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Efficacy of moisture content on the moulding properties of river Niger Onitsha beach sand using ukpor clay as a binder

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Abstract
This paper investigated the efficacy of moisture content and the bonding capacity of the River Niger Onitsha beach sand. Sieve analysis was conducted using electronic sieve shaker. Mechanical properties tested were green and dry compressive strengths, dry shear strength, permeability, refractoriness and fusion point using American Foundrymen Society Standard. The result obtained showed that green compressive strength was 21.69KN/m^2, dry compressive strength was 210KN/m^2, permeability was 150.50 No, refractoriness was 1388^{0}C, fusion point was 1390^{0}C and AFS grain fineness number was 81.81 for the moulded River Niger Onitsha beach sand. From the results, it was found that 3% moisture content and 4% of Ukpor clay were most suitable for moulding River Niger Onitsha beach sand for application in non-ferrous foundry and therefore, these results compared favourably with those obtained with bentonite. Ukpor clay could serve as a satisfactory alternative to bentonite for use as binding clay, in non-ferrous foundry.

Keywords: Moisture content, moulding properties, binder

1. Introduction

Sand is the principal moulding material in the foundry industry where it is used for all types of castings (ferrous or non-ferrous). This is because it possesses good properties needed for foundry purposes such as refractoriness, permeability, chemical resistivity etc. (Mathew *et al.*, 2010) [7]. The major ingredients of moulding sand include silica sand grain, clay and water content. The silica sand grains is of paramount importance in moulding sand because it impart refractoriness, chemical resistivity and permeability to the sand. While clay on the other hand imparts the necessary bonding strength to the moulding sand, so that after ramming, the mould does not lose its shape. However, as the quantity of the clay is increased, the permeability is reduced. Clay is defined by the American Foundry Society (AFS) as those particles of sand (under 20microns in diameter) that fail to settle at a rate of 25mm per minute, when suspended in water. The foundry industry in Nigeria use imported binders and synthetic sand for moulding. The quality of casting is influenced significantly by sand properties such as green compressive strength, dry strength, permeability, compactibility, refractoriness, moisture content and others as stated by Mahesh *et al.* (2008) [6]. All these properties are in turn dependent on the parameters of the binder, water and sand grain size used. Dieter, (1966) [2] gave the satisfactory mould property ranges for sand castings of various metal grades (Table 1). Some researchers have investigated the suitability of Nigerian clay deposits for foundry preparations (Ayoola *et al.* 2010) [1]. 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) [5]. Their results confirmed that Igbokoda clay had good value as a binder for synthetic moulding sand. Evaluation of the foundry properties of River Niger sand behind Ajaokuta town in Nigeria was carried out by Nuhu (2008) [9]. Bentonite and kaoline were used as binder. The sand gave good foundry properties when bonded with Kaolin or bentonite with kaolin having a stronger influence on the bond properties of the sand. Katsina *et al.* (2013) [4] Characterized the Beach sand for foundry application and discovered that sand from Ughelli River, Warri River and Ethiope River could be used effectively in the foundry. However the sand from Lagos bar beach requires to be sieved properly to remove the coarse fractions. Fatai *et al.* (2011) [3] also investigated the effects of binders (bentonite and dextrin) and water on the properties of recycled foundry sand made from silica sand obtained from Ilaro sand deposit of Ogun State, Nigeria. They found that with minimum additives of binders recycled Ilaro sand can be reused.

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) [2]

2. Materials and method materials

All the materials required for this research were sourced in-site. The silica sand was sourced from the River Niger at Onitsha, while the binding clay was sourced from Ukpor in Nnewi South local government area both in Anambra state Nigeria.

This study was experimental and consisted of the mechanical sieve analysis of the sand, green compression strength, green shear strength, dry compression strength, dry shear strength, moisture content and permeability test of the sand specimen.

