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An assessment of the binding capacity of bentonite and ukpor clay on the foundry properties of river Niger, Onitsha beach sand

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Abstract

This study assessed the binding efficacy of bentonite and Ukpor clay on the foundry properties of sand obtained from the River Niger Onitsha beach. Chemical analysis was conducted using the x-ray fluorescence technique. Sieve analysis was conducted using electric sieve shaker. The mechanical properties of the moulding sand were tested using standard techniques (AFS). The mechanical properties tested were green compressive strengths, green shear strength, dry compressive strengths, dry shear strength, permeability and fusion point. Result of the test obtained include: compressive strength (28KN/m^2, 23.48 KN/m^2), dry compressive strength (217 KN/m^2, 215 KN/m^2), permeability (146.64 No 148.451No) for bentonite and Ukpor clay respectively with fusion point (1390^{0}C) and AFS grain fineness number (81.81) of River Niger Onitsha beach sand. From the result it was found that 5% of Ukpor clay and 5% of bentonite respectively and then 4% water were most suitable for moulding river Niger Onitsha beach sand for application in non-ferrous foundry. Therefore, Ukpr clay is an excellent candidate to replace bentonite in mould production in the non-ferrous foundry.

Keywords: Assessment, binding effects, bentonite, foundry properties

1. Introduction

Foundry sand mixtures for moulding purposes should possess certain properties such as green strength, permeability, as well as dry strength (Onyeji, 2012) [11]. The required levels of these properties vary depending on the type of moulding, the type of metal casting, as well as the size and shape of cast (Bam *et al*. 2015) [2].

There have been various efforts by Nigerians aimed at developing suitable local materials to replace imported ones for the production of sound castings. But most of these works have been mostly on determining the refractory properties of various deposits of clays which are abundant in the country and are used as binder in the moulding sand industry (Katsina et 2013) [8]. Folaranmi (2009) [6] investigated the effect of additives (sawdust and ashes) on the thermal conductivity of clay, Results obtained showed that with sawdust addition, the clay was suitable as clay oven material as well as a good insulator. Fatai *et al.* (2011) [5] also investigated the effect of binders (bentonite and dextrin) and water on the properties of recycled foundry sand, made from silica sand obtained from Ilaro deposit of Ogun state Nigeria. The results showed that with minimum additives of binders, recycled Ilaro sand can be reused.

Development of Igbokoda clay in the south western part of Nigeria as a binder for synthetic moulding sand was carried out by Loto and Omotoso (1990) [9]. Their results confirmed that Igbokoda clay had good value as a binder for synthetic moulding sand. The satisfactory mould property range for sand castings are presented in Table 1. The properties are for ferrous and non-ferrous castings.

According to Brownes (1971) [3] the ratio of sand to weight of casting is 8.1 and a tonne of casting needs about 150tonnes of handling materials making it imperative that the source of sand be near to a foundry for better economics. It is established that the quality of casting is controlled considerably by sand properties such as green compressive strength, dry strength, permeability and compactibility. All these properties depend on such factors as the quality of binder used, amount of water and sand grain size (Dietert 1966) [4].

The natural bonded sand grains are normally coated with clay, which becomes sticky when water is added to it. The clay in the sand is used to cohesively bond sand particles, giving it some binding strength. The resulting sand-clay mixture thus has enough strength to hold the shape when pressed against a pattern producing good sand casting products. In fact, Abolasin *et al* (2007) produced some samples of brake disc and impeller-blade using silica sand without any additives and found that the cast yield was high with minimal surface defects. Solenicki *et al* (2009) concluded that the knowledge of the heating rates of sand moulds would help reduce the occurrence of defects generated by internal stresses due to high operating temperature.

2. Materials and Methods

All the materials required for this research were sourced locally. The silica sand was sourced from River Niger located at Onitsha, while the binding clay was sourced from Ukpor in Nnewi South Local Government Area both in Anambra State. Each of the test specimens from the various mixtures were subjected to the relevant sand mould test such as chemical analysis of River Niger Onitsha beach sand, sieve analysis, green compression strength, green shear strength, dry compression strength, dry shear strength, moisture content, and permeability tests.

