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Evaluation of the Foundry Properties of River Niger Sand Behind Ajaokuta Steel Company Limited, Ajaokuta, Nigeria

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Abstract: Ajaokuta Steel Plant is the largest integrated steel complex in black Africa, located along the west bank of river Niger in Nigeria. Though full take off was delayed, it is expected that when it becomes operational it will attract lots of ancillary and small to heavy industries to the area. These would require large foundry plants for the spare and completely knocked down parts. This study investigated foundry properties of river Niger sand behind the steel plant for its possible uses in sand casting in the foundries. Bentonite and kaolin were used as binders. Experimental techniques which included the mechanical sieve analysis, determination of clay content and refractoriness of river Niger sand and mechanical analyses consisting of green/dry compressive, green hardness, permeability and shatter index tests of moulded specimens were conducted to measure foundry properties of the sand. Its physiochemical properties showed it is alumino-silicate with low fusion temperature of 1380°C, made up of about 15% fine and 62% medium sand by classification standard and it is suitable for casting non ferrous alloys. The sand gave good mechanical properties when bonded with kaolin or bentonite clay, with kaolin giving better bond properties.

Key words: River Niger · Foundry · Kaolin · Bentonite

INTRODUCTION

River Niger is located in western Africa, flowing primarily from west to east, through Guinea, Mali, Niger, Benin and Nigeria to the Gulf of Guinea. With a length of 4,180km it is the third longest river in Africa, after the rivers Nile and Congo. The drainage basin covers an area of about 2,092,000km^2 and includes two deltas-an inland delta in central Mali and a coastal delta along the Gulf of Guinea [1]. Ajaokuta Steel Company Limited named after Ajaokuta village, where it is sited is an integrated steel plant located in Kogi state on the west bank of river Niger, some 546km north of the Atlantic ocean and 200km from Abuja, capital of Nigeria. The Ajaokuta Steel Company which operates on blast furnace method of iron smelting and the largest steel plant in black Africa was started when the Federal Government of Nigeria realized the indisputable fact that the country cannot industrialize without iron and steel industry due to the requirement of steel products in manufacturing and construction industries [2].

The first phase of the plant was to turn out about 1.3million tones of long steel products, the second phase 2.6million tones of flat products and third phase 5.2million tones with provisions for expansion to 10million tonnes of various types of finished and semi-finished steel products including heavy plates and sections eventually [2]. Based mainly on above approach, the experience and success achieved in rapid industrialization around different steel plants of the world, particularly the Bokaro Steel plant in Bihar state of India, many down stream and spin-off industries including the ancillary, small scale, medium scale and heavy engineering manufacturing industries are expected to emerge around Ajaokuta steel Company. This massive cluster of industries will require heavy presence of foundries to service the industries for maintenance spare and completely knocked down parts of plants and machineries. Although this plan of turning Ajaokuta into industrialization center of Nigeria is flattened she can not attain the Millennium Development Goals and her Vision 2020 of becoming one of the twenty biggest economies of the world without a strong plan mid-wifed by an industrial village like Ajaokuta complex. Consequently, it is important that every natural resource around the steel plant is researched on to determine its suitability for any of the industrial processes.

Foundry sand is sand of defined origin used in direct production processes of foundry casting operations [3].

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According to Brownes [4] the ratio of sand to weight of casting is about 8:1 and that a tonne of casting needs about 150 tonnes of handling materials, making it imperative that the source of sand be near to a foundry for better economics. According to Walker [5] natural sand is largely formed from the denudation of land from the decomposition of massive quartz based rock. This produces siliceous sand grain used for synthetic sand [6]. Siliceous sand with a specific gravity of 2.2 is the most common and most widely used base material for core and mould [6]. It occurs in natural deposits in many parts of Nigeria on earth surface such as sand dome and beaches.

They are found under water bed such as rivers, lakes and seashores. Guma [7] characterized river Kaduna sand, found out it has good surface characteristics, fine to almost uniform grain distribution and with a good binder and proper control it can serve as cheap source of good sand grain required for casting different alloys. Umar and Bashir [8] showed that Challawa river sand in Kano when mixed with 4% water and 20% clay can produce good synthetic sand for castings. The aim of this study is to characterize the foundry properties of river Niger sand at Geregu behind the Ajaokuta Steel Plant. The objectives are to determine physiochemical and mechanical properties of the river Niger sand using bentonite and kaolin clay binder and compare result to foundry standard so as to ascertain its suitability for sand casting. The significance lies on the fact that the sand grains needed by foundries at Ajaokuta for synthetic sand production would easily and cheaply be sourced from the nearby river Niger.

