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Investigation of the Moulding Properties of Gurara River Bed Sand in Niger State Using Kaolin and Bentonite as Binder

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Abstract: The study investigated foundry properties of Gurara river bed sand in Niger State for its possible use in sand casting in foundries. Bentonite and kaolin were used as binders. Experimental techniques which included sieve analysis, determination of clay content and refractoriness of river Gurara bed sand and mechanical analysis consisting of green/dry compressive strength, green hardness, permeability and shatter index tests of moulded specimens were conducted to measure foundry properties of the sand. The sand gave good mechanical properties when bonded with kaolin and bentonite clay. It revealed kaolin bonds better than bentonite. Its physiochemical properties showed silica to be highly present of 88% which gave refractoriness of 1,500^{o}C and made up of about 42% medium and 27% fine sand by classification standard and it is suitable for casting nonferrous metals and ferrous metals with melting point below 1,500^{o}C. However, further study is recommended on the sand test for core making.

Key words: Gurara River bed sand, Kaolin, Bentonite, Foundry

1. INTRODUCTION

One of the most ancient methods of metal forming is casting in a foundry. It includes such basic production processes as mould preparation, melting of metals, pouring into prepared moulds, solidification, shake-out and fettling of the casting (Fatai*et al*, 2011). Casting processes include permanent mould casting, centrifugal casting, die-casting, investment casting, shell casting and sand casting. Sand casting is the most widely used of the casting processes. It accounts for about 80% of cast product and can be employed for both ferrous and non-ferrous metals (Fatai*et al*, 2011).

The study of foundry sand constitutes one of the main sections of foundry technology and sand testing has become an essential part of the day-to-day control of foundry operation. All materials used for manufacture of sand mould and cores are usually termed moulding materials. The property requirements of the materials are determined by the moulding and casting conditions (Fatai*et al*, 2011). Hence, proper choice of the composition of a moulding mixture is of prime importance.

Nigerian foundry industries could still be said to bein its infancy after forty four years of independence (Shuaib*et al*, 2014). Shuaib*et al* (2014) in their study revealed tha talmost 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.

This research would characterize useful information on River Gurara sand to the present and future foundry plants in Niger State and her neighboring States and will help the foundry men in controlling the properties and performances of moulding sands used. Future foundry plant may also wish to site its location in Gurara as available information on the suitability of its river bed Sand has been documented in this work, thereby reducing the high cost of transporting foundry sand to elsewhere.
From literature, a lot of researches had been carried out on the southern and eastern sand region of the country having just few from the Northern part. Therefore, our foundry industries in this region has few information on the suitability of moulding sand around them, this can only be achieve by conducting a research with an in-depth laboratory tests.

2. Materials and Methods

For the purpose of this research, American Foundry Society standard procedure was used as a guide in making the sand test samples and sieve analysis. Samples were collected from the study area for analysis; tests were conducted at National Metallurgical Development Centre, Jos. The results were compared with standard moulding sand properties. The following tests were carried out on the sand samples:

- Sieve analysis
- Moisture content determination
- Permeability test
- Refractoriness
- Dry compression test
- Green compression strength test
- Chemical analysis
- Shatter index

2.1. Experimental Methods

The samples for this research were prepared based on AFS standard samples of 5.08cm by 5.08cm for all the tests. The sand sample was taken from five different points of about 100m distance spread in between. At each point a depth of about 0.35m was dug thrice and the sand after every 0.35m was excavated making 15 different samples. Each of the 15 samples were mixed together to ensure a true representation of the river Gurara bed sand.

2.2. Chemical Analysis

The ED-XRFS is a non-destructive method of quantitative and qualitative elemental analysis of solid and liquid sample materials. 20g of the sand sample was grounded to pass through a 200-250 mesh sieve. It was dried in an oven at 105^oC for an hour, the sample was mixed with a binder (cellulose flakes) in the ratio of 5g to 1g. The sample was pelletized at a pressure of 10-15tons/inch^2 in the pelletizing machine, thereafter the sample was kept in desiccators for analysis. The ED-XRFS was switched on and allowed to warm up for about two hours, appropriate programs for various elements of interest were employed to analyze the sample materials for their presence or absence.

