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Research Article

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Investigation of Local Synthetics Sand Mixture used for the Development of Foundry Industry in Nigeria (Case Study – Kebbi State)

Sani A. Salihu[1], Aliyu Buhari[1], M. Muhammad[2]

[*1]Department of Mechanical Engineering, Kebbi State University of Science and Technology, Aliero, Kebbi State.
[2]Department of Mechanical Engineering, Usmanu Danfodiyo University, Sokoto, Sokoto State.
*Email: sani.aliero@gmail.com

Abstract This research investigated the suitability of using local source to develop synthetic moulding sand in Nigeria for foundry usage. Lab sand tests were carried out on American Foundrymen's Society (AFS) standard test samples that was prepared with a Ridsdale lab sand rammer, to determine their moulding properties in both green and dry conditions. From the results of chemical analysis of the Dukku sand and Romo clay samples showed that the sand is of high silica content (89.20%) while the clay is rich in both silica and alumina contents (59.5% silica and 34.35% clay) and is an indication of their suitability for foundry mould production and refractory applications. From the results of sieve analysis of Dukku sand revealed grain fineness number (GFN) of 31.68 and an average grain size of 420.97μm, which is within by the international standard in sand casting. In addition, over 99% bulk of the sieved sand was retained after few consecutive sieves, which confirms that the sand met AFS standard specification for foundry sand. The obtained results of the moulding sand properties compared favorably with the standard property range required for the sandcasting of both ferrous and nonferrous alloys.

Keywords Moulding sand, chemical analysis, property

1. Introduction

Since the 1990s, synthetic sands have been introduced to the foundry industry to address the limited availability of special sands and cost associated with transporting these sands over long distances to the foundry industry. Nigeria is endowed with abundant natural deposits of many resources including silica and kaolin clay. These minerals have several areas of application and one of such area is in the civil and metallurgical engineering used in foundry industries. The effective application of these local raw materials in moulding sand production demand that its moulding properties must be known and compared with the standard properties required for such application. For this reason, it is considered necessary to study the moulding properties of synthetic moulding sand produced using river Niger sand (Dukku deposits) and Romo clay with a view to recommending to the needy local industries and abroad. The main source of moulding sand ingredients for Nigerian foundries has been overseas.

There are three types sand used in foundry industry are the *natural, synthetics and loam sands* (Salihu et al 2020 and AFS, (1963). Natural sand is the one which is available from natural deposit. Natural sand contains sufficient binder (clay), mined from its deposits. It is also called green sand as it is taken from river bed with 5 – 20% binder and 5 – 8 % of water. According to Atanda et al; 2012, green moulding sand is cheap, fastest, and is most common of all available moulding methods used in the foundry industry. Synthetic moulding sand is prepared artificially using basic sand moulding constituent (silica sand 87 – 93%, binder 6 – 12%, moisture content 3-6%) and other additives in proper proportion (Salihu and Suleiman (2018), Olakanmi and Khan, (2002). The advantage of synthetic sand over natural or green sand are that the properties can be adjusted with ease and they are better moulding sand since the properties are controlled according to needs. The synthetic sand with different properties could be prepared to suit different casting materials, pouring temperature, etc., but the cost of producing this sand is the major disadvantage of synthetic sand. Also, additives which are one of the requirements of good moulding sand is used the improve the properties of moulding sand used for foundry application. With addition of additives in moulding sand, it prevents penetration defects, improves surface finish, etc. Normally when additives (organic, inorganic or hybrid) are added to the moulding sand there are enhancement on properties of that sand. Loam sand contains many ingredients, like fine sand particles, finely ground refractories, clay, graphite and fibre reinforcement. Table 1 shows a comparison between the usefulness of natural sand and synthetic sand as foundry sand, while a comparison in properties of different synthetic sands is shown in Table 2.

Table 1: Comparison of natural and synthetic sands

Material	**Natural sand**	**Synthetic sand**	**Loam sand**
Moulding material	Natural sand (sand, clay, organic materials from weeds, trees, bacterium, etc.)	Sand, bentonite, starch, coal	
Sand treatment (use of machine)	Usually not necessary (if poor sand quality, a simple sand treatment will do)	Necessary	
Moulding	Easy	Easy	
Repair of mould	Easy	Relatively difficult	
Reclamation	Easy (need ware adjustment)	Easy	
Shake out	Easy	Easy	
Life sand	Limited	Not limited	
Effect of casting	Mould swelling. Sand adherence. Gas defects (depending on size materials).	Similarly, to natural sand but to a lesser degree (good for rather large size casting).	