MATERIALS AND METHODS

This study was experimental consisting of the mechanical sieve analysis of sand; determination of the clay content and refractoriness of the river Niger sand and mechanical analyses of moulded sand specimens. The sand sample was taken such that shovels full were taken from different points (surface and interior) along 0.5 Km distance of river Niger behind Ajaokuta Steel plant. It was mixed and 500Kg sample taken after quartering down to ensure a true representation of the parent material [9]. Chemical and proximate analyses were done in the laboratory of Geological Survey Agency, Kaduna. The sand sample was ground to pass through #120 British mesh sieve. 1g of powdered sample was fused and digested on hot plate with acids and then filtered. The filtrate was analyzed for the major components of sand for classification into basic mineral groups [10]. The refractoriness was determined at the Geological Survey, Kaduna using the Seyder Cone method on prepared specimen [11].

50g of the sand was taken and dried at a temperature of 110°C in an oven. It was transferred from oven into boiling distilled water into which a quantity of ammonia was added and boiled for 10 minutes. The normal clay determination procedure was then applied [12]. BS was adopted to sieve sand to determine the grain fineness and distribution. 942g of the washed and dried sand lot was weighed and transferred to the standard mechanical sieve and vibrated for 30 minutes [11] for grain size distribution. The sand for moulding specimen was dried at 110°C to remove free water. BS standard grain size 40-72 was used to produce specimen. The selected sand grains were thoroughly mixed in a roller mill for about 10 minutes and then moulded into test specimens with different percentage contents of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% of bentonite and kaolin as binders. 2 inches diameter by 2 inches height test specimens of average weight of 130g were rammed in three dropping blows with a 6.5Kg weight from a height of 2 inches [13-16]. Sample sand specimen without binder were made and tested for control experiment.

According to Dietert [6] green/dry compressive strengths; green permeability and harness; shatter index and moisture content test are the most tested of all mechanical properties of moulding sand. The tests give basic information of the other properties and desirability of sand. These tests were then carried out on prepared moulding sand specimens using foundry testing equipment in the laboratory and foundry workshop of Ajaokuta Steel Company Limited, Nigeria. Speedy moisture teller was used and the instantaneous readings of percentage of moisture were made from the gauge of the instrument [16]. Standard air pressure of $9.8x10^2 N\backslash m^2$ was passed through the specimen tube containing green sand specimen placed in parameter of the permeability meter and time the taken for $2000cm^3$ of air to pass through the sand specimen was read to determine the permeability [17]. The green and dry compressive strengths were tested with universal strength machine. Steadily increasing compressive force was applied on specimen until failure just occurred and the strength in $KN\backslash m^2$ read instantaneously. Dry compressive specimens were dried at 110°c for an hour and cooled down to room temperature before the tests. A shatter test apparatus was used to measure shatter index of specimens as usual [11].

RESULTS

The results of the research are presented in Table 3-5. Table 1 presents the proximate chemical analysis of the river Niger sand used as base sand. The analysis gave information about the mineral group, origin and refractoriness of the sand. Table 2 shows mechanical sieve result of the sand. Sieve analysis tells the grain distribution of sand and likely surface finish of casting. The results of mechanical property tests including moisture content; green and dry compressive strength; green permeability, hardness and shatter index tests for specimen moulded with water only, bentonite and kaolin clay binders are presented in Table 3-5, respectively. Moisture test determined the dampness of mould specimen; green/dry compressive strength measured the ability of the sand mould to withstand pressure of molten metal during casting either in moist or dry state; while green hardness measured mould resistance against abrasion to ensure casting accuracy. Green permeability measured ease of escape of evolved gasses to forestall defects like porosity and gas inclusions in castings; while shatter index measured collapsibility of sand after casting for easy shake out and cleaning. The fusion point of the sand specimen as experimentally determined is 1380°C. This was a measure of refractoriness and thermal stability that tells the alloy the sand is suitable for casting.