2.3 Sieve Analysis

AFS Sieve analysis of sand was carried out to determine grain fineness on a dry sand sample from which all clay substance have been removed. A set of standard testing sieve was used to screen the sand as shown in Fig. 1. The sieves were stacked in sequence with the coarsest sieve at the top and placed on a sieve shaker. About 150g sand was placed at the top sieve and, after 15minutes of vibration, the weight of the sand retained in each sieve was obtained. The AFS grain fineness number was determined by taking the percentage of sand retained on each screen and multiplying each by a multiplier to arrive at the product. The total sum of the product added and divided by the total sum of the percentage of the sand retained on the sieves gives the AFS grain finess number

1

Fig 1: Georgfischer Sieve Rack

2.4 Moisture Content Determination

About 6g of sand was weighed and transferred into the moisture content tester, two spoon full of calcium carbide in granulated form was immediately transferred into the tester and vigorously shaking for two minutes and the reading from the dial gauge was recorded in percentage. The same procedure was repeated for samples with varying percentages of kaolin and bentonite. Fig. 2 shows picture of speedy moisture tester set up

Fig 2: Speedy Moisture Tester for Moisture Content Determination

- ## Permeability Test

Permeability measures ease of escape of evolved gases to forestall defects like porosity and gas inclusions in casting. It depends upon grain size, grain shape, grain distribution, binder and its content. AFS Standard sand specimen of 50mm diameter and 50mm in height was prepared by ramming the required quantity of sand (150g) in a smooth surface tube with three blows of standard rammer. This sample was placed in the mercury cup of the permeability meter in an inverted form. 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. It's important to note that small orifices was used for this research which is ten times less than the big orifice. The same procedure was repeated for test samples with varying percentages of kaolin and bentonite. Fig. 3 shows test samples for permeability test and Fig. 4 and Fig. 5 shows standard permeability meter and sand rammer for making test samples of 50mm x 50mm respectively

Fig 3: Test Sand Samples For **Permeability** Test

Fig 4: Standard Permeability Tester

Fig 5: Sand Rammer

- **Refractoriness Test**

Refractoriness is a measure of the fusion point and thermal stability of the sand specimen that tells the type of alloy the sand is suitable to be used for casting (Ademoh, 2008)

A cuboid specimen of sand measuring 10.8 by 5.3 by 2.0cm were prepared, honey was used as a binder and pressed at 300 pa. Then the specimen was heated to 1200^{o}C and gradually increased to 1700^{o}C for 2 hours and the changes in dimension and appearance were observed. The sand specimen share shows very little expansion and begins to shrink and distort at 1,500^{o}C, hence the refractoriness of 1,500^{o}C was obtained. Fig. 6 shows heated refractory test samples

Fig 6: Refractory Test Samples

2.7 Dry Compression Strength

This is the property of moulding sand, which concerns the strength of the mould while in dry condition at deformation. It is the ability of the sand mould to withstand pressure of molten metal during casting. The sample was prepared using standard sand rammer and specimen tube accessories. The sand and the clay were thoroughly mixed in a roller for 10minutes and moulded into specimens of 50mm x 50mm. Each specimen measured 50mm diameter by 50mm height with average weight of 130g. It was rammed with three dropping blows weighing 6.5kg from a height of 50mm. The first scheduled test sample was bonded with water only, while the second was bonded with varying percentages of bentonite clay and the third with varying percentages of kaolin clay. The AFS standard sample of 50mm diameter x 50mm height was heated and dried in an oven at a standard temperature of 110^{o}C for a period of 30minutes, removed and allowed to cool in the air to room temperature. After cooling, the specimen was placed between two self aligning compressions; increasing load was applied until it failed at the ultimate compression strength of the sample. The point at which the failure occurred was recorded as dry compressive strength. The same procedure was repeated for samples with varying percentage of bentonite and kaolin as binder. Fig. 7 shows picture of the test samples while Fig. 8 and Fig. 9 respectively shows pictures of sand rammer and universal strength testing machine

Fig 7: Sand Samples for Dry Compression Stress Test

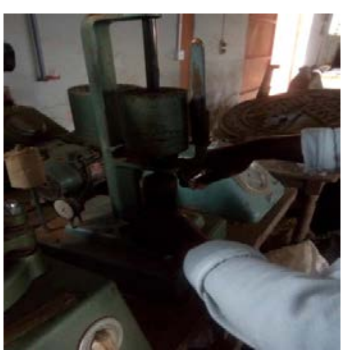

Fig 8: Sand Rammer for Making Sand Test Sample

Fig 9: Universal Sand Strength Testing Machine (Ridsadle-Dietert Design, Middlesbrough ENG, Serial Number: M8415)

- **Green Compression Test**

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 specimen was prepared using standard sand rammer and specimen tube accessories. The size of the specimen is 50mm x 50mm. The specimen was 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 GCS for the sample was recorded from the position of the magnet. The same procedure was repeated for samples with varying percentage of bentonite and kaolin as binder. Fig.10 shows picture of the test samples while Fig. 11 and Fig. 12 respectively shows pictures of sand rammer and universal strength testing machine.