2.1 Determination of grain size distribution
The stocks of sieve were arranged according to the sieve aperture with the largest aperture on top of the stock and the smallest aperture at the bottom (on top of pan). Some quantity of sand was dried in the air and 1000g of the sand sample was put into the top sieve stock. The stocks were placed on a sieve shaker which was then switched on, and allowed to vibrate for a period of thirty (30) minutes. The sieves were removed one after the other beginning with the one on top. The quantity of sand remaining on each sieve was weighed. The weight was recorded accordingly for each sieve in the column corresponding to the sieve mesh serial number of 1.00mm, 0.71mm, 0.50mm, 0.18mm, 0.125mm, 0.09mm and 0.063mm. Each separate sieve weight was multiplied by the corresponding sieve mesh number. The sum total of the product was divided by the total sample aligned and this produced the fineness number of the sand.

$$\text{AFS grain fineness number} = \frac{product}{amount\ related\ (\%)}$$

2.2 Determination of green compression strength
The green compression strength was carried out using universal sand strength testing machine. A prepared standard sample was positioned in the compression head already fixed into the machine. The sample was loaded gradually, while the magnetic rider moved along the measuring scale. As soon as the sample reached its maximum strength, the sample experienced failure and the magnetic rider remained in position of the ultimate strength (a value was noted), while the load was gradually released.

2.3 Determination of dry compression strength
A prepared standard sample of 5cm diameter x 5cm height was dried in the oven at a temperature of 110^{o}C for a period of 20minutes and then removed and allowed to cool in the air to ambient temperature. After cooling, the sample was fixed into the universal sand-testing machine with the compression head in place. The compressive load was applied and the samples failed at the ultimate compressive strength of the sample. The point at which the failure occurred was recorded at DCS

2.4 Determination of dry shear strength
The prepared standard sample of 5cm diameter x 5cm height was dried in the oven at a temperature of 110^{o}C for 20 minutes and then removed from the oven to cool in an air to ambient temperature. The same universal testing machine was used for dry compression strength. In this case, the shear head was replaced for the compression head. The shear strength was recorded at the point of failure of the standard test sample.

2.5 Determination of green shear strength
The machine used for the GCS was also used for the determination of green shear strength (GSS), except that the compression head was replaced with shear head in the machine. The green shear strength was recorded at the point of failure of the sample loaded

2.6 Determination of permeability
The permeability test was done on the standard sample specimen of 5cm diameter x 5cm height. The specimen, while still in the tube, was mounted on permeability meter. The permeability meter is an electrical perimeter and it employed the orifice method for rapid determination of sand permeability. Air at a constant pressure is applied to the standard sample specimen, immediately after producing the sample and the drop in pressure was measured using a pressure gauge, which is calibrated directly in permeability numbers.

2.7 Fusion point
The fusion point of the selected sand grains was determined using heat treatment furnace, a method similar to loss on ignition was used, with the sand condition monitored at intervals to observe the temperature at which the sand grains fused together.

2.8 Chemical analysis
The chemical composition of the samples (River Niger Sand and Ukpor Clay) were determined using x-ray fluorescence (XRF) spectroscopy technique at National Defence Industry Kaduna. This is a non-destructive analytical method in which x-ray tube is used to irradiate the sample with a primary beam of x-ray. Some of the impinging primary x-rays are absorbed by the sample (elements) in a process known as photoelectric effect, (Aliyu *et al* 2013)

3. Results and Discussion
The results of the research are presented in Tables 2 – 5 and in figures 1 -7. Figure 1, shows the graphical representation of the mechanical sieve analysis of the River Niger Onitsha beach sand, summarized in the form of a bar chart. The sieve numbers and the weight percentages retained are shown in the horizontal and vertical axis. The figure 1 and Table 2 revealed that the grains of the sand were sub-angular and had well defined grading with 70.85% concentration retained by the three adjacent sieves of 0.18mm, 0.125mm and 0.09mm. This implies a highly concentrated small grain structure, which would enhance fine surface finish of casting (Adesina 2010). The grain fineness number (81.81) falls within the acceptable range. According to the American Foundrymen's society (AFS) standard. Fatai *et al* (2011) [5] stated that 40 to 330 average fineness is suitable for foundry applicaton. The River Niger Onitsha beach sand has an average fineness number of 81.81. Table 3 showed that the River Niger Onitsha beach sand has 94.49% SiO_2, 1.30% K_2O and 1.675% Fe_2O_3 as the major components. The silica content of 94.49% compares well with the acceptable values of between 80% and 97% recommended for moulding (Jain, 2008) [7], which is below the range recommended for ferrous castings, because according to Mclaws (1971) [10] ideal sand for ferrous casting should contain silica in the region of 98% - 99%.