Table 1: Chemical analysis of river niger bed sand at ajaokuta

River Niger bed sand	SiO_2	Al_2O_3	CaO	MgO	Na_2O
Composition by weight (%)	71.66	19.50	3.65	1.20	1.20
River Niger bed sand	Fe_2O_3	TiO_2	K_2O	MnO	H_2O^+
Composition by weight (%)	0.79	0.10	0.11	0.01	0.85

H_2O^+ =lost on ignition; Fluxing agent=sodium hydroxide, Fusion Point of the river Niger sand=1380°C

Table 2: Mechanical sieve analysis of the project sand

S\No	BS sieve No	Retained (%)	Cumulative (%)
1	16	00.05	00.05
2	30	22.59	22.64
3	40	61.95	84.54
4	52	00.00	84.54
5	60	00.00	84.54
6	72	15.24	99.78
7	100	00.03	99.81
8	150	00.01	99.84
9	200	00.10	99.94
10	Pan	00.04	99.98
11	Clay	00.02	100.00

DISCUSSION

The fusion point measured the refractoriness and gave very useful information about the thermal resistance of the river Niger sand. It showed that the sand is mainly suitable for non ferrous metals with melting point lower than 1380°C.

Table 3: Measured Foundry Properties of River Niger Sand using varying percentages of water only as binder

Sample: Water used as binder for sand	A	B	C	D	E	F
Added water (%)	2.0	3.0	4.0	5.5	7.0	8.0
Moisture content (%)	2.0	2.0	3.0	3.0	4.0	5.0
Green strength (KN\m^2)	-	-	-	-	-	-
Dry strength (KN\m^2)	-	-	-	-	-	-
Green permeability (No)	-	-	-	-	-	-
Green hardness (No)	-	-	-	-	-	-
Shatter index (No)	7.6	6.6	3.8	3.4	2.0	0.3

Table 4: Measured foundry properties of river niger sand using varying percentages of bentonite clay binder with 3% of water

Sample: Bentonite clay used as binder	A	B	C	D	E	F
Clay content (%)	0.5	1.0	1.5	2.0	2.5	3.0
Moisture content (%)	2.0	2.0	1.8	1.8	1.7	1.6
Green strength (KN\m^2)	12.0	14.0	20.0	23.0	26.0	28.0
Dry strength (KN\m^2)	162.0	168.0	182.0	196.0	207.0	218.0
Green permeability (No)	120.3	115.7	111.4	107.4	103.7	100.5
Green hardness (No)	28.0	29.0	30.0	31.0	32.0	34.0
Shatter index (No)	90.0	86.0	83.0	75.0	62.0	56.0

Table 5: Measured foundry properties of river niger sand using varying percentages of kaolin clay as binder with 3% of water

Sample: Kaolin clay used as binder	A	B	C	D	E	F
Clay content (%)	0.5	1.0	1.5	2.0	2.5	3.0
Moisture content (%)	2.0	2.0	2.0	1.9	1.9	1.8
Green strength (KN\m^2)	20.0	24.0	26.0	28.0	30.0	32.0
Dry strength (KN\m^2)	180.0	220.0	268.0	290.0	329.0	340.0
Green permeability (No)	157.3	150.2	143.7	131.8	128.3	126.6
Green hardness (No)	45.0	48.0	53.0	56.0	58.0	60.0
Shatter index (No)	68.0	62.0	60.0	54.0	51.0	50.0

Table 6: Calculation for AFS grain fineness number for sand

S\N	BS Sieve No	Sand retained (%)	Multiplier	Product
1	16	0.05	10	0.50
2	30	22.59	20	451.80
3	40	61.95	30	1858.50
4	52	0.00	40	0.00
5	60	0.00	52	0.00
6	72	15.24	60	914.40
7	100	0.03	72	2.16
8	150	0.01	100	1.00
9	200	0.01	150	1.50
10	Pan\Clay	0.06	200	12.00
		Total = 100.00		Total = 3241.41

The clay content after washing sand was 0.04. This is within acceptable limit [15]. The proximate analysis of the sand as shown in Table 1 showed content in percentages by weight of various mineral oxides [17]. By respectively. From the result, the sand is coarse as the lower the AFS number, the coarser the sand. By Boswell sand classification [17] though not a reliable measure Parkes [11], it belongs to class 7A. By this standard [17], 61.95% of the sand is in medium grade (BS no. 36, 44, 52 & 60) and about 15.31% is in the fine grade (BS no. 72, 85, 100, 120 & 150). The grain distribution is within acceptable standard. This means that the experiment used sand grains in BS sieves 40-72, implying a mixture of 70% medium and 30% fine sand [17].