Fig 10: Sand Samples for Green Compression Stress Test

Fig 11: Sand Rammer for Making Sand Test Sample

Fig 12: Universal Sand Strength Testing Machine (Ridsadle-Dietert Design, Middles Brough ENG, Serial Number: M8415)

2.9 Hardness Test

Measures mould resistance against abrasion to ensure casting accuracy. The hardness achieved by ramming the moulding sand mixture was measured by using an indentation-type mould hardness tester where a spring-loaded 1/2 inch diameter steel ball was pressed into the AFS standard sand sample and the hardness number was read directly from a dial gauge which calibrated from 100 to 0 where no penetration occurred, the hardness reading was set arbitrarily to 100. Where the ball sunk completely into the sand up to the limiting surface of the tester, the reading was set to 0; i.e. the sand was very soft. A "hard rammed" mould generally read 90, while a "soft" mould read 50 to 60. Severe penetration by the liquid metal and washing of the sand occurred when the hardness reading was below 50. The same procedure was repeated for samples with varying percentage of bentonite and kaolin as binder

2.10 Shatter index test

The shatter index test was carried out using shatter index tester at NMDC Jos. The standard specimen of size 50mm diameter and 50mm height was prepared and kept in the steel tube as in the case of permeability. The tube holding the specimen was fixed on the machine. The plan (receiver) was set at zero and fixed on the normal position at the foot of the machine directly below the specimen. The handle of the mechanism was pulled downward and the plunger entered and ejected the specimen from the steel tube. The sand fell under gravity and hit the anvil in the sieve on top of the receiver. The mass of the sand in the receiver was measured and the shatter index was calculated for each mix as follows,

Initial mass of the sand, M0

Mass of sand in the Receiver, M1

2

The same procedure was repeated with varying percentages of bentonite and kaolin.

Table 1 shows the recommended sand properties for casting

Table 1: Sand Properties for Casting (Ademoh And Abdullahi,2009)

Metal	Green Compressive Strengths (KN/m²)	Permeability No	Dry Strengths (KN/m²)
Heavy Steel	70-85	130-300	1000-2000
Light Steel	70-85	125-200	400-100
Heavy Grey iron	70-105	70-120	350-800
Aluminium	50-70	10-30	200-550
Brass & Bronze	55-85	15-40	200-860
Light Grey iron	50-85	20-50	200-550
Malleable iron	45-55	20-60	210-550

Table 2 shows the particles and their corresponding sizes in sieve.

Table 2: Particle Size and Sieve Analysis (Turkeli, 2009)

Particles	Sizes
Soil separate	Diameter range (mm)
Gravel	2.0 and larger
Very coarse sand	2.0-1.0
Coarse sand	1.0-0.5
Medium sand	0.5-0.25
Fine sand	0.25-0.10
Very fine sand	0.10-0.05
Fines	Less than 0.05

Table 3: Recommended Dimensional Allowances for Patterns of Different Alloy Castings (Murtala, 2009)

Alloys	Allowance (%)
Cast Iron	0.8-1.0
Steel	1.5-2.0
Aluminum	1.0-1.3
Magnesium	1.0-1.3
Brass	1.5

3 RESULTS AND DISCUSSIONS

3.1 Chemical analysis

Chemical analysis was conducted to determine the silica content, aluminum oxide and other impurities in the sand sample. Table 4 shows the various chemical properties present in the sample sand.

Table 4: Chemical Analysis of River Gurara Bed Sand at Niger State

Component Element	Composition by weight (%)
SiO_2	88.80
Al_2O_3	2.12
SO_3	ND
K_2O	3.02
CaO	0.50
TiO_2	2.12
V_2O_5	0.06
Cr_2O_3	0.11
MnO	0.06
Fe_2O_3	3.02
NiO	0.005
CuO	0.01
ZnO	ND
As_2O_3	0.004
Rb_2O	0.009
SrO	0.02
ZrO_2	0.33
PbO	0.02
Loss on Ignition	1.13

The chemical compositions of the specimen sand using XRF is as shown in table 4. It shows the amount of silica present and the presence of impurities such as lime, manganesia, alkalis etc. The presence of excessive amounts of iron oxide, alkali oxides and lime lowers the fusion point to a considerable extent which is undesirable (Turkeli, 2009). However, Silica (SiO_2) was found to be highly present up to 88.80% which is in line with recommended basic sand molding constituents (Turkeli, 2009). K_2O was found to be next in large proportion of about 3.02%, Al_2O_3 and TiO_2 of about 2.12%. Other constituents such as oxides of manganese, calcium, chromium among others are found to be in small proportions which result in the high fusion point, therefore yielded refractoriness of about 1,500^oC in returns.