2.1 Preparation and Determination of Grain Size

The silica sand was washed, oven-dried at 110ºC and sieved to remove coarse and dusty materials. The size and distribution of sand grain was determined with sieve analysis. 1000g of the dried silica sand was measured on a weighing balance. The weighted sand was then placed on top of a set of sieve of decreasing aperture (1.0-0.063mm) size contained in a shaker. The shaker was switched on for a period of 30mins, after which the sand retained in each sieve and the bottom pan was weighed and recorded against the sieve aperture size and their percentages to obtain the grain size according to the equation 1. The tests were all carried out according to American Foundry Society (AFS) standard for foundry sands.

AFS grain fineness number =

$$\frac{product}{amount\,retained\ (\%)} \qquad 1$$

2.2 Determination of Green Compression Strength

The green compression strength was determined using universal sand strength testing machine. A prepared standard sample (5 diameter x 5cm height) 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 which value was recorded

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 110ºC for a period of 20minutes and then removed and allowed to cool in the air to ambient temperature. After cooling, the sample was fixed onto the universal sand-testing machine with the compression head in place. The compressive load was applied and the samples failed at the maximum load capacity 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 110ºC for 20 minutes and then removed from the oven to cool in air to ambient temperature. The same universal testing machine used for dry compression strength was also used. In this case, the shear head was replaced with 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 the permeability meter. Air at a constant pressure was applied to the standard specimen, and the drop in pressure was measured using a pressure gauge, calibrated directly in permeability numbers.

2.7 Refractoriness

The sand for the refractory test was mixed with the desired quantities of alkali free dextrin and water. The mixture was moulded into cone shaped and then dried in oven at 110^0C. Followed by sintering the cone shaped sample in the furnace to a temperature of 1000^0C. The standard pyrometric cones of known softening temperature and the prepared sample were arranged in furnace to test for the refractoriness. The cones are heated gradually until softening of the cones are observed in the furnace. The softening point of the pyrometric cones which corresponded with the time of the softening of the test sample was recorded. The temperature at which this occur was measured as the refractoriness. After which the fusion point was also observed and noted.

3. Results and Discussion

The results of the investigation are presented in Tables 2-4 and figures 1-8. Table 2 shows the results of sieve analysis values, while Table 3 depicts the parameters and the grain fineness number of River Niger Onitsha beach sand. According to the American foundrymen's society (AFS) (1963) standard. 40 to 330 average fineness is suitable for foundry application. The River Niger Onitsha beach sand has average fineness number of 81.81 (Table 3). The grain fineness number is a useful parameter that represents the sieve number through which all the sand grains would pass through, if they were of the same sizes. The grain fineness number though is a useful parameter but the choice of sand for moulding should be based on particle size distribution. The size distribution of the sand affects the quality of casting.

The fusion point of the River Niger Onitsha silica sand is 1390^0C, this is the measure of the refractoriness of the sand. The fusion point gives important information about the thermal resistance of the sand. It showed that the sands are mainly suitable for non-ferrous metals with melting point lower than 1390^0C.

The green compressive strength increased with increase in moisture content reaching a maximum at 3% water content Thereafter, it decreased as shown in Table 4 and Figure 3. The green strength increased from 15.50kN/m^2 at 1% water content to 21.69KN/m^2 at 3% water, thereafter decreased to 20.30 kN/m^2 at 5% water content. Further increase in the percentage of water content above 3% led to reduction in the green compressive strength. Decrease in green compressive strength with increase in water content suggest the presence of excess moisture in the sand mould. The maximum moisture content of 3% is adequate to obtain sound cast product with 4% Ukpor clay content based on green sand property.