The washed and dried river Niger sand bonded with varying percentages by weight of ordinary water showed that without binder the sand could not bond together into test mould as shown in Table 3. This confirmed the almost total absence of chemical analysis, it is alumino-silicate of quartzite origin. Silica (SiO_2) is dominant of the oxides present. Sodium oxide is high causing reduction in refractoriness as it fluxes at high temperature. The sand is mostly suitable for non ferrous castings.

The AFS fineness number which is the standard for reporting the grain size and distribution of sand was used to assess the particles [11]. This was applied to the sieve result as in Table 6 to obtain the AFS number. From the table, grain fineness=total product\% sand substance = 3241\100=32.4. The sieve analysis for two other samples gave AFS numbers 32.1 and 31.9 organic contaminants or residual clay in the sand after washing.

Moulding experiments using bentonite and kaolin clay separately as binder of varying composition were carried out to measure basic mechanical properties. Green compressive strength ranged from 12KN\m^2 for 0.5% to 28KN\m^2 for 3.0% bentonite clay content. It ranged from 20KN\m^2-32KN\m^2 for the same kaolin clay content. The dry strength, green permeability, green hardness and shatter index were determined as shown in Table 4 and 5 respectively. The results showed kaolin is about 20% a better sand binder than bentonite. The results of the property analysis when compared with foundry standard [18] showed it is suitable for all categories of non-ferrous alloy castings in green or dry sand moulds from 1.5% bentonite clay and 1.0% kaolin with about 2% moisture. The limitation to application of the sand is due mainly to low refractoriness of the sand caused by presence of low melting point oxide like sodium oxide that fluxes out as sodium hydroxide at high temperature.

CONCLUSION

This study revealed that river Niger sand taken from Geregu village behind Ajaokuta Steel Plant is alumino-silicate with physio-chemical properties that are suitable for non-ferrous alloy casting because of its low refractoriness. It responded well to bentonite and kaolin clay binders that gave good mechanical properties to sand mould specimens. Kaolin clay was found to give better with the sand bonding properties than bentonite clay. The result of the mechanical properties analysis of the sand was compared to existing foundry standard and it was discovered to be very suitable to all types of non ferrous alloy castings at 2.5% bentonite clay and 1.0% kaolin clay with about 2% moisture content.

Appendix A: Plot of compsional analysis of river niger sand

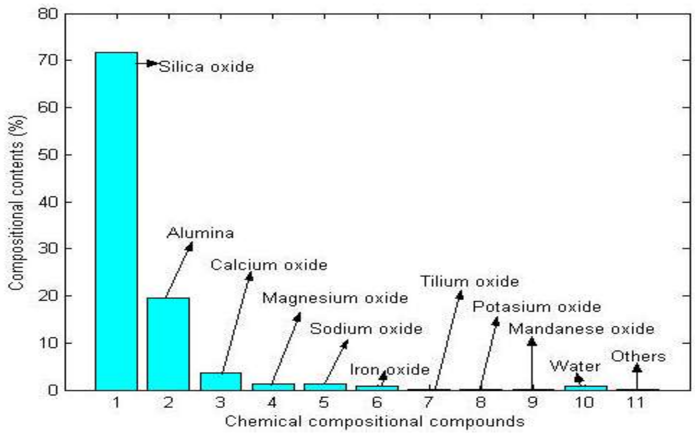

Fig. A1: Proximate/chemical analysis of river Niger sand

Appendix B: Sand sieve analysis for grain size distribution

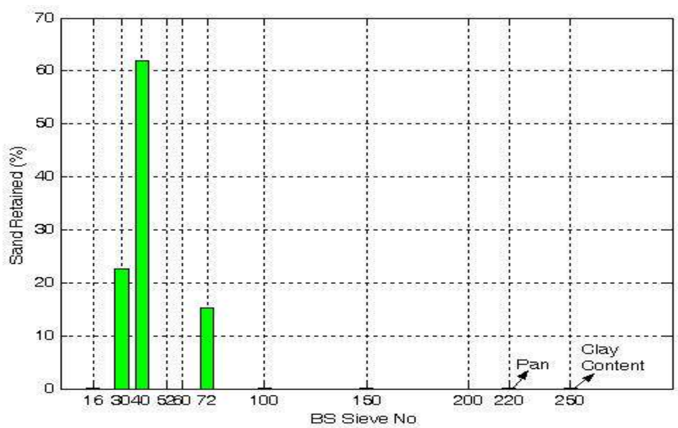

Fig. B1: Mechanical sieve analysis of the River Niger base sand obtained from Geregu behind Ajaokuta Steel Company Limited used for the project showing the percentages retained on each sieve.