3.2. Refractoriness

The refractoriness was found to be 1,500°C. It gave very useful information about the thermal resistance of the Gurara river bed sand. It showed that the sand is suitable for all types of non ferrous alloy metals and ferrous alloy metals with melting point below

1,500°C. According to Ademoh (2008), he found the refractoriness of River Niger bed sand to be 1,380°C and recommended that the sand be suitable for casting of non ferrous metals of melting point below 1,380°C

3.3. Sieve analysis

Table 5 shows the various grains distribution of sand which determines the likely surface finish of casting

Table 5: Mechanical Sieve Analysis of Sand Sample

Sieve size (mm)	Weight Retained (g)	(%) Retained	(%) Cumulative	Multiplier	Product
1.40	7.85	5.23	5.23	6	31.38
1.00	13.01	8.669	13.899	9	78.021
0.71	32.11	21.39	35.289	15	320.85
0.50	32.92	21.93	57.219	25	548.25
0.355	26.75	17.82	75.039	35	623.7
0.250	17.84	11.88	86.919	45	534.6
0.18	9.39	6.257	93.176	60	375.42
0.125	7.45	4.96	98.136	81	401.76
0.09	1.192	1.279	99.415	118	150.922
0.063	0.65	0.433	99.848	164	71.012
Pan/Clay	0.17	0.113	99.96	275	31.075
Total	**150.06**	**99.96**			**3166.9**

The AFS fineness number which is the standard for reporting the grain size and distribution was use to assess the particulate distributions as done by Ademoh (2008)

From table 5, using equation 2, the AFS fineness number is 31.68

Grain sizes and their distribution in molding sand influence greatly the properties of the sand. The size and shape of the silica sand grains have a large bearing upon its strength and other general characteristics. The sand with wide range of particle sizes has higher compatibility than sand with narrow distribution (Turkeli, 2009)

The mechanical sieve analysis in table 5 shows that the sand is more of medium, fine and very fine sand as 70% of the sand size falls within 0.18mm-0.75mm on the sieve. According to table 2, the sand size particle falls between 42% medium and 27% fine sand, therefore it will give a good surface finish to the a cast material.

3.4 Mechanical Properties

The most tested of all mechanical properties of moulding sand are permeability, green compression, dry compression, hardness and shatter index test. Tables 6, 7 and 8 show the measured foundry properties of the bed sand with various percentages of water, bentonite and kaolin respectively used as binders.

Table 6: Measured Mechanical Foundry Properties of River Gurara Bed Sand with Varying Percentage of Water

Measured properties	Varied water content (%)					
	2.0	3.0	4.0	5.5	7.0	8.0
Permeability	12.2	10.4	9.6	8.1	7.8	6.2
Green Compression Strength (KN/m^2)	NA	NA	NA	NA	NA	NA
Dry Compression Strength (KN/m^2)	NA	NA	NA	NA	NA	NA
Green Hardness (No)	NA	NA	NA	NA	NA	NA
Shatter Index (No)	11.6	10.6	7.8	5.4	3.2	1.4

From Table 6 the mechanical properties of the bed sand when bonded with water only at different percentages shows that the permeability was far below the recommended value for foundry use as such not suitable for casting according to table 1 as shown by Ademoh and Abdullahi (2009). Also, the green compression strength, dry compression strength and green hardness gave no measurable result because the sand when bonded with water alone shatters when placed in the universal strength testing machine, therefore no result was read. This indicates that water alone as binder is not sufficient enough as to bond the sand together for casting

Table 7: Measured Mechanical Foundry Properties of River Gurara Bed Sand With Varying Percentage of Bentonite as Binder

Measured properties	Bentonite clay content (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Permeability (No)	130.3	125.7	121.4	117.4	113.7	110.5
Green Compression Strength (KN/m)	18.0	20.0	26.0	29.0	32.0	34.0
Dry Compression Strength (KN/m)	182.0	188.0	202.0	216.0	227.0	238.0
Green Hardness (No)	48.0	49.0	50.0	51.0	52.0	54.0
Shatter Index (No)	110	106.0	103.0	95.0	82.0	76.0

Table 7 shows the result of permeability, green compression strength, dry compression strength, green hardness and shatter index of the sand sample when bonded with 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, 3.0% bentonite clay. Permeability decreases as the clay content increases from 0.5% to 3% because more clay particles fill up the available spaces thereby lowering the passage of air. When compared with standard in table 1, it shows that with 0.5% bentonite, it is suitable for heavy steel casting, 1.0% for light steel casting, 2.0% to 3.0% for heavy grey iron. The green, dry compression strength and hardness increases as the clay content increases.

