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Moulding properties of ikole ekiti silica–clay mixture for foundry application

Borisade Sunday Gbenga[1*], Audu Yemi[1] Adebayo Abdullahi Olawale[1], Madueke Ifeyinwa Chioma[1], Oyelaran Olatunde Ajani[2] and Aina Adegboyega[1]
[1]Department of Materials and Metallurgical Engineering, Faculty of Engineering, Ikole-Ekiti Campus, Federal University Oye-Ekiti, PMB. 373, Ekiti State, Nigeria
[2]Department of Mechanical Engineering, Faculty of Engineering, Ikole-Ekiti Campus, Federal University Oye-Ekiti, PMB. 373, Ekiti State, Nigeria
[*]Corresponding Author's E-mail: sunday.borisade@fuoye.edu.ng

Abstract
This study focuses on the characterisation of Ikole Ekiti sand for foundry application, and the mould properties of the sand such as Clay Content, Shatter Index, Permeability, and Green Strength. Dry Strength and Refractoriness were investigated. The characterization of Ikole Natural Sand and Synthetic Moulding Sand (Ikole Natural Sand and River Sand bonded with clay respectively) were examined in order to determine their suitability for Foundry Mould production. The sand samples were taken from three sites, rinsed, and dried in the sun for three days to remove any water. The sand samples were sieved via a British Standard (BS) sieve to get the desired grain size for the experiment. Powdered moulding sand was then thoroughly mixed by hand for about 10 minutes with clean water to create a homogeneous sand-water combination. Each sample was then moulded in a specimen tube using a standard sand rammer to create standard test specimens measuring 50 mm by 50 mm. With the addition of a binder to the Ikole Natural Sand some of the physical properties were improved. From the results, an addition of 5% Clay, results in the following change in values; Shatter Index (from 3% to 20%), Permeability (from 65 to 60), Green Strength (from 75.15 to 95.14kN/m^2 for compression, and 14.48 to 17.23kN/m^2 for shear) and Dry Strength (399.89 to 482.63kN/m^2 for compression and 103.42 to 127.55kN/m^2 for shear). The synthetic moulding sand has improved foundry moulding properties for foundry application than the other sands in this study.

Keywords: Foundry, Pattern-making, Casting, Moulding Sand, Silica, and Ikole Sand.

1. Introduction

Nigeria's economy has suffered from a heavy reliance on imports. Despite the country's overall richness of natural moulding sand and clay resources (Muhammed *et al.*, 2003), foundry industries have not seen much growth or involvement (Idachaba Aladi *et al.*, 2016). One of the first techniques for shaping metal that humans are aware of is casting, which is the subject of foundries. It is a method of manufacturing where a liquid substance is often put into a hollow or mould that has the required shape, and then allowed to harden. A casting is the term for the solidified component that is released from the mould or cavity to complete the casting process (Kolo *et al.*, 2019). After years of independence, the foundry industry in Nigeria could still be considered to be in its infancy (Shuaib-Babata and Olumodeji, 2014). In their investigation, Atanda and Ibitoye (2004) observed that practically all foundries in Nigeria use the sand casting method and import 60% of their raw materials. The study recommended extensive research and development to domesticate a number of imported materials.

Any country's rapid industrialization depends heavily on foundry technology (Shuaib-Babata and Olumodeji, 2014). Compared to other manufacturing techniques, metal casting has a number of benefits. According to Oke and Omidiji (2016), these include adaptability, weight reduction, size, complexity, and dimensional correctness. Both permanent mould procedures and disposable mould processes can be used to cast objects (Ademoh and Abdullahi, 2009).

However, the most popular technique uses a disposable mold procedure that uses molding sand (Oke and Omidiji, 2016). In Nigeria, industrialisation and economic independence have been proven to be significantly influenced by the foundry (Okundaye, 2015; Ademulegun, 2008). The availability of moulding sands is a significant obstacle to the development of the foundry industry in Ikole, yet there is a lot of opportunity for growth. The natural moulding sands now employed in foundry applications from Ikole deposit areas have not been described. For Ikole to have a successful and productive foundry industry, natural moulding sands must be identified and described.