The effect of moisture content on the values of green shear strength is shown in Figure 4. The green shear strength of the moulding sand mixture was observed to increased from 3.0 kN/m^2 at 1% water to 4.01 kN/m^2 of 3% water content. Thereafter it decreased to 3.80 kN/m^2 at 5% water content. The dry compression strength of the moulding mixture was observed to increase from 165 KN/m^2 at 1% water to 210 kN/m^2 at 5% water content. This indicated that the sand in dry condition can withstand the pressure of 200KN/m^2 of the molten metal during the period of solidification in the mould once the moulding water was at the maximum content. This makes the dry moulding sand to be more suitable for large castings. This property evaluated is in agreement with the American Foundrymen standard (AFS). The dry shear strength of the moulding mixture was observed to increase with the increase in water content addition reaching a maximum value of 60kN/m^2 of 5% water content (Figure 6).

Figure 7. Shows the effect of moisture content on the permeability of the moulding sand mixture as percentage water content increased. The permeability was observed to increased from 148No at 1% water to 151No at 2% water content thereafter, decreased to 147No at 5% water content. This behaviour could be attributable to the fact that water acts as blockage to the air pores in the sand thereby impeding the free passage of air through the sand. As water content increased, the excess moisture available occupies the pores in the sand mould thus, leading to a corresponding decrease in the permeability of the sand.

Table 2: Sieve analysis values of the River Niger Onitsha beach sand

Sieve serial No	Aperture size in (mm)	Sand retained on each sieve (g)	Percentage of sand retained	Cumulative % retained
1.	1.00	9.80	0.98	0.98
2.	0.71	10.50	1.05	2.03
3.	0.50	40.20	4.02	5.07
4.	0.355	95.20	9.52	13.54
5.	0.25	44.70	4.47	13.99
6.	0.18	340.50	34.05	38.52
7.	0.125	205.00	20.50	54.55
8.	0.09	163.00	16.30	36.80
9.	0.063	55.00	5.50	21.80
10.	Pan(-63)	36.1	3.61	9.11
11.		1000	100	

Table 3: Parameters of River Niger Onitsha beach sand and AFS grain fineness number

Sieve serial No	Aperture size in (mm)	Sand retained on each sieve (g)	Percentage of sand retained	Multiplier	Product	AFS grain fineness number
	1.00	9.80	0.98	9	8.82	81.81
	0.71	10.50	1.05	15	15.75	
	0.50	40.20	4.02	25	100.50	
	0.355	95.20	9.52	35	333.20	
	0.25	44.70	4.47	45	201.15	
	0.18	340.50	34.05	60	2043	
	0.125	205.00	20.50	81	1660.5	
	0.09	163.00	16.30	118	1923.4	
	0.063	55.00	5.50	164	902	
	Pan(-63)	36.1	3.61	275	992.75	
		1000	100		8181.07	

Table 4: Properties of mould sand mixture with 4% Ukpor clay

Water %	1	2	3	4	5
Green compression strength (kN/m^2)	15.50	19.80	21.69	21.44	20.30
Green shear strength (kN/m^2)	3.00	3.91	4.01	4.00	3.80
Dry compression strength (kN/m^2)	165.00	180.00	201.00	206.00	210.00
Dry shear strength (kN/m^2)	42.00	45.00	51.00	57.00	60.00
Permeability No	148.00	151.00	150.50	150.00	147.00

Refractoriness: 1388^{0}C {For pure silica sand blended only with alkaline free dextrin}

