Suitability of some Selected Ado-Ekiti (Nigeria) Natural Moulding Sands' Properties for Sand Casting

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***Abstract*:** In achieving accelerated and sustaining economic growth and development in Nigeria, there is need for domestication of finished goods production through sustainable industrialization. Foundry technology is one of the vital bases for rapid industrial development of any nation. Samples of moulding sand at green state were collected from four different moulding sand deposits within Ado-Ekiti in Nigeria. The samples were prepared using ASTM and British standards, while the materials' Physico-mechanical properties were evaluated using American Foundry Society (AFS) guidelines. The results obtained from the tests were compared with the AFS's satisfactory mould sand properties for various types of metal castings.

The sand samples were found to meet the requirements for casting various metals of different types like Aluminum, brass and bronze, light and malleable iron, light and medium grey iron, except heavy steel. The presence of red oxide in the sands and the specimens' higher compressive strength values show that the natural sands will be suitable for casting of non- ferrous metal of low temperature. Effective application of the sample sands in casting will also enhance industrialization, job creation and the nation self-reliance through reduction in importation of foundry sand and foundry products into the country.

Keywords: Casting, Moulding, Industrialization, Importation, goods and Mineral-resources

1.0 Introduction

Nigeria over dependence on importation of goods (such as ceramic wares, automobile parts, building materials, laboratory equipment, among others) to meet its citizenry needs has negatively affected the nation's economy [1, 2]. Different varieties of imported goods (durable and non-durable; new or fairly used) filled Nigeria markets, which makes locally produced goods to be seeing as inferior goods [2]. Economy situation of the country has resulted to high rate of unemployment, hardship and poverty [3]. Nigeria's economy has been in recession for good five quarters with the negative growth recorded as revealed recently by the National Bureau of Statistics (NBS) [4].Several researchers attributed the cause of this significant nation's problem to include over dependence on oil and gas sector, heavy importation of goods to meet its citizenry needs, and negligence on other economic sectors, like inadequate exploitation of available mineral resources, and poor industrialization [1,5,6,7,8].

Industrialization is significant to reduce over dependence of a nation on foreign goods and enhance export base [9]. According to Seipati and Itumeleng, "if production is subject to increasing returns, export growth becomes a continual source of productivity growth" [10]. Exportation of locally produced goods to other countries makes a nation not to be commodity dependent economy. This will enable the nation to participate actively in international trade. Nigeria's participation in international trade has yielded tremendous contribution in productivity of domestic industries and advancement of the nation's technology [10, 11, 12]. Seipati and Itumeleng assume that "if a poor and smaller country can trade, there is some prospect of industrialization and of dispensing with traditional methods of production" [10].

To achieving accelerated and sustaining long economic growth and development in Nigeria, there is need for domestication of finished goods productions through industrialization at high rates, which will boost the nation's exportation. Osondu's opinion is that "there is no other route to achieving a national sustainable economic growth other than to find the appropriate ways to diversify the export base" [13]. This can be easily achieved through Industrialization with proper usage of available mineral resources like natural moulding sands, which Nigeria is greatly blessed with. Studies have shown that Nigeria is well blessed with variety of natural resources like moulding sands, clay, gold, bronze, agricultural products, among others,

which are not adequately utilized [14,15,16,17,18.19].

Enhancing industrialization in the country provides avenue for exporting all exportable products, which is perceived by Osondu [13] as the only way to improve the government revenue, provide export markets for locally produced commodities, products specialization and job creation from export and services in industrial sector. Industrialization greatly depends on production capacity from availability of locally available raw materials used in development of technology in the transformation of the raw materials to finished products [1]. The bases for the development of an industrial sector include access to raw materials, labour force, funds and technology [20]. Availability of raw materials and labour force are not serious problems in Nigeria.

Foundry technology is one of the vital tools for rapid industrial development of any nation [15]. Sand cast is found suitable in casting (foundry technology) of all metals of different sizes, ranging from very small to extremely large sizes [21, 22]. Effective *a*pplications of naturally available sand in Nigeria in foundry technology (casting) will help in development of Small and Medium Scale Enterprises (SME). This serves as a good way to solve problem of unemployment, since it has been long believed to be catalysts for economic growth and national development both in developed and developing countries

[23]. According to Safiriyu [24], "Small and medium scale enterprises are strategic to attainment of economic prosperity objective of any government". Adequate utilization of moulding sand as a material foundry processing will help towards enhancement of Nigeria's industrialization. Thus, different locally needed goods and equipment in the country can be robustly produced through indigenous small and medium scale enterprises.