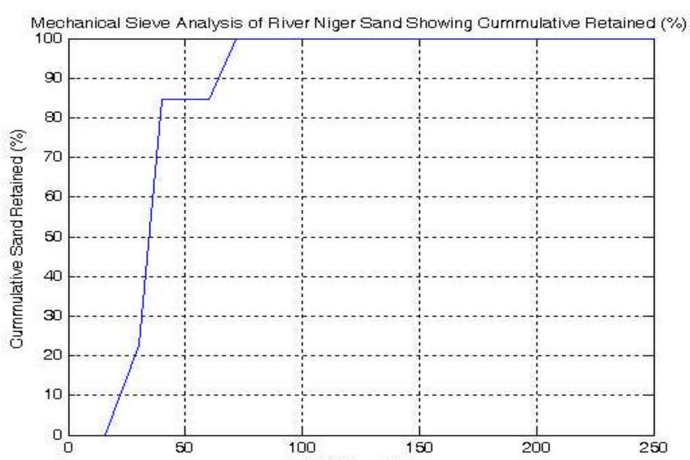

Fig. B2: Mechanical sieve analysis of the River Niger base sand obtained from Geregu behind Ajaokuta Steel Company Limited used for the project showing the cumulative percentages retained on each sieve

Appendix C: Graphical plots of the moulding sand analysis

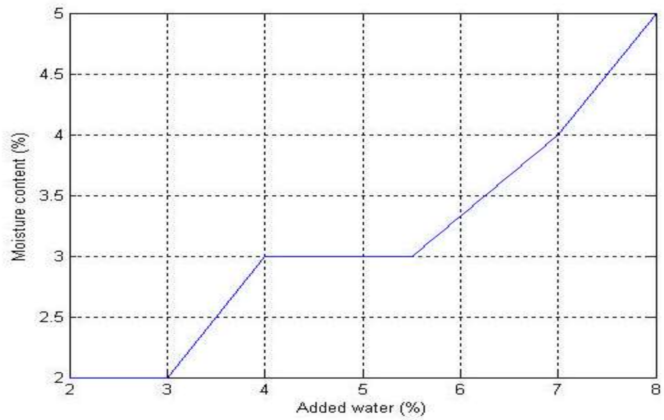

Fig. C1a: Moisture content (%) of River Niger sand moulds bonded with varying percentages of water

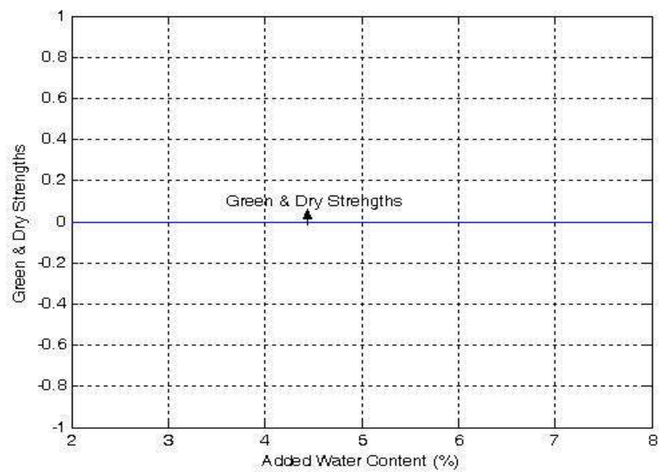

Fig. C1b: Green and Dry compressive strengths (KN\m^2) of River Niger sand moulds bonded with varying percentages of water content