All across the world, foundry industries use locally accessible resources to cut down on transit costs and manufacturing costs overall. Identification and characterization of regional raw materials are required for foundry applications in Nigeria. Numerous studies on the topic of using domestic sand instead of imported sand for molding purposes have been conducted (Idachaba *et al.*, 2016; Mshelia *et al.*, 2016; Shuaib-Babata *et al.*, 2017). In order to decrease shipping costs and lower overall production costs, foundry companies throughout the world employ locally accessible resources; as a result, this research will contribute to the development of substitute moulding sand for foundry use. Testing and analysis of sand qualities can be used to gain a full understanding of foundry sand technology, which is necessary for the efficient and affordable manufacture of high-quality sand castings in today's foundries (Shuaib-Babata *et al.,* 2017; Oke and Omidiji, 2016). To be suitable for use in foundries, moulding sand needs to possess a number of qualities. These characteristics include control over the preparation of casting finish sand, strength, permeability, refractoriness, thermal stability, flow ability, reusability, collapsibility, and heat conductivity (Ayoola *et al.,* 2010). The purpose of this study is to evaluate certain chosen Ikole-Ekiti natural moulding sand samples to ascertain their appropriateness for foundry applications by comparing their characteristics to those of approved materials.

2.0 Material and methods

2.1 Materials

The sand samples for this study were obtained at a depth of 2 meters using basic hand tools, such as a cutlass, shovel, and hole, with the help of foundry men at a nearby foundry workshop in Ikole, Ekiti, as indicated below. Ikole-Ekiti is situated between longitudes 7° 47' 0" N and 5° 31' 0" E in Ekiti State, South Western Nigeria. Ikole Clay (Sample A), Ikole Natural Sand (Sample B), and Ikole River Sand (Sample C) were the three sand samples.

Figure 2.1: Google Map Showing the Ikole sand Location

2.2 Equipment

The hand rammer, shovel, hoe, weighing scale, sieve shaker, and set of sieves from the foundry shop, department of Materials and Metallurgical Engineering, Federal University Oye, Ekiti, were the tools used for this study. Others include the treatment furnace, tong, universal sand strength machine, standard rammer, permeability meter, shatter index tester, electronic weighing balance, and department of metallurgical and materials engineering at Ahmedu Bello University Zaira's foundry unit. The X-ray fluorescence (XRF) spectrometer is from the Naseni Centre of Excellence in Nanotechnology and Advanced Materials, National Agency for Science and Engineering Infrastructure (NASENI), Akure, Ondo State, and the Atomic Absorption Spectrophotometer (AAS) is from the Soil Science and Land Resources

2.3 Preparation of Natural Moulding Sands and Determination of Chemical Composition of the Natural Moulding Sands

The sand samples were taken from the aforementioned places, rinsed, and allowed to dry in the sun for three days to remove any water. They were then sieved to remove any debris that had also been gathered with them. The dried samples were retained for additional lab/experimental analysis. X-ray fluorescence (XRF) spectrometer Model: EDX3600B and Atomic Absorption Spectrophotometer (AAS) was used to determine the chemical composition of the sand samples in accordance with American Foundry-Men Society Standards (AFS, 1982) and previous research methods (Ayoola *et al.*, 2013; Mshelia *et al.*, 2016).

2.4. Production of Sand Specimens for Laboratory Analyses

To create specimens for laboratory analysis, samples were extracted from the dried sands acquired from the previously mentioned three chosen sites. To get the desired grain size for the experiment, the sand samples were sieved via a British Standard (BS) sieve. Using a foundry flat edge rammer, the sand grains and pebbles were broken into little pieces. Powdered moulding sand was then thoroughly mixed by hand for about 10 minutes with clean water to create a homogeneous sand water combination. Each sample was then molded in a specimen tube using a standard sand rammer to create standard test specimens measuring 50 mm by 50 mm. As successfully completed by earlier researchers (Ayoola, et al., 2013; Bala and Khan, 2013; Danko, et al., 2014; Jimoh, et al., 2015; Mshelia, et al., 2016, Audu et al, 2021), 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) as presented Table 2.1

