Analysis of Ilorin Sand Moulding Properties for Foundry Applications

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Abstract

The strength of foundry rests on the fundamental behaviour of sand. Foundry industries in Nigeria, especially Ilorin are still in its infancy, despite abudant available of moulding sands. Suitability of Ilorin sand for foundry application was investigated. The research involved analyses of chemical and mechanical moulding properties using standard foundry laboratory test equipment. Samples of Ilorin natural sand were obtained from major six (6) locations. The experimental results obtained when compared to satisfatory foundry standard showed the grain structure, AFS GFN values and other mechanical properties were within accepted moulding sands standards. The corresponding green compressive strength values of Ilorin natural sand ranges between 36KN/m^2 and 60KN/m^2. The the sands permeability and shatter index values range between 47 and 68.3, and 31 and 84 respectively which were found adequate for production of sand castings of non-ferrous and ferrous metals. The results indicate that the natural sands within Ilorin metropolis exhibit appropriate casting properties for non-ferrous and ferous metals, which can facilitate the establishment of small and medium castings industries within the locality in accordance with American-men's Foundry Society (AFN) standards and specifications. This will help to boost both the social and economy status of Ilorin people and address the problem of unemployment in Nigeria in general.

Keywords – Foundry, Casting, Moulding sand, pattern making, Silica, and Core making.

1.0 Introduction

Foundry is the field of engineering that deals with production of castings. It has been found to be an important source of industrial emancipitation and economic self reliance in Nigeria (Ademulegun, 2008). Casting plays important roles in production of modern equipment for transportation, communication, power, agriculture, agro-allied, construction, space, chemical and petrochemical, and other industries. It makes easy to produce devices and equipment that are very difficult in other engineering processes. In castings, products with either regular or irrregular shapes in various sizes and large quantities for making necessities and comforts of life can be easily and cheaply made to close tolerance with little metal waste.

Nigerian foundry industries could still be said to be in its infancy after fourty four years of independence (Atanda and Ibitoye, 2004). Atanda and Ibitoye (2004) in their study revealed that almost all foundries in Nigeria embark on sand casting technique with 60 percent of the needed raw materials are imported. The study suggested the need to domesticate a number of imported materials through intensive research and development efforts.

Sand is the most crucial factor in the practice of foundry. It is very essential to have better understanding of this material through the knowledge of its properties. This wiil greatly assist to determine the sand suitability for foundry use. The strength of foundry rests on the fundamental behaviour of sand, which is basically use in pattern making and moulding or core making, as principal raw material or tool during casting process. The quality of casting produced depends largely on the pattern and core boxes, its materials, design and construction (Ukachi, 2011). Mould and core moulding sand must be readily mouldable and produce defect free castings. This can only be achieved, if the properties and behaviours of the sand are known. The properties of good moulding sand include permeability, cohesiveness (i.e. grain size and shape, moisture content, bonding material, among others), plasticity, refractoriness and chemical resistivity (Ademulegun, 2008). The properties vary in sands and some sands tend to be defective in these properties (Adesina, 2005).

Considerable economies in the cost of raw material for foundry moulds and cores for casting can be achieved by fully exploiting those sources of sand nearer to the foundry than better known and more publicised types of sand (Ukachi, 2006). Though, good quality sand is essential for foundry work regardless of initial cost.

The sand properties are not only determined by chemical composition, but also amount of clay, moisture content and by the shape and size of silica grains in the sand (Jain, 1981). To ascertain if sand in certain location is suitable for foundry uses, periodic sand tests are required (Ukachi, 2011). These tests include grain shape and grain size distribution test (sieve analysis) or grain fineness test, permeability test, strength test, moisture contents test and hardness test. The information from these tests is compared to the standard values to determine the sand suitability for foundry applications. Guma (1998) affirmed that other properties of sand depend greatly to an extent on these sand properties.

Alabi and Abdulkareem (2011) revealed that aluminum pots production is a common practice trade in Ilorin, most especially in KanKatu Area. This trade contributes immensely to the ecomomic development of the town. The technique use in the production of different variety of aluminum pots is based on the use of locally available moulding sand in different patterns.

This paper tends to provide necessary foundry information about Ilorin sands to reduce the habit of incorrect sand selection of foundry sand that greatly contributes to various casting defects. The information from this paper will also assist to optimize the utilization of Ilorin sand, and avoid material and financial wastages as result of casting defects in production of intricate parts and other products of engineering through foundry practice.