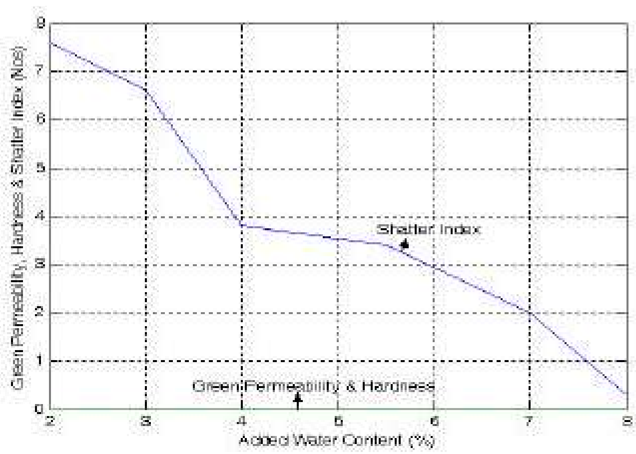

Fig. C1c: Green permeability no green hardness no and shatter index No of River Niger sand moulds bonded with varying percentages of water contents

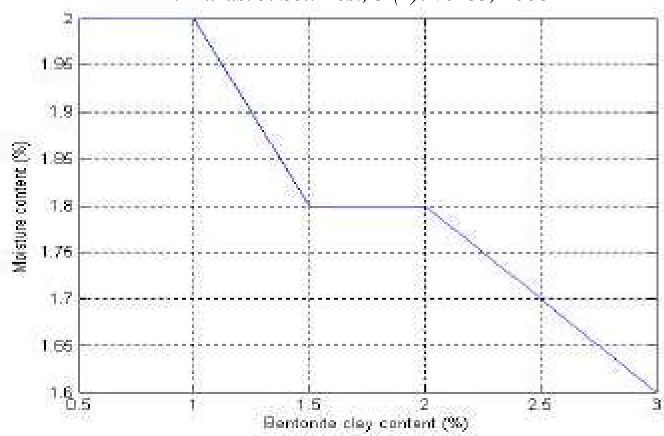

Fig. C2a: Moisture content(%) of River Niger sand moulds bonded with varying percentages of bentonite clay and 3% water content

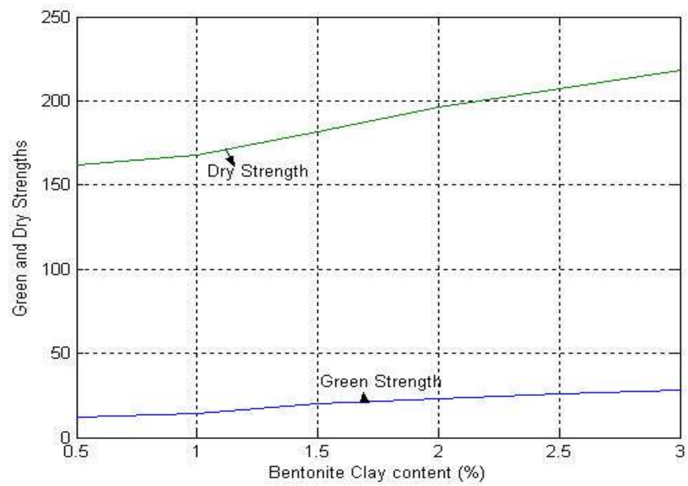

Fig. C2b: Green and Dry Compressive strengths (KN\m^2) of River Niger sand moulds bonded with varying percentages of bentonite clay and 3% water content

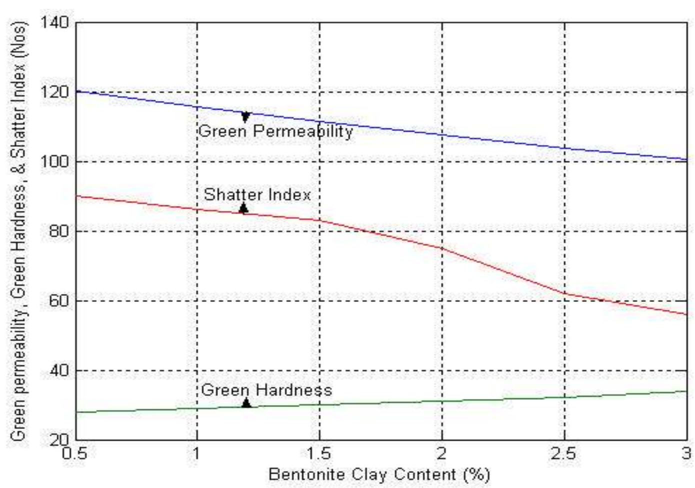

Fig. C2c: Green Permeability No, Green Hardness No and Shatter index No of River Niger sand moulds bonded with varying percentages of bentonite clay and 3% water contents