Efficient and economic production of quality sand castings in the modern foundry requires a thorough knowledge of foundry sand technology [25], which can be achieved through testing and analysis of sand properties. This study aims at evaluation of some selected Ado-Ekiti natural moulding sands to desire their suitability for casting applications, by comparing their properties with acceptable materials' standards. Information from this study will at long run assist in boosting the nation's industrialization, positively address problem of unemployment and aid the nation's self-reliance through reduction in importation of foundry sand into the country.

Towards appropriate characterization of the study sands, some of the American Foundry Society's satisfactory mould sand properties for various types of castings were collated from technical literatures is presented in Table 1.

Table 1: American Foundry Society's Satisfactory Mould Sand Properties for various types of Castings [26,27]

Metal	Clay Content (%)	Moisture content (%)	Green Compressive Strength	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	-

2.0 Materials and Methods
2.1 Materials
The sand samples for this study were collected from four different river banks within Ado-Ekiti metropolis, Ekiti State of Nigeria; situated in between longitude 5^0 11' and 5^0 25' and latitude 7^0 11' and 7^0 37'. The river are designated as Sample A (*Omi Amun* – Yidi, Poly Road river banks), Sample B (*Elemi* – Housing Road river bank), Sample C (*Omi Ofin*- Iworoko Road river bank) and Sample D (*Awedele* – Textile Road river bank).

2.2 Methods
2.2.1 Preparation of natural moulding sand
The green sand samples from the above named locations were prepared in accordance with ASTM and British Standard (BS) Standards [28,29] as discussed in details elsewhere [9]. The samples were then kept in desiccators for further laboratory/experimental analysis,

2.2.3 Production of sand specimens for laboratory analyses
The sand samples for preparation of specimens were prepared and classified for various foundry tests in accordance with the American Foundry-Men Society Standards guidelines [30] as earlier discussed [9,22] to obtain the sands' foundry properties presented in the results of this study. Some of the specimens produced from the selected natural moulding sands are shown in Figure 1.
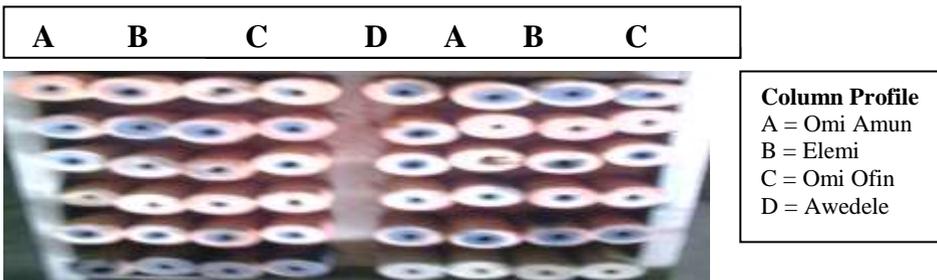

A	B	C	D	A	B	C

Column Profile
A = Omi Amun
B = Elemi
C = Omi Ofin
D = Awedele

Figure 1: Specimens from the samples of the natural moulding sand

2.2.4 Determination of chemical and physico-mechanical properties of the natural moulding sands

The chemical constituents of the samples of the sand samples were determined using both x-ray fluorescence (XRF) spectrometer and atomic absorption spectrophotometer (AAS). The Physico-mechanical properties of the moulding sands (such as moisture content, clay content, flowability, bulk density, permeability, shatter index, compression strength, green compression strength of natural moulding sand, dry compression strength, hot compression strength, refractoriness value of moulding sand) were also examined in line with AFS recommendations [30] and the details of the procedures have been adequately discussed elsewhere [9].

4.0 Results and Discussion

Table 2 shows the results of the chemical composition analysis for the selected moulding sands in Ado-Ekiti. The chemical composition of the foundry sand is significant as it relates directly to the metal moulded [31].