Table 2.1: Mixture Proportion of the Samples

Samples	Ikole Clay (A) %	Ikole Natural Sand (B) %	Ikole River Sand (C) %	Water %
Synthetic Sand (I)	15	0	80	5
Natural Bonded Sand (II)	0	95	0	5
Ikole Natural Sand + Clay (III)	5	90	0	5

2.5 Determination Physico-Mechanical Properties

2.5.1 Determination of Grain Fineness

The department of Materials and Metallurgical Engineering at the federal university in Oye, Ekiti, used a sieve analyzer, which consists of a sieve stack and a sieve shaker, to determine the sieve analysis (grain size distribution). The top of the sieve stack was filled with the 100g dry sand sample, which was then allowed to vibrate for the predetermined 15 minutes (Sharma, 2005). These sieves were put in a sieve shaker after being arranged in order, with the coarsest sieve at the top. For fifteen minutes, the shaker was allowed to vibrate. Each sieve's leftovers were taken off and weighed. The mesh numbers were used to categorize the sieve sizes. The American Foundry-Men's Society Grain Fineness Number (AFS-GFN) for each sample was calculated using Equation 2.1 (Burns, 1986; Elanchezhian and Vijaya Ramnath, 2006, Audu et al, 2021).

$$AFN\ Grain\ Fineness\ Number\ (GFN) = \frac{p}{WS} \qquad (2.1)$$

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

2.5.2 Determination of Moisture Content

The sand samples were collected from specific locations and heated to a temperature of 110^0C for an hour in an oven in accordance with the British standard (BS 1377:1990) procedures as described by Faluyi, et al. (2013), Mittal and Shukla (2003), and Head (1992). This was done to evaporate any moisture that was present. Up until a constant weight was reached, each sample was reweighed. Equation 2.2, which is credited to Faluyi, *et al.*, (2013), Mittal and Shukla (2003), and Head (1992), was used to compute the percentage of moisture from the variations in the weights of the initial damp and the subsequently dried sand samples.

$$Moisture\ Content\ Percentage\ = \frac{Mw}{Md} \quad (2.2)$$

Where: Mw = Mass of water removed by drying at 110ºC; Md= Mass of dried soil

2.5.3 Determination of Clay Content

A wash bottle of sand washer was filled with 5.0 kg of sand that was separately weighed out of each sample of natural moulding sand. 25ml of sodium hydroxide was dissolved in 475ml of distilled water. For ten minutes, the system was in turmoil. The sand level in the measuring cylinder was covered with water, which was then swirled and given time to settle. The remaining wet sand was dried in the oven at 105°C after the liquid content was drained out. The average value for each sample was calculated after this process was repeated three times. According to the advice of the American Foundry-men Society, AFS (1989), the value was transformed to a percentage.

2.5.4 Determination of Sands' Permeability

The flow of air at a standard pressure through a cylindrical specimen tube containing standard-moulded green sand specimens put within the permeability equipment's parameters was used to calculate each sand sample's permeability number. The permeability of each sand sample was measured using the relation in Equation 2.3 (Mittal and Shukla, 2003; American Foundry-Men Society Standards, AFS, 1989; and Head, 1992) for each period for 2000 cm^3 of air to pass through the specimens.

$$Permeability\ No. = \frac{V.h}{p.a.t} \quad (2.3)$$

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 102 N/m^2), a = Cross-sectional area of specimen in cm^2 of water, t = Time for air to pass in minutes

2.5.5 Determination of Moulding Sands' Shatter Index

By letting the weigh-green specimens fall freely from a height of 1.83m onto a steel anvil, the shatter tester was used to calculate the shatter index values of the green specimens and oven dried specimens. According to the BS standard specification, the hardness or plasticity of the sand was calculated from the degree of disintegration of each specimen (Mittal and Shukla, 2003). In previous studies (Aradime, *et al.*, 2011; Shuaib-Babata and Olumodeji, 2014; Bala and Olabisi, 2017), the shatter index was calculated using Equation 2.4**.**

$$Shatter\ Index\ = \frac{M1 - M2}{M1} \times 100 \quad (2.4)$$

Where: M1 = Initial mass of the sand (g), M2 = Mass of the sand in the receiver (g)

2.5.6 Determination of Green Compression Strength

The compression holding mechanism was used to secure the 50mm x 50mm (diameter) green standard mold specimen to the strength testing equipment. The specimen was subjected to an evenly increasing load until it was crushed or squeezed. The specimen's crushing or squeezing point on the green compression scale was recorded as the green compression strength.