Moulding experiments using bentonite and Ukpor clay as binder at varying composition were carried out to determine the basic mechanical properties such as the green compressive strength, green shear strength, dry compressive strength, dry shear strength, permeability and moisture content of the moulded River Niger Onitsha beach sand. Green compressive strength increased from 14.20kN/m^2 for 1.0% bntonite to 28kN/m^2 for 5.0% bentonite content. It increased from

12.41kN/m^2 of 1.0% Ukpor clay to 23.48kN/m^2 of 5% Ukpor clay content. Dry compressive strength increased from 151.0KN/m^2 of 1% bentonite content to 217.0kN/m^2 of 5.0% of bentonite content. While Ukpor clay sample, increased from 150.0 kN/m^2 for 1.0% to 215.0 kN/m^2 for 5.0% Ukpor clay content. The values obtained using 4% - 5% of the binders are shown in Tables 4 and 5. Dry compressive strength values were in agreement with the American Foundrymen Standard (AFS) shown in Table 1. The permeability tests decreased with increase in percentage binder content additions, the green permeability decreased from a maximum of 150.0 No at bentonite addition of 1.0% content to 146.64 No at 5% bentonite content. This pattern is also exhibited for Ukpor clay sample, but with a higher value of 154.20 No at clay content of 1.0% and decreased to 148.45 No at 5.0% of Ukpor clay content addition. The green shear strength, dry shear strength and moisture content tests were determined as shown in Table 4 and 5. The results of the property analysis when compared with foundry standard showed that it is suitable for all categories of non-ferrous alloy casting, in green or dry sand moulds from 4% to 5% bentonite or Ukpor clay content addition with about 4% water addition.

River Niger Sand is sub-angular in shape and brownish in colour. It is very fine silica sand, the free content of clay of the sand makes it suitable for use as core sand in addition to its suitability for use as a moulding sand. The fusion point of River Niger Onitsha beach sand is 1390^{o}C. The fusion point gives important information about the themal resistance of the sand

Table 1: satisfactory mould property ranges for sand castings

Metal	Green compressive strength (kN/m^2)	Dry strength (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	50 – 800	70 – 120
Aluminium	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

Source: (Dietert 1966) [4]

Table 2: AFS grain fineness number for sand

Sieve No	Aperture size in (mm)	Sand retained on each sieve (g)	Percentage of sand retained	Multiplier	Product
1	1.00	9.80	0.98	9	8.82
2	0.71	10.50	1.05	15	15.75
3	0.50	40.20	4.02	25	100.50
4	0.355	95.20	9.52	35	333.20
5	0.25	44.70	4.47	45	201.15
6	0.18	340.50	34.05	60	2043.00
7	0.125	205.00	20.50	81	1660.50
8	0.09	163.00	16.30	118	1923.40
9	0.063	55.00	5.50	164	902.00
10	Pan(-63)	36.1	3.61	275	992.75
11		1000	100		8181.07

AFS grain fineness number = 81.81

Table 3: Chemical composition of River Niger Onitsha beach sand

Comp	SiO_2	K_2O	CaO	TiO_2	V_2O_5	Mno	Fe_2O_3	NiO	CuO	Ag_2O	BaO	Nd_2O_3	OSO_4	Au	HgO
Conc unit	94.49	1.30	0.48	0.34	0.01	0.03	1.68	0.01	0.00	0.90	0.05	0.05	0.14	0.23	0.30

Table 4: Properties of mould sand mixtures with 4% water content constant

Bentonite %	1	2	3	4	5
Green compression strength (kN/m^2)	14.20	18.40	21.76	25.80	28.00
Green shear strength (kN/m^2)	1.25	1.52	3.89	5.20	6.80
Dry compression strength (kN/m^2)	151.00	174.00	196.00	210.00	217.00
Dry shear strength (kN/m^2)	40.00	49.00	53.00	68.00	73.00
Permeability No	150.00	148.00	146.94	146.90	146.64
Moisture content %	3.60	3.50	3.20	3.11	3.11

Table 5: Properties of mould sand mixtures with 4% water content constant.