Source: American Foundrymen Society (1963)

Synthetic sands are basically high silica sands containing little or no clay binder in the natural form. The desired strength and bonding properties of these sands are developed by separate additions of clay and other additives. This allows for greater flexibility in the control and adjustment of the properties of synthetic sands (Edoziumo et al 2017). According to Armond, 1982, and Aweda Jimol (2001) the control of the quantity of the principal constituents of synthetic foundry sand is key to determining the properties of the moulding sand. Therefore, since the use of synthetic sand in foundry is increasing because of increased reclamation rates and has reduced the costs associated with dumping spent sand, hence the need to investigate the local synthetic sand mixture of sand and clay deposits in Kebbi and Sokoto States, Nigeria. Figure 1 shows an example of a prepared synthetic moulding sand (silica sand + clay). Synthetic sands have been widely adopted for steel foundry where relatively coarse grained sands are bonded with bentonite and cereals to provide properties such as shown in Table 3.

Figure 1: Sample of prepared synthetic moulding sand

Table 2: Comparison of properties of different sands

Properties	Silica	Zircon	Olivine	Chromite
Colour	White	Brown	Green	
Melting point, ^{0}C	1720	2660	1880	1550
Specific gravity	2.28 – 2.65	4. 4 – 4.8	3.2 – 3.4	4.4 -4.5
Hardness, Moh scale	6.0 – 6.5	7.5	6.5 – 7.0	-
Thermal expansion at 900 ^{0}C, %	1.56	0.25	1.0	0.4 – 0.7
High temperature reaction	Acidic	Slightly acidic	Basic	Neutral to basic

Source: American Foundrymen Society (1963)

Table 3: Synthetic sand mixtures used in steel foundry

Properties	Green moulding aggregate	Dry moulding aggregate
Composition	Medium grade silica sand 5% bentonite 0.75% starch	50% coarse silica sand 50% medium silica sand 6% ball clay 0.5% Dextrin
Moisture content, %	3.0	6.0
permeability	170	100
Green compressive strength, kN/m^2	7	8
Dry compressive strength, kN/m^2	0.7	1.7

Source: American Foundrymen Society (1963)

2. Materials and Methods

2.1 Materials and Equipment

The following materials were used to compose and produce local synthetic sand mixture. Silica sand obtained from Dukku tail of river Niger in Kebbi state and clay from Romo river, in Sokoto state, Nigeria. Aluminium scraps as parts of the material for this work were sourced from Aliero of Kebbi State. This study was experimental and therefore consisted of conducting lab tests physically and characterizing and analyzing the mechanical properties, sieve analysis of both clay and sand content, green and dry compression strengths, compatibility shatter Index, cohesiveness, refractoriness, plasticity, adhesiveness, permeability meter, core baking oven, moulderbility tester, sand mixer and dispersive X-ray fluorescence spectrometer (ED-XRFS).

2.2. Experimental Methods

2.2.1. Sand and clay preparation

The silica sands were collected from Dukku, along river Niger tail, washed to remove clay and dirt. The processed silica sands were separately dried and sieved using shaker of different meshes and aperture. Same procedure was conducted on clay obtained from Romo in Sokoto State. The obtained sands and clay were studied with ED X-ray fluorescence analyzer for mineralogical compositions as shown in Tables 4.

Table 4: The chemical compositions of Dukku silica sand samples

SiO_2	Al_2O_3	K_2O	MgO	Fe_2O_3	CaO	TiO_2	ZrO_2	Na_2O
89.20	2.10	2.01	0.72	2.20	0.50	1.10	0.12	0.65

Loss on Ignition = 1.40

2.3. Moulding of sand tests

AFS procedures and equipment were used to evaluate the permeability, green compressive strength, green shear strength, moisture content, bulk density, and shatter index of the moulding sand samples

2.3.1 Moisture content determination

This property was determined by the speedy Ridsdale moisture content teller. To determine the moisture content, the moisture was set up to warm for 3 minutes by setting the time switch to 3 minutes while warming the machine, 50g of green sands and additives were weighed and spread over the pan of the moisture teller. After 3 minutes, the machine stopped itself and the pan together with the sand sample was then inserted into the lower part of the machine that holds it in position as fast as possible. The heating time was set for 2 minutes.