2.0 EXPERIMENTAL METHODS:

2.1 Materials

The sand samples for the experimental work were collected from different major locations in Ilorin metropolis in Nigeria namely:

Sand A - Ita-Amo, Fomo Area
Sand B - Okelele, Dada Area
Sand C - Ogidi, Oloje Area
Sand D - Asa Dam
Sand E - Airport Area
Sand F - Garage Offa Area

2.2 Methods

2.3 Determination of chemical composition

The samples of Ilorin sand were tested in the laboratory to determine their chemical constitutents using x-ray fluorescence (XRF) spectrometer and atomic absorption spectrophotometer (AAS).

2.3.1 Specimen preparation

Sands as obtained from various selected sites were washed and dried in oven at 110^{o}C to remove free water.

Specimens were prepared from the samples of the Ilorin sand obtained from different locations as stated above. A quantity of the sand was sieved through 2mm BS sieve to obtain grain size required for the experiment. The sand grains were throughly mixed with clean water in laboratory sand mixer for about 10 minutes to have homogeneous sand-water mixture. The samples were then moulded to produce standard test specimens of 5.0cm by 5.0cm using standard sand rammer that delivered a compaction blow of 6.4kg thrice from a height of 5.0cm. The specimens were classified for various foundry tests. The specimens were kept in dessicator for further expermental analysis.

The sands foundry properties were obtained as presented below in accordance with the American Foundry-Men Society standards, AFS (1989) guidelines

2.3.2 Grain size distribution test

5.0kg weight of naturally dried sample from each selected sand sample was taking unto a set of electrical sieve shaker of sieves with different sizes. 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 and presented in table 4.

$$AFN\ Grain\ fineness\ No. = \frac{Total\ \ Product}{Total\ \ \%\,retained\ \ by\ different\ \ sieves} \ldots \text{eqn 1.}$$

$$= \frac{Total\ Product}{\%\ sand\ substance}$$

2.3.3 Moisture Content

The moisture contents of the test specimens were determined using a speedy moisture teller. The instanteneous moisture content values in percentage were recorded from the instrument range.

2.3.4 Clay Content

5.0kg weight of sand from each sample was separately weighed put into wash bottle of sand washer. 475ml distilled water with 25ml of sodium hydroxide were added. The system was agitated for the period of 10 minutes. Water was added and filled to measure level, 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 AFS (1989) recommendation and presented in table 5.

2.3.5 Permeability Test

Standard air pressure of 9.8 x 10^2 N/m^2 was passed through the cylindrical specimen tube containing standard moulded green sand specimen placed in parameter of the permeability equipment. Each period for 2000cm^3 of air to pass through the specimens was taken to determine permeability of each sand samples using relation 2 below.

$$Permeability\ No = \frac{V.h}{p.a.t} \dots \text{eqn 2}$$

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 x 10^2 N/m^2)

A = Cross-sectional area of specimen in cm^2
(i.e. 20.26 cm^2 adopted standard value)

t = Time for air to pass in minutes

2.3.6 Green and Dry Strength Test

The green strength was determined through application of steadily increasing compressive force on the specimens until the failure occurred on compressive strength machine. The strength values in KN/m^2 were instantenously recorded. The specimens for dry compressive strength test were dried at 110^{o}C for about 2 hours and cooled at room temperature.

2.3.7 Shatter Index Test

The index value of the specimen was determined by allowng the specimen to fall freely from a height of 1.83 meters unto a steel anvil. The degree of disintegration of each specimen was measured, from which the toughness or plasticity of the sand was determined.

2.3.8 Green hardness test

The green hardness value of the individual specimens was measured with a hardness tester by bringing into contact the unloaded plunger of the tester with the specimen surface. The load was firmly applied to the plunger. The depth of the penetration was taken directly as indicated by hardness tester.

3.0 RESULTS AND DISCUSSION

3.1 Results of the Analysis

3.1.1 Results of Samples Chemical Composition

The results of chemical composition analysis for the selected Ilorin moulding sands are shown in table 1.

Table 1: Chemical constituents of selected Ilorin moulding sands

Elements	Composition by weigth (%)					
	A	B	C	D	E	F
SiO_2	75.20	89.30	92.11	95.13	78.70	68.83
Al_2O_3	16.50	3.63	3.24	2.16	12.2	23.76
CaO	3.71	1.25	0.33	0.23	0.31	0.43
MgO	1.54	0.89	0.61	0.29	0.42	1.04
Na_2O	1.12	0.41	1.41	0.37	1.87	0.18
Fe_2O_3	0.63	1.02	0.31	0.67	1.63	1.98
TiO_2	0.21	0.31	0.11	0.47	1.74	0.61
K_2O	0.21	0.47	0.31	0.28	0.19	1.26
MnO	0.13	1.12	0.37	0.05	1.89	0.88
LOI	0.77	1.29	1.12	0.35	0.81	1.01

3.2 Results of Sieve Analysis of the Moulding Sands

Some of the satisfactory mould sand properties for various types of castings as presented in literatures (Dietert, 1966; Mikhailov, 1989; Ademoh & Abdullahi, 2009) are showed in table 2.