2.5.7 Determination of Green shear strength

With the exception of switching the compression strength holding device for a shear strength holding device, the processes in the green compression strength were followed. The specimen's fracture point on the green shear scale was used as the green shear strength.

2.5.8 Determination of Dry compression strength

The test specimen (Green) was dried in an oven at 110 °C for 10 minutes. It had dimensions of 50 mm in diameter and 50 mm in height. It was allowed for the specimen to cool to room temperature. The specimen was then attached using a compression holding mechanism on the strength testing apparatus. The specimen was subjected to an evenly increasing load until it was crushed or squeezed. The dry compression strength was determined by reading the point on the dry compression scale at which the specimen crumpled or was compressed.

2.5.9 Determination of Dry shear strength

The procedure in the dry compression strength were used except that compression strength holding device was changed to shear strength holding device. The point on the dry shear scale at which fracture occurred on the specimen was read as dry shear strength.

3.0 Result and Discussion

3.1 Result

The results obtained were presented as follow in Table 3.1 – 3.4, and figure;

3.1.1 Sieve Analysis Result

Table 3.1: Sieve Analysis Result for Ikole Natural Sand (Sample B)

S/No.	Aperture (mm)	BSS No	% wt Retained	Product	Cum % O.S.	Cum. % U.S.
1	1.7	10	10.45	104.5	10.45	89.55
2	0.8	18	16.8	302.4	27.25	72.75
3	0.6	25	8.40	210	35.65	64.35
4	0.425	36	13.60	489.6	49.25	50.75
5	0.3	52	16.35	850.2	65.60	34.4
6	0.212	72	11.60	835.2	77.20	22.8
7	0.15	100	9.65	965	86.85	13.15
8	0.106	150	3.85	577.5	90.70	9.3
9	0.075	200	4.80	960	95.50	4.5
10	Pan	300	4.50	1350	100.00	0
			100	6644.4		

$$AFN\ Grain\ Fineness\ Number\ (GFN) = \frac{p}{WS} = \frac{6644.40}{100} = 66.44 \qquad (3.1)$$

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

Table 3.2: Sieve Analysis Result for Ikole River Sand (Sample C)

S/No.	Aperture (mm)	BSS No	% wt Retained	Product	Cum % O.S.	Cum. % U.S.
1	1.7	10	2.4	24	2.4	97.6
2	0.8	18	6.55	117.9	8.95	91.05
3	0.6	25	6.45	161.25	15.4	84.6
4	0.425	36	16.60	597.6	32	68
5	0.3	52	29.20	1518.4	61.2	38.8
6	0.212	72	21.00	1512	82.2	17.8
7	0.15	100	11.15	1115	93.35	6.65
8	0.106	150	2.65	397.5	96	4
9	0.075	200	2.40	480	98.4	1.6
10	Pan	300	1.60	480	100	0
			100	6403.65		

$$AFN\ Grain\ Fineness\ Number\ (GFN) = \frac{p}{WS} = \frac{6403.65}{100} = 64.04(3.2)$$