Ukpor clay %	1	2	3	4	5
Green compression strength (kN/m^2)	12.41	15.30	17.25	21.44	23.48
Green shear strength (kN/m^2)	1.40	2.20	2.81	4.00	4.91
Dry compression strength (kN/m^2)	150.00	175.00	196.00	206.00	215.00

Dry shear strength (kN/m^2)	31.00	41.00	50.00	57.00	61.00
Permeability No	154.20	153.00	150.30	150.00	148.45
Moisture content %	3.35	3.25	3.20	3.00	2.94

Fusion point of River Niger Onitsha sand=1390^{o}C

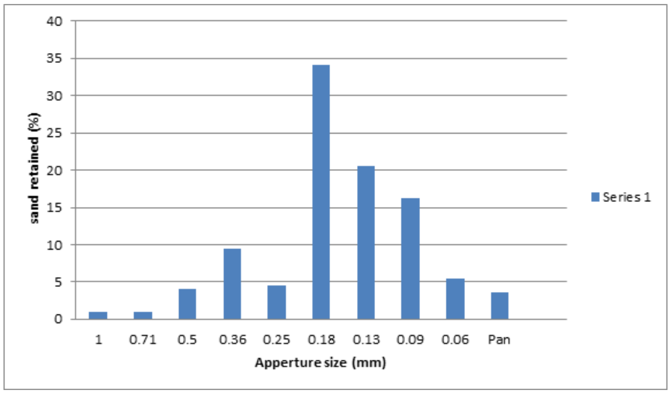

Fig 1: Percentages of Sand retained on each aperture size.

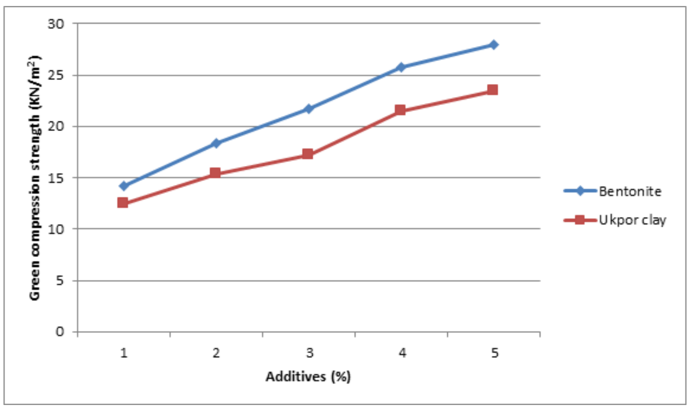

Fig 2: Effect of additives on the green compression strength and 4% water constant