Fusion point: 1390^{0}C

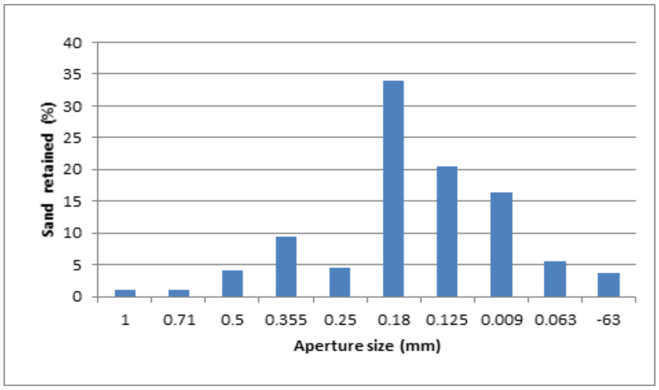

Fig 1: Relationship between aperture size and percentage sand retained

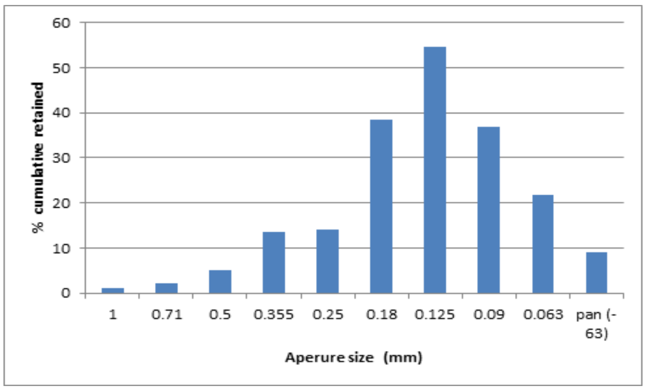

Fig 2: Relationship between aperture size and cumulative percentage retained

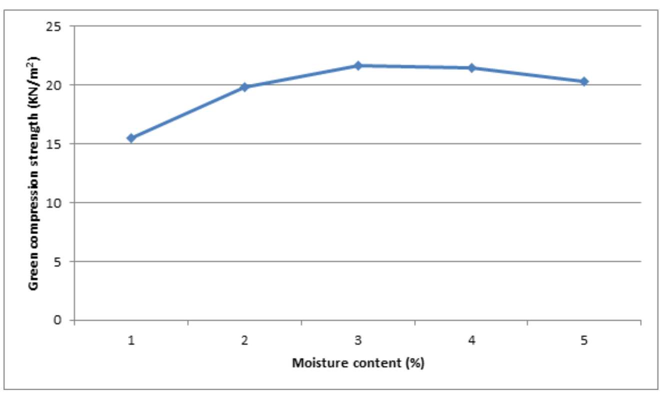

Fig 3: Effect of moisture content on the green compression strength of River Niger Onitsha beach sand

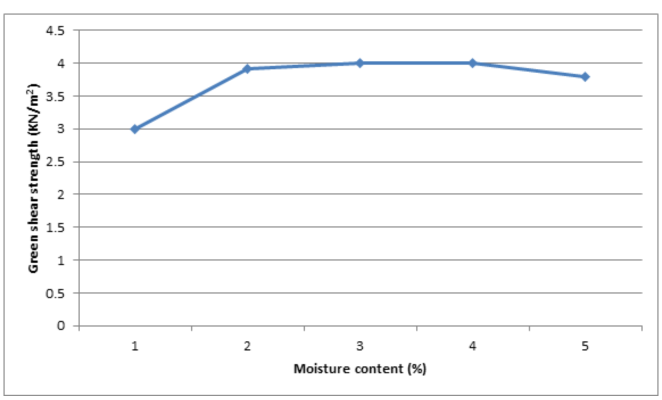

Fig 4: Effect of moisture content on the green shear strength of River Niger Onitsha beach sand

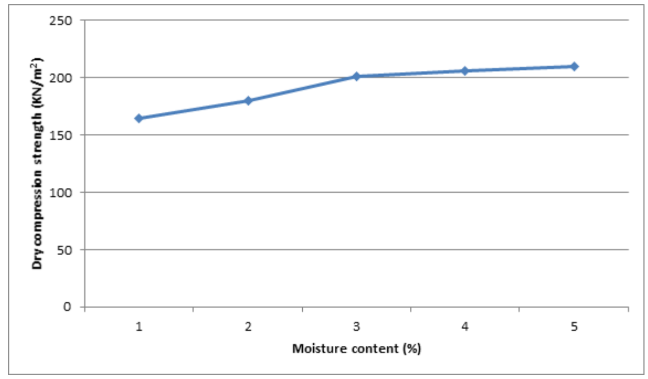

Fig 5: Effect of moisture content on the dry compressive strength of River Niger Onitsha beach sand