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

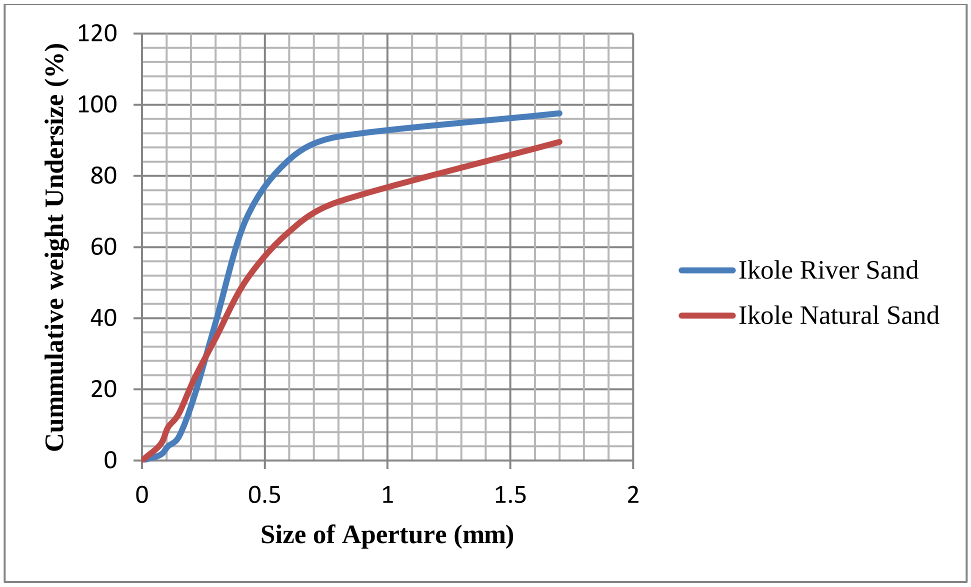

Figure 3.1: The Cumulative Frequency of the Grain Size Distribution for Ikole Natural Sand and River Sand.

3.1.2 Chemical Composition of Natural Moulding Sands

The findings of the chemical composition study for the chosen Ado-Ekiti molding sands are shown in Table 3.3. This finding is crucial because, in the foundry, the chemical makeup of the sand directly affects the metal that is molded there (Akinyele and Oyeyemi, 2014). It is crucial to identify or characterize moulding sand through an investigation of its chemical composition because sand testing regulates the qualities of moulding sand by regulating its composition.

Table 3.3: Chemical Composition

Samples	SiO_2	Al_2O_3	CaO	CoO	CuO	Fe_2O_3	K_2O	MnO	TiO_2	LOI
A	52.88	5.28	0.18	0.53	0.48	37.46	0.51	0.10	2.58	0.36
B	56.41	6.91	0.40	0.58	0.60	31.95	1.84	0.14	1.17	0.45
C	70.59	6.46	0.08	0.23	0.52	19.82	1.74	0.17	0.39	0.38

3.1.3 Physico-mechanical properties

Results of physical and mechanical properties of Ikole Ekiti natural sand is presented in Table 3.4. According to previous research (Ademoh and Abdullahi, 2009; Dietert, 1966), the properties presented in Table 3.5 are most commonly used in industry to determine the foundry suitability of sand and binder in metal casting.

Table 3.4: Physio-Mechanical Analysis Result of the Sand Samples

S/N	Sand Properties	Synthetic Sand (I)	Natural Bonded Sand (II)	Ikole Natural Bonded + Clay (III)
1	Green Compressive Strength (kN/m^2)	51.71	75.15	95.14
2	Green Shear Strength(kN/m^2)	11.72	14.48	17.23
3	Dry Compressive Strength(kN/m^2)	544.68	399.89	482.63
4	Dry Shear Strength(kN/m^2)	158.58	103.42	127.55
5	Permeability(Wmm)	95	65	60
6	Shatter Index	0.47	0.03	0.20

Table 3.5: Sand properties for casting (Ademoh and Abdullahi, 2009; Dietert, 1966)

Metal	Green Compressive Strengths (KN/m^2)	Dry Strengths (KN/m^2)	Permeability No
Heavy Steel	70-85	1000-2000	130-300
Light Steel	70-85	400-1000	125-200
Heavy Grey iron	70-105	350-800	70-120

Aluminum	50-70	200-550	10-30
Brass & Bronze	55-85	200-860	15-40
Light Grey iron	50-85	200-550	20-50
Malleable Iron	45-55	210-550	20-60
Medium Grey Iron	70-105	350-800	40-80