The moisture in the moulding sand is thus evaporated. Figure 2 shows the speedy moisture tester used for testing the moisture contents of Dukku sand. After 2 minutes the machines automatically stopped and pan with dried sand was taken out and put in a cooling place. It was then allowed to cool to room temperature. The cooled sand weighed and moisture content determined as follows:

Taking the initial readings to be L (g)

The final readings at room temperature to be M (g)

Then the percentage moisture content, $= \frac{L-M}{L} \times 100$

Figure 2: Speedy moisture tester

2.3.2 Refractoriness

It is the ability of the moulding sand mixture to withstand the heat of melt without showing any signs of softening or fusion. This property is greatly influenced by purity of the sand particles and their size. It increases with the grain size of sand and its contents and with the diminished amount of impurities silt.

2.3.3. Shatter Index

A shatter Index tester was adopted for this test. The standard specimen of size 50 mm diameter and 50 mm height was prepared and kept in the steel tube as in the case of permeability. Moulding sands and additives specimen was rammed in a sample tube and the weight of the sample (150g) was recorded. The specimen was ejected from the specimen tube by placing it on the shatter index tester and the plunger was used to eject the sand by making a free fall a height of 1.83 metres onto the anvil squarely in the centre. The anvil cap was then removed carefully and the sieve assembly lifted off to allow removal of sieve from pan. The sand in the receiver is weighed and the weight of sand remaining on the sieve is taken. The same procedure was repeated for test samples with varying percentages of silica flour, corn flour, shea butter shell powder, and marula shell powder. Fig. 3 shows the shatter index machine used for the determination of shatter index values for Dukku sand mixtures. The shatter index was calculated as the percentage of the difference of these two weights. The mass of the sand in the receiver was determined and the shatter index was determined for each mix as follows:

Initial mass, M_1

Mass of sand in the receiver, M_2

Shatter index, $x = \frac{M1-M2}{M1} \times 100$ (1)

The significance of shatter index value was used to determine the toughness and collapsibility of the moulding sand (Loto and Akeju, (1990).

For toughness determination:

Shatter index = $W_1/W \times 100$ (2)

For collapsibility:

Shatter index = W_1/W; (3)

where W is the weight of specimen, and W_1 is weight of sand remaining on the sieve.

Figure 3: Shatter Index machine

2.3.3. Permeability test

The quantity of air that passed through a standard specimen of the sand at a particular pressure condition is called the permeability of the sand. It is a physical property of the moulded mass of sand mixture which allows gas to pass through it. It depends upon grain size, grain shape, grain distribution, binder and its content. The apparatus used for the determination of permeability are: electric permeability meter was used to determine this property; stop-watch; standard sand rammer. AFS standard specimen of 50 mm diameter and 50 mm in height were prepared by ramming the required quantity of sand (150) each in a smooth surface tube with three blows of standard rammer. These samples were placed in the mercury cup of the permeability meter in an inverted form. Standard air pressure of 9.8 x 10^2 N/m^2 and 2000 ml of air were passed through the specimen tube containing the specimen. The machine was put on and the pressure lever was pushed, the readings were recorded when the arrow indicator was stable and represent the permeability number. The same procedure was repeated for test samples with varying percentages of silica flour, corn flour, shea butter shell powder, and marula shell powder. Fig. 4 Shows the test samples for permeability test while Fig. 5 and Fig. 6 shows standard permeability meter and sand rammer for making test samples of 50 mm x 50 mm respectively.

Figure 4: Sand test samples for permeability test

Figure 5: Standard permeability tester

The permeability number was calculated using the formula:

Permeability number (N) = $\frac{V.H}{A.P.T}$ (4)

Where, V= volume of air that passed through the specimen = 2000cm^3,

H= height of the test specimen = 5cm,

A = cross-sectional area of the test specimen = 19.63 cm^2,

P = air pressure in cm of water = 9.8 cm,

T =time taken by the air to pass through the sand specimen (seconds)