Table 2: 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 No
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	4.5 – 5.5	50 – 70	200 – 550	10-30
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	40-80

Source: Dietert (1966), Mikhailov (1989), Ademoh & Abdullahi (2009).

The results of sieve analysis of the samples tested for the grain distribution of sands are presented in table 3.

Table 3: Sieve analysis of the specimens

S/N	Sieve Nos (B.S.)	Sieve Size (mm)	Percentage of sand retained (%)					
			A	B	C	D	E	F
1	8	2.000	0.0	0.0	0.0	0.0	0.0	0
2	10	1.700	0.1	0.0	0.0	2.6	0.4	0.2
3	16	1.000	0.5	0.1	21.0	6.1	1.1	0.7
4	22	0.710	0.8	22.3	17.1	11.0	4.5	1.3
5	60	0.355	26.0	59.5	19.8	19.0	10.3	2.0
6	100	0.250	25.2	11.6	26.4	25.7	15.7	7.3
7	150	0.150	23.4	2.3	6.1	27.6	20.6	9.9
8	200	0.106	9.7	1.7	3.5	3.6	13.0	12.6
9	300	0.075	7.5	0.4	2.1	1.1	21.0	25.7
10	350	0.053	4.2	0.3	1.5	0.3	7.8	33.1
11		Pan / clay	2.6	1.8	2.5	3.2	5.7	7.2
		Total	100	100	100	100	100	100

3.2.1 The analysis of the specimens GFN

The result of AFS GFN analysis for the various specimens is presented in table 4.

Table 4: Determination of the sand samples AFN Grain fines number (GFN)

S/N	Multiplier (Previous B.S.Sieve Nos)	Products (% sand retained x multiplier)					
		A	B	C	D	E	F
1	-	-	-	-	-	-	-
2	8	0.8	0.0	0.0	20.8	3.2	16.0
3	10	5.0	1.0	210.0	61.0	11.0	7.0
4	16	12.8	356.8	273.6	176.0	72.0	20.8
5	22	572.0	1309.0	435.6	418.0	226.6	44.0
6	60	1512.0	696.0	1584.0	1542.0	942.0	438.0
7	100	2340.0	230.0	610.	27000.0	2060.0	990.0
8	150	1455.0	255.0	525.0	540.0	1950.0	1890.0
9	200	1500.0	80.0	420.0	2200.0	4200.0	5140.0
10	300	1260.0	90.0	450.0	30.0	2340.0	9930.0
11	350	910.0	630.0	875.0	1120.0	1995.0	2520.0
	Total	9567	3647.8	53832	8791.8	13799.8	20,995.8
	AFS GFN	96	37	54	88	138	21

3.3 Results of mechanical properties of the natural moulding sand

The results of the mechanical properties of various sand samples tested for compressive strength, moisture contents, permeability, shatter index, etc are presented in table 5.

Table 5: Mechanical Properties of the Natural Foundry (Moulding) Sand

Samples / Properties	A	B	C	D	E	F
Moisture content (%)	5.6	5.8	5.6	5.3	5.1	4.8
Clay content (%)	9.0	10.9	10.2	8.9	8.2	7.3
Green Compressive strength (KN/m^2)	52	50	60	53	35	55
Dry compressive strength (KN/m^2)	350	298	206	290	197	171
Green permeability (NO)	57.1	68.3	54.3	51.2	49.0	47.0
Green	65	63	57	62	17	20

hardness (NO)						
Shatter Index (%)	42	84	39	38	37	31

4.0 Discussion of Result

4.1 Chemical constituents

In table 1, the elemental chemical compositions of the specimens are shown. The major constituents of specimens are silica and aluminium with values ranging between 63.83 - 95.13% and 2. 16 - 23.76% respectively. Other substances such as oxides of iron, sodium, titanium, and calcium among others are in small proportions. The values of the specimens' chemical constituents are in line with the recommended mould sand chemical compositions in literature (Ademulegun, 2008), except sample F with less value of 68.83% silicate. The sand can still be used as moulding with application of additive, such bentonite

4.2 Sand AFN and sand distribution

Tables 3 and 4 present analysis of grain size distribution and AFN grain fines number determination respectively. The characteristics shape of the sand grain is an important factor in sand (Ukachi, 2002). The grain size distribution affects many of the sand properties (Richard et al., 2003; AFS, 1966). The grain analysis in table 3 shows high concentrated grain retained of 74% and above ranging between 0.150mm and 0.710mm by sieve sizes (i.e. BS No. 22 – 150). The samples had well defined grading. Sample E has less concentrated structure. Highly concentrated small grain structure enhances fine surface finish casting (Adesina, 2010; Mikhailov, 1989).