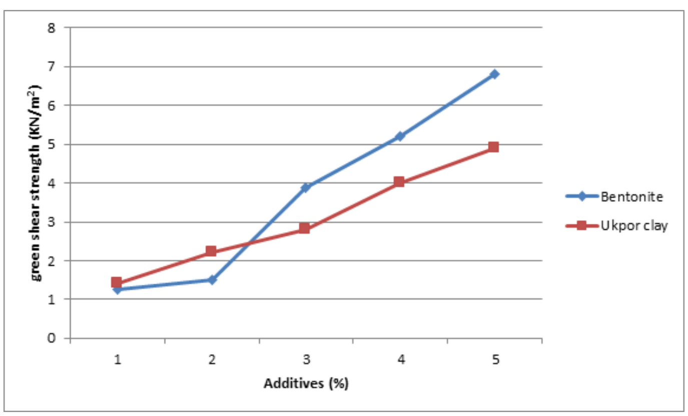

Fig 3: Effect of additives on the green shear strength and 4% water constant

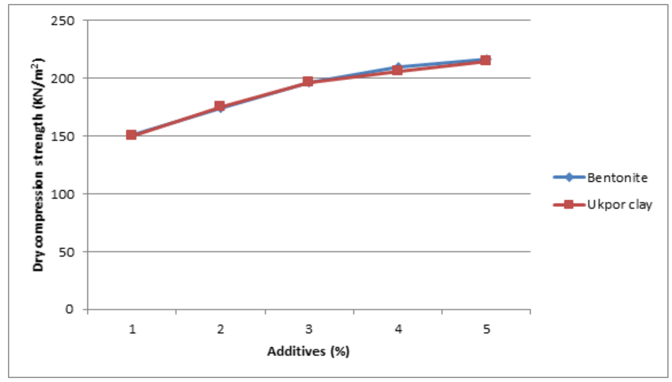

Fig 4: Effect of additives on the dry compression strength and 4% water constant

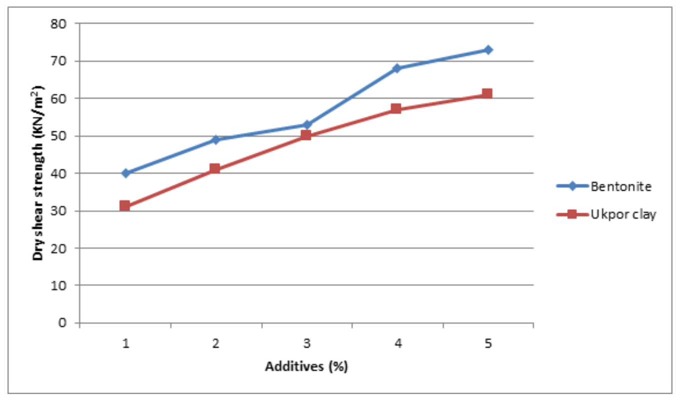

Fig 5: Effect of additives on the dry shear strength and 4% water constant

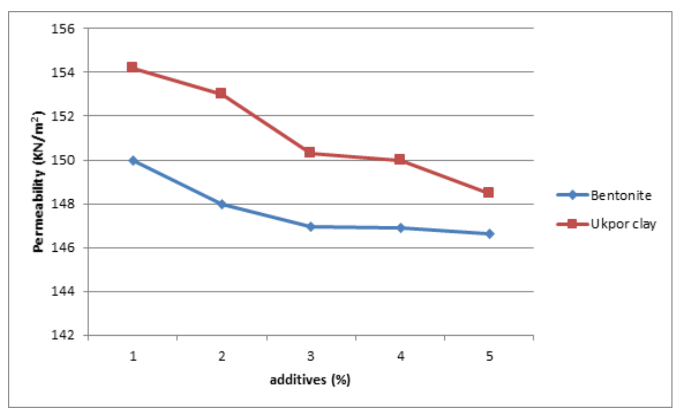

Fig 6: Effect of additives (%) on the Permeability (KN/m^2) and 4% water constant

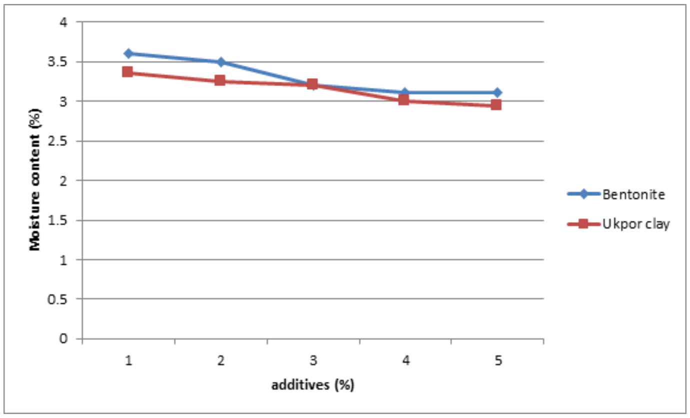

Fig 7: Effect of additives on the Moisture content and 4% water constant

4. Conclusion

The following conclusions are drawn from the results presented

1. The sand mix with 5% bentonite and 4% water content was the best mixture followed by 5% Ukpor clay and 4% water content. These properties compared favourable with the proportion of the moulding sand currently used in foundries for casting of non-ferrous alloys
2. The fusion point reveals that River Niger sand beach located at Onitsha is mainly suitable for non ferrous metals, with melting point lower than 1390^0C.
3. Chemical analysis results reveals that the sand is pure silica with physio-chemical properties that are suitable for non-ferrous alloy casting because of its low refractoriness.

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