Table 2: Chemical Composition of Natural Moulding Sand

Sample	Elemental Composition by Weight (%)									
	SiO_2	Al_2O_3	CaO	MgO	Na_2O	Fe_2O_3	TiO_2	K_2O	MnO	LOI
A	68.35	21.69	0.66	1.37	1.51	2.71	1.67	0.31	0.91	1.23
B	80.59	11.03	3.70	1.54	1.14	0.64	0.23	0.22	0.15	0.76
C	79.98	12.20	0.35	0.40	1.80	1.66	1.11	0.13	1.62	0.75
D	80.29	18.17	0.13	0.23	0.17	0.16	0.11	0.09	0.12	0.53

The percentage of the silica in the moulding sands are within 68.35 and 80.59%, with sample A having the least value (68.35%), while sample B recorded the highest value of 80.59%. The results in Table 2 reveal that the sample sands contain high proportion of silica, which fall within the American Foundry Society (AFS) standard. According to AFS, most metal casting sand (foundry sand) is high quality silica with physical characteristics [32].

Table 3 presents the results of the selected natural moulding sands' physico-mechanical properties.

Table 3: Some of the properties of the natural moulding sand

Sample	AFS GFN (%)	Clay content (%)	Bulk density (g/cm^2)	Moisture content (%)	Permeability (L/min)	Green strength (kN/m^2)	Dry compression strength (kN/m^2)	Green shatter index (g)	Dry shatter index (g)	Refractoriness (°C)	Flowability (%)
A	63.37	9	12.13	5.71	87.1	83.4	71.5	0.13	0.13	>1200	67.70
B	58.98	12	11.53	6.97	81.9	87.9	93.2	0.33	0.20	>1200	69.00
C	60.238	12	10.93	6.86	82.6	86.5	91.8	0.41	0.30	>1200	68.73
D	51.00	10	11.45	6.11	83.9	85.7	81.7	0.23	0.23	>1200	67.90

The values of the sand samples' AFS-GFN are within the range of 51.00 and 63.37. These values are within 35 to 90, the standard ranges values of fineness number for non-ferrous metal [33] The sand samples tends to have the ability of 2% maximum yields good surface finish at low binder levels; allow low binder level to be used and allows low binder levels, since sand with AFN 50 – 60 with average grain size of 220 – 250 microns and fines content (below 20 microns) has the abilities [34]. This shows that the sands' grain distributions are appropriate for casting since AFS GFN analysis is a useful parameter with the average grain size of the sand with which its choice should be based on particle size distribution [35].

The level of the clay in the sand samples (9 – 13%) is an indication that the natural molding sand is expected to contain sufficient amount of binder material [36], except sample A with 9% clay contents that may require addition of little quantity of binder. The clay content stipulated for moulding sand is between 10 - 12%, while the satisfactory values of clay contents for aluminum, brass and bronze, iron and steel castings are between 12 and 18% [27]. Samples B, C and D with the clay contents between 10 – 12% (Table 3) satisfy the clay content requirements for various metal castings, such as casting of light and heavy steel, heavy grey steel, aluminum, brass and bronze, light grey iron, malleable iron and medium grey iron (Table 1).

Sample A, B, C and D respectively possess bulk density value of 12.13, 11.53, 10.93 and 11.45 g/cm^3, which fall within the recommended AFS specification [37]. The recommended bulk density for green moulding sand is 1.49 g/cm^3 and above [35].

The percentages of the moisture contents (MC) in the samples as presented in Table 3 are between 5.71 and 6.97%, which are within the satisfactory AFS moulding sand moisture content for various types of castings [33].

Table 3 also shows the permeability values of the sand samples to be between 81.9 and 88.2. An indication that the sand samples possess good natural green permeability for casting a good number of ferrous and non-ferrous metals [27], since their recommended green permeability number for green sand is within 80 – 110. The sand samples green permeability numbers are within the recommended standard ranges. Comparing the samples' permeability numbers with the AFS recommended permeability numbers in Table 1 for casting of various earlier mentioned metals, except heavy and light steel, the values also satisfy the requirements. The sand samples' permeability values reveal the level 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 the [14,36,38]. The water content (moisture) of the moulding sand samples has influence on the sand permeability.