Grain foundry number is a rapid method to express average grain sizes of a particular foundry sand (Adesina and Adegbite, 2013). The fineness of foundry sand is determined by its size and distribution. The sand particles can be broadly grouped as sand grains (large particles) and foundry sand clay. Fineness has an important bearing on the physical properties of sand grains and clay in foundry sand. Determination of fineness of foundry sand is therefore essential to serve as a guide in determining the amount of quantity of bonding material required to produce a desirable properties in a new foundry sand. It is also significant to control the proportion of clay bonding material and the proper distribution of grain sizes in foundry sand.

The grain fineness number for the specimens A, B, C, D and F are 96, 37, 54 88, 138 and 21 respectively. The GFN for samples B, C, D and F fall within the standard value of 35 -90. The sand from these locations may therefore be suitable for both medium and heavy steel casting, and dry sand castings (John, 2000). Finenesss of a sand is significant to determine its suitability. The higher the fineness of a sand ensures greater suitability of such sand for foundry use (Richard et al., 2003).

4.3 Clay content

The clay content value of specimen A, B, C, D, C, E and F as showed in table 5 is 9%, 10.9%, 10.2%, 8.9%, 8.2% and 7.3% respectively. The specimens' clay contents fall within acceptable range as moulding sand for most castings, except for specimen F. The sand (Specimen F) clay content can be modified with addition of additive (binder) to meet the clay content requirement for metal casting. Though, may not be suitable in casting of light steel.

Specimens B and C with the clay contents value of 10.9% and 10.2% respectively meet the required value stated in table 2 and may be used as mould casting for all categories of metal. The clay in specimens D and F need to be increased with addition of other binders (bentonite) when being applied for medium grey iron, heavy steel and grey iron castings.

4.4 Moisture content

Moisture content is an important parameter that needs to be considered to determine the suitability of any moulding sand for casting. It ensures ease of moulding, good quality mould and casting.

The specimens' percentage (%) moisture contents are within 4.8% and 5.8% as presented in table 5, which fall within the satisfactory sand property range (5 – 7.5) for various types of castings, except in the cases of light steel and heavy grey iron, which require 4 – 5 and 6 – 8 moisture content respectively.

4.5 Green permeability

Permeability number of a moulding sand depends on degree of fineness of the sand, as well as its moisture content (Ademulegun, 2008). Inadequate sand permeability usually results to explosions and other detrimental casting defects.

The experimental results of the green permeability for the specimens in table 5 indicate that the sand samples had good natural green permeability for casting a good number of ferrous and non-ferrous metals. The sands green permeability values are within the stated standard range in table 2 for major ferrous and ferrous metals.

4.6 Green and Dry compressive strengths

The results analysis in table 5 compared with the literature values in table 2 shows that the green compressive strength values for all the specimens are within the acceptable standard range for most ferrous and non-ferrous metals, and therefore meet the need for their casting applications. The casting from these moulding sands are likely to be of fine surface finish with little or no defect if properly handled and other necessary factors are considered.

The sand samples A, B, C, D and F from various locations in Ilorin metropolis in dry condition can withstand the pressure intensity up to 350KN/m^2, 298KN/m^2, 206KN/m^2, 290KN/m^2, 197KN/m^2, and 171 KN/m^2 respectively during the period of solidification in the mould. It is an indication that the moulding sands may be suitable for large variety of castings.

4.7 Shatter Index

Water in the sand activates the clay which makes it to be more toughed to resist shattered. Low value of shatter index leads to friability in mould withdrawal. Too high values of shatter index are also unsatisfactory moulding quantities from excessive clay or water content in sand, which is not suitable for foundry use.

From the results in table 5, the values of the shatter index increases with the value of moisture content. It is also observed from the result that the need for the addition of binding materials, such as gum Arabic as recommended by Ademoh and Abdullahi (2013) is not required in the use of Illorin natural moulding sand for non-ferrous castings.

5.0 Conclusion

In conclusion, the experimental analysis shows that the chemical and mechanical properties of Ilorin moulding sand from major locations within the metropolis agree with the satisfactory mould sand properties for various types of Castings, most especially non-ferrous and ferrous metals. This makes the natural sands in Ilorin suitable and appropriate for sand casting of non-ferrous and ferrous metals. This will greatly enhance possibility of creating both small and medium iron castings firms and industries within the locality to address the problem of unemployment being faced in Nigeria.

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