2.3.4. Green compressive strength

This is the property of moulding sand which concerns the strength of the mould while in moist condition at deformation. The strength depends on the degree of ramming, the moisture of the sand and the granulation composition of the sand. The specimens were prepared using standard sand rammer and specimen tube accessories. The sizes of the specimens were 50 mm x 50 mm. The specimens were placed in between two self aligning compression heads on the universal testing machine. A uniformly increasing load was applied, while the magnetic rider moved along the measuring scale. As soon as the sample reaches its maximum strength, the sample fails. The magnetic rider remained in position of the ultimate strength while the load was gradually released; the green compression strength for the sample was recorded from the position of the magnet. The same procedure was repeated for samples with varying % of silica flour, corn flour, shea butter shell powder, and marula shell powder. Fig. 6 shows sand samples for the test, while Fig. 9 and Fig. 10 respectively shows pictures of sand rammer and universal strength testing machine used the determination of green compression strength of Dukku sand. Green compression strength is calculated as follows:

Green compression strength, gf/mm^2 = F/A (5)

where: F = load at rupture in gf, and A = cross-sectional area of the test specimen in mm^2

Figure 6: Sand samples for green compression test

Figure 7: Sand rammer for making sand test sample

2.3.5 Green shear strength

Green shear strength indicates the strength of the mould during the removal of pattern. The universal testing machine as shown in Fig. 8 was fitted with a different adapter in order that loading can be made for the shearing of the rammed sand specimens. Specimen pads used for measuring the shear strength are different from the specimen pads used for measuring the compressive strength because of the replacement of compression head with shear head in the machine. The green shear strength was recorded at the point of failure of the sample loaded. The stresses required to shear the specimens along the axis were determined and recorded as the green shear stress.

2.3.6. Compatibility

The compatibility indicates the water tempering degree of the green sand moulding. Compatibility is the percentage decrease in height of a loose mass of sand under the influence of a controlled compaction. Compatibility test was carried out to know the way moulding sand will withstand repeated cycles of heating and cooling during casting operations. How compatibility test is carried out.

An empty sand sleeve with the stopper plugged underneath it is placed under the funnel outlet of the compatibility tester's sieve as shown in Fig. 9. The sand is sieved until a heap is formed. The heap is then stickled off the sand. The sand is rammed four times and the value X is read off the calibration. The compatibility value is then calculated as

$$\text{Compatibility} = X.100/67 \quad (6)$$

Figure 9: Compatibility tester

2.3.7 Plasticity test.

It is the measure of the moulding sand to flow around and over a patten during ramming and to uniformly fill the flask. This property may be enhanced by adding clay and water to the silica sand.

3. Results and Discussions

Quantitative and qualitative analysis of silica sand and clay were carried out and the results are shown in Tables 5 to 10. Tables 5 and 6 show the results of chemical analysis sand and clay and as indicated from the Table 5 that the sand is of very high silica content (89.2%) while in Table 6 clay is rich in silica and alumina contents (59.5%) and (34.35%) respectively. The clay belongs to the aluminosilicate group.

Table 5: The chemical compositions of Dukku silica sand samples

SiO_2	Al_2O_3	K_2O	MgO	Fe_2O_3	CaO	TiO_2	ZrO_2	Na_2O
89.20	2.10	2.01	0.72	2.20	0.50	1.10	0.12	0.65

Loss on Ignition = 1.40

Table 6: The chemical composition of Romo clay samples

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	Ag_2O	MnO	TiO_2	ZnO	MgO	Na_2O
%	59.5	34.35	4.2	0.15	0.89	0.1	1.21	0.2	0.09	0.01

Loss on Ignition = 2.40

As indicated by Edoziuno, et al, (2017) and Ridsdale (2009) the purity of sand grains influence their refractoriness. It is clear that silica is the predominant component in the sand sample. This this desirable since high % of silica in moulding sand, usually enhance its refractoriness, thermal stability and chemical inertness (Brown (1994) and Mclaws (1971). Where maximum refractoriness is required, as in steel moulding, high purity silica sands are used. Table 7 shows the Sieve analysis and AFS grain fineness number (GFN) of Dukku tail silica sand.