3.2 Discussion

From the result obtained in Table 3.1 and 3.2 Ikole Natural Sand has a grain fineness number (GFN) of 66.44, whereas Ikole River Sand has a GFN of 64.04. The grain fineness number is important for the physical properties of foundry sand. High GFN results lead to reduced porosity due to organic matter, making it unsuitable for foundry applications. Therefore, due to the average GFN of sand, sand samples tend to have a good surface finish with low amounts of binder because the GFN serves as a guide in determining the amount of binder required to produce the desired properties foundry application (Shuaib-Babata et al, 2019; Tuncer, 2017; Burns, 2000). This equally contributed to the lower permeability of the Ikole Natural Sand compared to that of the Ikole River Sand bonded with binder. This is evident from the results in Tables 3.1 and 3.2. The graph of the particle size distribution of the two sand samples is shown in Fig. 3.1.

Based on the findings in Table 4.4, which illustrates how the three sand samples' variations in Shatter Index numbers. The Ikole Natural Sand with added binder has a Shatter Index number of 20%, followed by the synthetic moulding sand with a Shatter Index number of 47%, and the Ikole Natural Sand without binder with a Shatter Index number of 3%. This demonstrates that adding a binder to Ikole Natural Sand makes it acceptable for molding.
The lowest permeability value for Ikole Natural Sand with binder was 60, followed by Ikole Natural Sand without binder at 65, and the maximum permeability value for Ikole Natural Sand with binder at 95. With a Green Compression Strength and Shear Strength of 95.14kN/m^2 and 17.23kN/m^2, respectively, Ikole Natural Sand with Binder has the highest results. The Synthetic Moulding Sand has the greatest value for Dry Strength, with values of 544.68 kN/m^2 for Dry Compression Strength and 158.58 kN/m^2 for Dry Shear Strength. Additionally, the Dry Strength of Ikole Natural Sand with binder is higher than Ikole Natural Sand without binder.

4.0 Conclusion

According to the results of the experiment, Ikole natural sand has a grain fineness number (GFN) of 66.44 AFS, a shatter index value of 3%, a permeability of 65, and compression and shear strengths in both the green and dry states. The green compression strength is 75.15 kN/m^2, the dry compression strength is 399.89 kN/m^2, and the green shear strength is 14.48 kN/m^2. Some of those characteristics changed when Ikole Clay was used as the binder. According to the results, adding 5% more clay changed the following values: permeability decreased from 65 to 60, shatter index increased from 3 to 20%. Green shear and compression strengths range from 14.48 to 17.23 kN/m^2 and 75.15 to 95 kN/m^2, respectively. Dry compression and shear strengths range from 399.89 to 482.63 kN/m^2 and 103.42 to 127.55 kN/m^2, respectively. Table 2.1 shows that Ikole Natural Sand can be utilized. This will significantly increase the likelihood of establishing both small and medium-sized iron castings businesses and industries in the area, which will help to alleviate Nigeria's unemployment issue.

References

Ademoh, N. A. and Abdullah, A. T., 2009. Assessment of Foundry Properties of Steel Casting Sand Moulds Bonded with the Grade 4 Nigeria Acadia Species (Gum Arabic), *International Journal of Physical Sciences*, Vol. 4(4), 238-241.

American Foundry-Men Society Standards, AFS, 1989. *Mould and core testing handbook*, 2nd edition. Foseco Ltd, Permgamon Press, Oxford, England.

Aramide, FO., Aribo, S. and Folorunso, DO. 2011, Optimizing the moulding properties of recycled Ilaro silica sand, *Leonardo Journal of Science*, 19: 93-102.

Atanda and Ibitoye 2004, An Appraisal of Foundry Industries in Nigeria, A Way Forward. Proceeding of the 3rd Nigerian Materials Congress (NIMACON) and Meeting of the Nigerian Materials Research Society (Nigerian-MRS), pp.22-29.

Audu, Y., Borisade, S. G., Yusuf, A. L., & Ajah, O. 2021. Suitability of Okenya Natural Sand for Metal Casting Industry. *Adeleke University Journal of Engineering and Technology*, *4*(1), 33-39.

