recommended green sand's strength ranges between 70 – 100 kN/m^2 (Ihom *et al.*, 2011). This implies that the sand samples possess adequate green strength that will retain its shape and will not distort or collapse even after the pattern has been removed from the moulding box, except Ogbese sand.

3.2.11 Hot Compression Strength of Natural Moulding Sand

In Table 6, various hot compression strengths (HCS) for the sand samples at different temperatures are presented. In foundry usage, crucial properties of mold sands are green compression strength, dry compression strength, wet tensile strength, hot compression strength, flowability and durability (Bergaya, *et al.*, 2006).

Table 6: Hot Compressive Strength of Moulding Sand

S/N	Temp. °C	Compressive strength (kN/m^2)			
		A	B	C	D
1	100	282.8	230.6	304.7	228.7
2	200	413.4	247.6	435.2	368.4
3	300	458.2	239.4	478.7	304.7
4	400	500.5	348.2	522.2	282.9
5	500	522.2	478.7	587.5	287.0
6	600	631.1	544.0	544.0	200.5
7	700	500.5	500.5	522.2	167.5
8	800	435.2	465.9	500.5	153.6
9	900	391.7	282.9	465.9	152.4
10	1000	326.4	217.6	348.1	125.7
11	1100	304.6	174.1	326.4	120.3
12	1200	261.1	130.6	305.6	120.1

Generally, the HCS increased with temperature from 100°C to 600°C in descending order of sample C, A, B, and D. That is, sample C and D exhibited the highest HCS values and the lowest HCS values respectively. While between 700°C to 1200°C, the HCS values decreased, an indication that the sands can be used naturally as core if the core length is short except sample D (Ogbese sand), with low compressive strength values at higher temperature. Through the hot compressive strength results, it is revealed that the various sands can withstand the compressive forces of mostly the non-ferrous metals (metals of low melting temperature) and for ferrous metals except sample D (Ogbese Sand), which can be improved by addition of additive such as bentonite. In casting, sand would reach at a high temperature when the metal in mold is still in liquid state as soon as the moisture is eliminated from it (Bergaya, *et al*., 2011). Hence, hot strength is required to hold the shape of the cavity. In the absence of hot strength, the mold may enlarge, break, erode or crack (Bergaya, *et al*., 2011). This result therefore reveals the strength of the sample sands at various temperatures, especially from 100°C to 1200°C.

3.2.12 *Refractoriness of the Moulding Sands*

Each of the moulding sand samples had refractoriness above 1200°C as presented in Table 5. A relatively low-uniform thermal linear expansion up to 500°C was noted during the experimental processes. At 600°C, there was a sudden change in the colour of the specimens to a very reddish color. This is possibly due to the presence of red oxide, and most of the specimen compressive strengths are in their highest value. This shows that the natural sand in Ado-Ekiti will be suitable for casting of non- ferrous metal of low temperature, as there will be small or no cracks on the mould. To resist high temperature of the molten metal without fuse with metal or breaking down, the molding sand refractoriness must be high (Ibitoye, *et al*., 2014), that is higher than the metal's temperature.

4.0 Conclusion

The following conclusions were drawn from the study:

i. The tested sand samples possessed chemical compositions which are within the AFS acceptable limits for moulding sands. The sand samples exhibited high quality of silica suitable as raw materials for low temperature ferrous and nonferrous metal castings, except that of Ogbese sand sample which has a bit lesser value of silica oxide. This property can be enhanced by application of additive like bentonite to meet the required limit for most metal casting.
ii. The results of physico-mechanical properties of the sand samples revealed that Ureje, Omisanjana and Odo Ayo mould sands were better than that of Ogbese sand.
iii. The physico-mechanical properties of the sand samples also revealed that the sands can be suitably used in casting of metals like grey steel/iron, light steels and aluminum.
iv. The presence of red oxide in the sands and the high values of their compressive strengths their suitability for casting of non- ferrous metal of low temperature.
v. The Ekiti State has potentials of foundry sands and could take this advantage to convert these resources to usable foundry industries.

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