The observed increase in strength occurred because as the clay content of the moulding sand increases, its binding strength also increases which result to increase in strength and hardness. The green and dry compressive strength when compared with standard in table 1 showed that the bentonite is unsuitable for green mould casting but suitable for dry mould casting of non-ferrous alloys, malleable and light grey iron from 2.0% to 3.0%. Also the shatter index number decreases with increased binder content from 110 to 76.0 due to increase in compatibility as a result of the increased binder.

Table 8: Measured Mechanical Foundry Properties of River Gurara Bed Swith Varying Percentage of Kaolin As Binder

Measured properties	Kaolin clay content (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Permeability	167.3	160.2	153.7	141.8	138.3	136.6
Green Compression Strength (KN/m^2)	26.0	30.0	32.0	34.0	36.0	38.0
Dry Compression Strength (KN/m^2)	200.0	240.0	288.0	310.0	349.0	360.0
Green Hardness (No)	65.0	68.0	73.0	76.0	78.0	80.0
Shatter Index (No)	88.0	82.0	80.0	74.0	71.0	70.0

Table 8 shows the result of permeability, green compression strength, dry compression strength, green hardness and shatter index of the sand sample when bonded with 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, 3.0% kaolin clay. Permeability decreases as the clay content increases from 0.5% to 3% because more clay particles fill up the available spaces thereby lowering the passage of air. When compared with standard in table 8, it shows that with 0.5% to 3.0% kaolin, it is suitable for heavy and light steel casting. The green, dry compression strength and hardness increases as the clay content increases. The observed increase in strength occurred because as the clay content of the moulding sand increases, its binding strength also increases which result to increase in strength and hardness. The green and dry compressive strength when compared with standard in table 1 showed that kaolin is unsuitable for green mould casting but suitable for dry mould casting of non-ferrous alloys, malleable and light grey iron from 2.0% to 3.0%, while at 3.0% it is also suitable for heavy grey iron and medium grey iron. Also the shatter index number decreases with increased binder content from 88.0 to 70.0 due to increase in compatibility as a result f the increased binder.

4 CONCLUSION

The research revealed that:

1. The physiochemical properties of River Gurara bed sand has high silica and high refractoriness which makes it suitable for casting of all forms of non ferrous metals and ferrous metals of melting point below 1,500°C.

2. It responded well to bentonite and kaolin clay binders that gave good mechanical properties to sand mould specimens.

3. The result of the mechanical properties analysis of the sand when compared to existing foundry standard was discovered to be very suitable for casting all types of non ferrous alloy and some ferrous alloy such as heavy steel casting, light steel casting with 0.1% to 3% bentonite and for heavy grey iron with 2.0% to 3.0% bentonite and 2% moisture content. While that of kaolin clay is suitable for malleable and light grey iron from 2.0% to 3.0%, while at 3.0% it is also suitable for heavy grey iron and medium grey iron and all forms of non ferrous alloys with 2% moisture content.

APPENDIX A: Plot of compositional analysis of River Gurara bed Sand

Figure AI: Plot of compositional analysis of River Gurara bed sand

APPENDIX B: Sand sieve analysis f or grain size distribution

Figure B1: Plot of sand retained (%) against sieve size (mm)

Figure B2: Plot of cumulative retained (%) against sieve size (mm)

APPENDIX C: Graphical plots of the moulding sand analysis

Figure C1: Plot of Green and Dry compressive test against varying percentages of water

Figure C II: Plot of Permeability no., Green hardness no., Shatter index no. against varying percentages of water

Figure C III: Plot of Green and Dry compressive strength against varying percentages of bentonite clay

Figure C IV: Plot of Permeability no., Green hardness no., Shatter index no. against varying percentages of bentonite clay

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Figure CVI: Plot of Permeability no., Green hardness no., Shatter index no. against varying percentages of kaolin clay

Figure CVI: Plot of Permeability no., Green hardness no., Shatter index no. against varying percentages of kaolin clay

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