Ayoola, WA., Adeosun, SO. And Oyetunji, A. 2013. Investigation into foundry properties of Oshogbo and Saki silica sand deposits, *International Journal of Engineering*, XI(3): 213-218

Bala and Khan. 2013, Characterization of beach/river sand for foundry application, *Leonado Journal of Science*, 23(12): 77-83.

Bala, K.C. and Olabisi, BA. 2017. Deterioration of moulding sand properties with number of castings. *Leonardo Electronic Journal of Practices and Technologies*, 30: 209-220.

Burns, T.A. (1986). The Foseco foundryman’s handbook: Facts, figures and formulae, 9th edition, Pergamon Press Plc, Headington Hill Hall, Oxford, England.

Dietert, H.W. 1966. Foundry Core Practice, 3rd edition. American Foundry Men‟s Society, Des Plains, Inc. 2-154.

Elanchezhian, C. and VijayaRamnath, B. 2006. *Manufacturing Technology-I*, 2nd edition, Laxmi Publications (P) Ltd., New Delhi,

Faluyi, O., Adam, O., Akinwamide, A. and Okoroafor, DG. 2013. Geo-technical practical guide for civil engineers, Civil Engineering Department, Federal Polytechnic, Ado-Ekiti, 1-62p.

Fayomi O. S. I, Ajayi O. O. and Popoola A. P. I., 2011, Suitability of local binder compositional variation onsilica sand for foundry core-making, *International Journal of the Physical Sciences* Vol. 6(8), pp. 1940-1946,

Hassan, SB. 2005. *Modern Refractories: Production, Properties, Testing and Applications*, Timo Commercial Printers, Zaria, 1-70p.

Head, KH. 1992. *Manual of Soil Laboratory Testing*, Volume 1: Soil classification and compaction tests, Pentech Press, Plymouth, London.

Idachaba Aladi et al, 2016. Shea Butter (VitellariaParadoxa) Binder Addition to Okenya Sand in Kogi State Nigeria and Its Effects on Moulding Properties of The Sand, *Journal of Multidisciplinary Engineering Science and Technology (JMEST)*, Vol. 3 Issue 1, pp 3630 – 3638

Kalpakjian, S. R, Schmid, Steven., 2009. *Manufacturing Engineering and Technology*, Sixth edition in SI units, Pearson.

Mittal, S. and Shukla, JP. 2003. *Soil Testing for Engineers*, Khanna Publishers, Naisarak, Delhi-110006, India, 1-218p.

Mshelia, ZA.,Abolarin, MS., Abubakre, OK. andAdemoh, NA. 2016, Characterization of natural moulding sands from selected deposits in Maiduguri-Nigeria for casting applications, *Arid Zone journal of Engineering, Technology and Environment*, 12: 110-121.

Muhammed, M. H., Bawa, M. A. and Akuchi, N. T. 2003. Characterization of Alkeleri and Gombe foundry sand sample, Proceedings of the Nigerian Metallurgical Society.

Sharma, P. C. 2005, *Textbook of Production Technology (Manufacturing Processes)*, S. Chand & Company Limited, India.

Shuaib-Babata Y. L., Yaru S. S., Abdulkareem S., Ajayi S., Busari Y. O., Ajao K. S., Ibrahim H. K., Ambali I. O. & Mohammed G. A. 2017. Suitability of some Selected Ado-Ekiti (Nigeria) Natural Moulding Sands' Properties for Sand Casting, *Covenant Journal of Engineering Technology (CJET)* Vol.1 (2), 53-64.

Shuaib-Babata, YL.and Olumodeji, JO. 2014, Analysis of Ilorin sand moulding properties for foundry applications, *International Journal of Engineering Research and Technology (IJERT)*, 3(1):1520 – 1526.

Shuaib-Babata, Y. L., Ibrahim, H. K., Ajao, K. S., Ambali, I. O., & Bello, M. O. 2019. Evaluation of the foundry properties of Oyun river (Ilorin) moulding sand. *Adeleke University Journal of Engineering and Technology*, 2(1), 12-24.

Tuncer, B. E. 2017. Foundry Sand: Characteristics, Specifications, Environmental Considerations, Availability, Recycled Materials Resource Center (RMRC), University of Wisconsin Madison