Table 7: Mechanical Sieve analysis and AFS grain fineness number (GFN) of Dukku sand

S No	Sieve Aperture (mm)	BS Sieve No	Weight retained (g)	% weight retained	% cumulative	Multiplier	Product (% weight retained x BSS No
1	1.400	10	7.85	5.23	5.23	6	31.38
2	1. 000	16	13.01	8.669	13.899	9	78. 021
3	0.71	22	32.11	21.39	35.289	15	320.85
4	0.5	30	32.92	21.93	57.219	25	548.25
5	0.35	44	26.17	17.82	75.039	35	623.71
6	0.250	60	17.84	11.88	86.919	45	534.6
7	0.18	100	9.39	6.257	93.176	60	375.42
8	0.125	150	7.45	4.960	98.136	81	401.76
9	0.09	200	1.19	1.279	99.415	118	150.922
10	0.063	300	0.65	0.433	99.848	164	71.012
11	Pan	350	0.17	0.113	99.960	275	31.075
Total			150.06	99.96			3166.9

$$GFN = 3166.9 \div 99.96 = 31.68$$

Table 8: Calculation of average grain size of Dukku sand obtained from Sieve Analysis

Sieve Aperture (μm)	% sand retained	Multiplier	Product
1400	2.49	1180	2,926.42
1000	1.40	1180	1680
710	4.35	1180	5,097.60
500	13.80	610	8, 292.05
355	25.90	430	11,012.27
250	29.20	300	8,600.20
180	16.90	220	3, 595.50
125	5.82	150	876
Total	99.04		42, 080.04

Average Grain Size $(AGS) = 42{,}080 \div 99.96 = 420.97$μm

From the analysis of the result of the sand grain size, it showed that more than 99% of the bulk sand was retained on the first few consecutive sieves, and therefore, the sand deposit met the American Foundrymen's Society (AFS) standard specification for sand casting (Brown (1994) and Mclaws (1971). From the results, it shows that the grain fineness number (GFN) and average grain size of the sand deposit are 32 and 420.97μm respectively. This grade of fineness number is suitable for most types of alloy steels and nonferrous alloys as this belongs to the group of fineness number that has wide range of application in sand casting. The average grain size of the sand falls within the common foundry sand range of 150- 400μm as explained by Brown, (1994). However, it was noted that the choice of sand should be based on particle size distribution, since the size distribution affects the quality and properties of casting products. Rundman (2000) agrees also that the properties of moulding sand depend strongly upon the size distribution of the sand that is used, whether it is silica, olivine, chromites or other aggregates.

Table 9 shows the results of the moulding sand properties tested and it would observe that the percentage mouldability is high, showing an increase in the tendency of the moulding sand conform the moulding processes as indicated by Salihu et al (2020), Edoziuno, et al (2017), Nwajagu and Okafor (1989), and Beeley (2001). This is as a result of the moulding sand being more plastic and pliable, thus increasing the ability and ease with which the sand can fill intricate mould cavity and reproduce in fine details the embedded pattern.

Table 9: Moulding properties of the prepared synthetic foundry sand from Dukku sand.

properties	Dry Shear Strength kN/m^2,	Green Compression Strength kN/m^2	Mouldability (%)	Green Shear Strength, kN/m^2	Dry Compression Strength, kN/m^2	Green Permeability No
Value	79.47	46. 70	98.45	38. 34	596.50	18. 50

Comparing the results with the standard property range specified for sand casting (Table 3.6), it will be seen that the moulding sand is suitable for dry mould casting of Al and alloys, medium grey iron, heavy grey iron, bronze, light grey iron and malleable grey iron.

Table 10: Standard property ranges for sand casting of different alloy.s

METAL	Green Compression Strength (kN/m^2	Dry Compression Strength (kN/m^2	Permeability, No
Heavy steel	70-85	1000-2000	130-300
Light steel	70-85	1000-4000	125-200
Heavy grey iron	70-105	350-800	70-120
Aluminum	50-70	200-550	10-30
Brass and 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

4. Conclusion

From the results of the analysis presented concerning preparation of local sand mixture with silica sand and clay deposits to obtain synthetics sand mixture, following conclusions were drawn.

source: (Dietert, 1966)

- The synthetic moulding sand produced from Dukku sand and Romo clay is suitable for dry moulding of nonferrous and ferrous alloys.
- The chemical analysis done on the silica sand and clay samples shows that both have the required purity for enhancing refractoriness, thermal stability and chemical inertness of moulding sand.
- Grain size analysis showed that more than 99% of the bulk sand was retained on the first few consecutive sieves and thus, the sand deposit met the AFS standard specification for foundry sand.
- The grain fineness number (GFN) and average grain size of the sand deposit fall within the recommended range for wide application in sand casting.
- The results of experiments highlight the strength and weakness of various sands and clays.

Conflict of Interest

The authors declare that there is no conflict of interest.

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