Analysis of the results in Table 3 reveals that the high moisture content decreases permeability of the sand. The sand sample (sample A) with highest permeability number of 87.10 also recorded the lowest moisture content (5.71%), while the sand sample (sample B) with the lowest permeability number of 81.90 equally recorded the lowest moisture content (6.97%). Other samples results follow this trend. The

trend of these results is in accordance with assumption that high moisture content (MC) decreases permeability [39]. The samples' moisture contents (5.71 – 6.97%) are found suitable for casting of metals, except for casting of heavy steel (Table 1).

The green compression strength exhibited by Sample A, B, C and D respectively are 83.4, 87.9, 86.5 and 85.7 kN/m^2. The recommended green sand's strength ranges between 70 and 100 kN/m^2 [35], while AFS recommends 45 – 105 kN/m^2 for casting of various categories of matals (Table 1). Each of 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 at moist condition. The strength helps in making and handling the moulds unless the mould is hardened in contact with pattern surface, it will not be possible to achieve dimensional stability and high accuracy of the required size. Compression strength of natural moulding sand is defined as the ability of the sand casting mixture to hold its geometric shape under the conditions of mechanical stress imposed during the sand casting process as the sand's strength [40]. Therefore, the sands' strengths range between 82.0 and 87.9 kN/m^2.

Also, the values of the dry compression strength exhibited by Sample A, B, C and D respectively are 71.5, 93.2, 91.8 and 81.7 kN/m^2. This result shows that the dry compression strength increases with the moisture content, in line with the assumption that natural dry compression strength increases with the MC of sand [35]. The sand's strength also depends on the clay and water content, type of clay, the clay size

distribution, among other factors [35]. The moulding sand samples' dry compression strength (71.5 - 93.2 kN/m^2) fall within the AFS satisfactory mould sand dry compression strength for casting the various metals, except heavy steel (Table 1).

The experimental results in Table 3 show that the sand sample's strength increases with the moisture content. Moisture content affects the other properties of the mixture such as strength [40]. It was made known that too much moisture can cause steam bubbles to be entrapped in the metal casting. Though, low moisture content in the moulding sand does not develop strength properties [39].

The green and dried shatter index of the specimens ranges between 0.13- 0.41 and 0.13- 0.30 respectively as shown in Table 3. The shatter index values also indicate that the sand samples are tough enough to aid satisfactory lift during pattern withdrawal. The content of clay and corresponding moisture content are attributed to this high value [37].

The refractoriness value of each of the moulding sand sample is above 1200°C (Table 3). A relatively low-uniform thermal linear expansion up to 500°C was observed during the experimental processes. A sudden change in the colour of the specimens to a very reddish colour was also observed at temperature of 600°C. The presence of red oxide in the sands and most of the specimen compressive strengths are in their highest value might be responsible for the sudden change in the colour to reddish. This is an indication that the natural sand in Ado - Ekiti will be suitable for casting of non- ferrous metal of low temperature (like aluminum), as there will be small or no cracks on the mould. The moulding

sand refractoriness must be high to resist high temperature of the molten metal without fuse with metal or breaking down [41].

The specimens' flowability values which are between 67.70 and 67.90% vary in sand with moisture and clay contents [36]. The high flowability value in the sands is as a result of rounded grains nature of the sand. This enhances the ease compaction of the sand [42]. The AFS satisfactory mould sand percentage flowability for casting aluminum is 65 [26, 43, 44, 45]. Flowability increases with decrease in grain size of sand [36].

Conclusion and Recommendation
Conclusion
The following conclusions are drawn from this study:

i. The sand samples are found to comprise chemical compositions which are within the AFS acceptable limits for moulding sands. The sand samples exhibited high quality of silica suitable as raw sand for low temperature ferrous and nonferrous metal castings, except that of Omi Amun moulding 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 studied mould sands' properties are comparable with the standards. Thus, they can be effectively used for adequate casting.

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, except heavy steel.

iv. The presence of red oxide in the sands and most of the specimen compressive strengths are in their highest value show that the natural sand in Ado-Ekiti will be suitable for casting of non- ferrous metal of low temperature.

v. This study has shown that Ekiti State has potentials of foundry sands and has to take the advantage with suitable conversion technologies.

vi. The abundant sand resources available are enough for Ekiti to develop the technology of conversion of these resources to usable foundry industries.

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