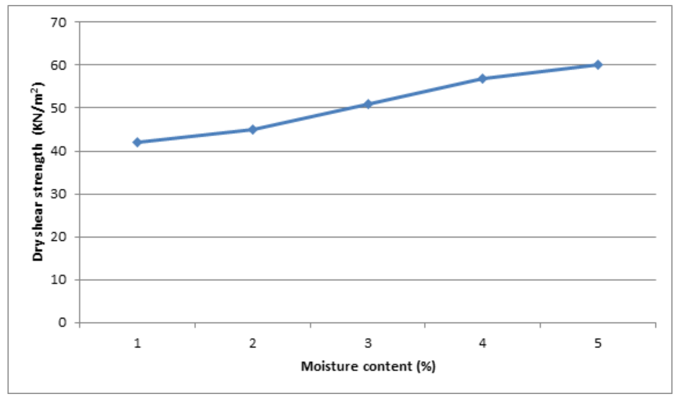

Fig 6: Effect of moisture content on the dry shear strength compressive strength of River Niger Onitsha beach sand

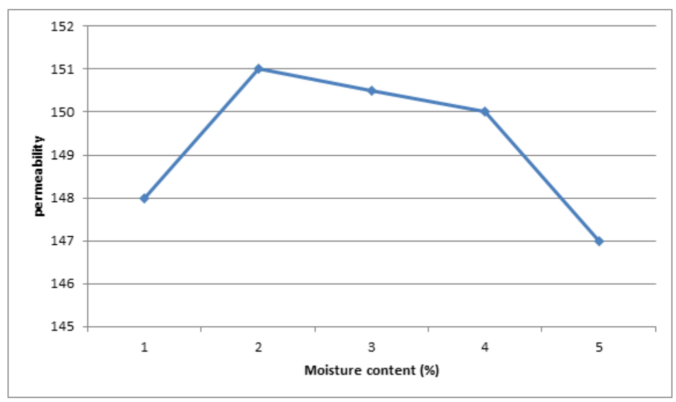

Fig 7: Effect of moisture content on permeability of River Niger Onitsha beach sand

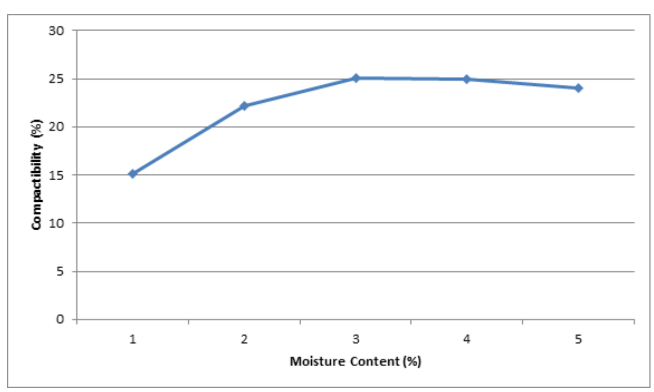

Fig 8: Effect of moisture content on Compactibility of River Niger Onitsha beach sand

4. Conclusion

Moisture has a very strong influence on the foundry properties of the River Niger Onitsha beach sand. These properties include the green compressive strength, green shear strength, dry compressive strength, dry shear strength, and permeability tests, all of which attained their maximum value with moisture content of 3%. Hence 3% moisture content is most suitable for maximum moulding properties required as shown in figures 3 –8. According to Scott (2000), increasing the water content in sand increases the green compressive strength to a point referred to as temper point. However, beyond the temper point, water content addition does not lead to further increase in the properties of sand, but rather for instance leads to a reduction in the sand green compressive strength. Therefore, River Niger beach sand is recommended to be used for moulding sand for non-ferrous foundry at moisture content of 3% and Ukpor clay content of 4%. This will ease off the importation of foundry materials and improve the local content of our non-ferrous foundry products

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