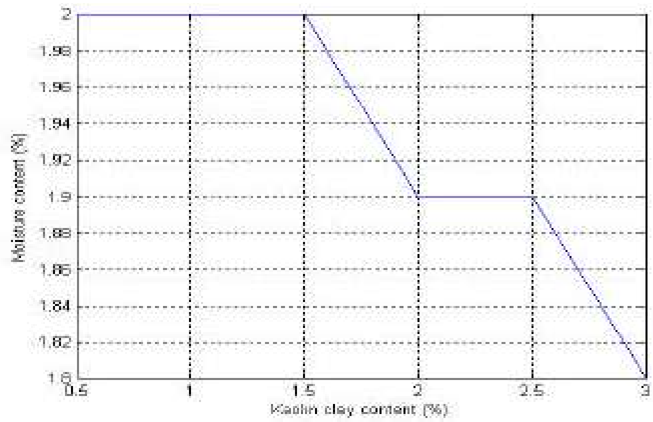

Fig. C3a: Moisture Content (%) of Foundry sand moulds bonded with varying percentages of Kaolin 3% water

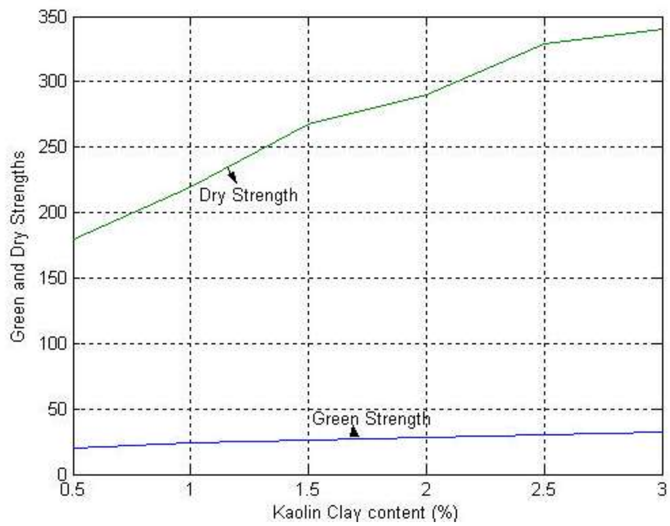

Fig. C3b: Green and Dry Compressive strengths (KN\m^2) of Foundry sand moulds bonded with varying percentages of Kaolin clay and 3% water content

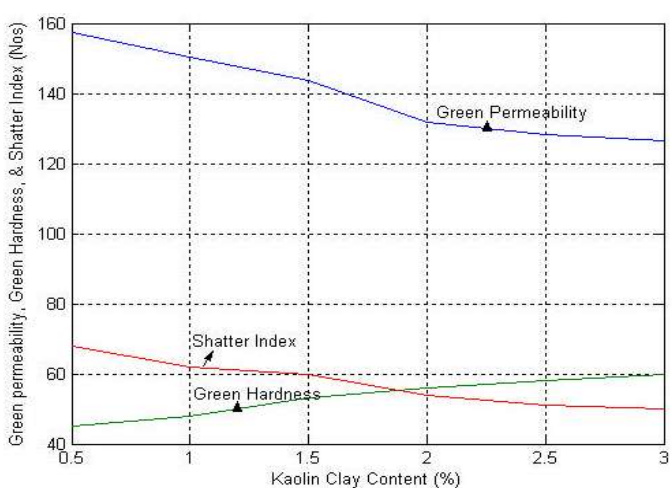

Fig. C3c: Green Permeability No, Green Hardness No and Shatter index No of Foundry sand moulds bonded with varying percentages of Kaolin clay and 3% water content

Since the river sand sourced from the point location covered by this research was found be unsuitable for ferrous casting, it is hereby recommended that sand from other locations like the confluence point of rivers Niger and Benue, along other locations on river Niger, along river Benue and other close sources to the Ajaokuta Steel Plant should be research on to discover the sand that is suitable for ferrous castings to complement this work. The bed sand of some major streams around the steel plant could be included in the investigation.

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