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Variation of moisture content with the properties of synthetic moulding sand produced from river Niger sand (Onitsha deposit) and Ukpor Clay

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Abstract

The effects of variation in moisture content on the moulding properties of River Niger sand (Onitsha deposit) bonded with Ukpor clay has been investigated in this research. The samples were prepared by washing and sorting to remove impurities and other foreign objects. Weighed samples were sieved and mixed in a Ridsdale laboratory sand mixer (Serial No: 845). American Foundrymen's Society (AFS) standard test specimens (50mm diameter by 50mm height) were prepared using Ridsdale laboratory sand rammer and moulding properties such as green compression strength, dry compression strength, green shear strength, dry shear strength, green permeability and mouldability were measured using universal sand strength testing machine (Serial No: M8415), electric permeability meter (Serial No: 872) and mouldability tester. Results obtained showed variations in green and dry strengths (Compression and shear), green permeability and mouldability with moisture content. Moisture contents of 4%, 5% and 6% produced maximum values for green compression and green shear strengths (43.40KN/m^2 and 24.50KN/m^2), dry compression and dry shear strengths (395.50KN/m^{2}and 437.50KN/m^2) and green permeability number (12.00) respectively. Percentage mouldability was highest (98.80%) at 3% moisture content and very low above 5% moisture content. The results of moulding sand tests obtained from the produced synthetic moulding sand indicated that the sand could be used in the production of cast iron and non-ferrous alloys castings.

Keywords: moisture content, synthetic moulding sand, moulding properties

1. Introduction

Moulding sand for metal casting is usually sourced from natural deposit or from synthetic mix of refractory base sand grain, binder and moisture that provides the right atmosphere for bonding reaction [1, 2]. Each constituent is important in determining the properties of the moulding sand [3, 4]. With the use of natural sand there is limitation and constraint to the extent of control on the principal ingredients of moulding sand; but with synthetic sand, the three major constituents are well selected to give desired properties within acceptable limits. This makes it mandatory that the effects of these major constituents on the properties of moulding sand be investigated to ascertain the optimum compositional mix.

Clay is mixed with the requisite amount of water to acquire its bonding action. When water is added to clay, it penetrates the mixture and forms a microfilm which coats the surface of each flake–shaped clay particles. The molecules of water forming this film are not in the original fluid state but in a fixed and definite position. As more water is added the thickness of the film increases up to a certain limit after which the excess water remains in the fluid state. The bonding quality of clay depends on the maximum thickness of water film it can maintain.

Moisture content has been cited by many researchers with foundry sand as one of the variables that affect the properties of a moulding sand mixture. The variation of moisture affects properties like bulk density, permeability, green compression strength, dry compression strength, shear strength, and other properties of moulding sand [5, 6]. When sand is rammed in a mould, the sand grains are forced together. If the water added is the exact quantity required to form the film, the bonding action is best. If the water is in excess strength is reduced and the mould becomes weakened.

Thus moisture content is one of the most important parameter affecting mould and core characteristics and consequently, the quality of the moulding sand or core produced.

2. Materials and Methods

2.1 Materials and equipment

The local materials used to compose the synthetic moulding sand were green silica sand from the Onitsha bank of river Niger which lies between latitude 6°06'N and longitude 6°42'E; and Ukpor clay , with the location coordinates 5°56'34"N and 6°55'58"E. The instruments used included set of standard test sieves mounted on a sieve shaker, standard sand rammer (Serial No: 845), motor driven universal sand strength machine (Serial No: M8415), electric permeability meter (Serial No: 872), mouldability tester, laboratory core baking oven (40ºC to 240ºC), laboratory sand mixer and Energy Dispersive X-ray fluorescence Spectrometer (ED-XRFS mini PAL model © 2005).

2.2 Experimental Techniques

2.2.1 Sand and Clay Preparation

Impurities such as hard lumps, metal objects and stones were removed from the natural sand collected from River Niger, Onitsha Bank, along Niger road, Onitsha, Anambra State.

Ukpor clay was dug from a pit in lumps. The lumps of the clay were spread and dried in the sun for about two weeks. The dried clay were then crushed and finely ground to pass through a 200-250 mesh sieve.

2.2.2 Chemical Analysis

Energy Dispersive X-Ray Fluorescence Spectrometer (ED-XRFS Mini PAL 4 Model © 2005) was used to carry out the chemical analysis (Oxide analysis) of the sand and clay samples. The ED-XRFS is a non-destructive method of quantitative and qualitative elemental and oxide analysis of liquid and solid materials.

The machine was switched on and allowed to warm up for about 2 hours. Then, appropriate programs for the various elements and oxides of interest are employed to analyze the sand and clay samples for their presence or absence. In this process, high energy content of an X-ray beam causes the samples to generate X-rays characteristics of the atoms in the samples.

Elements and oxides present in the samples are identified from the energies of the characteristics radiations, and their concentrations are evaluated from intensity measurements. The results of the oxide analysis are recorded in percentage (%) for both minor and major components of the samples.

2.2.3 Sieve Analysis (Grain Size Determination)

Sieve analysis is a process of grading sand sample into different grain size using a stack of standard test sieves and sieve shaker. The stack of sieves were arranged according to the sieve aperture with the largest aperture on top of the stack and the smallest at the bottom. 100g sample of the sand was weighed out of the dry sand and poured onto the topmost sieve stack. The stack was placed on a sieve shaker and then coupled for effective vibration. The time was set to allow vibrations for a period of fifteen (15) minutes. After vibrating for a period of 15 minutes, the sieve shaker stopped automatically. The sieves were dismantled one after the other, beginning with the one on top. The quantity of sand remaining on each sieve was used to determine the average grain size and the grain fineness number respectively.

2.2.4 Mixing Operation

840g of the silica sand was placed in the mill with the required quantity of the bonding clay sprinkled over it. The mill was started to allow the dry ingredients to mix for about 1 minute before adding the required quantity of water. After pouring gradually a measured amount of water into the turn dish, it was allowed to mix for approximately 3 minutes to develop bond. The mill was emptied of the molding sand by withdrawing the sliding door in the bottom of the pan while the rollers were still in motion. A piece of steel plate was used to scrape the sand which was not ejected from the mill.

2.2.5 Preparation of the Test Specimens

The Ridsdale laboratory sand rammer was used for preparing AFS standard test specimens (50mm diameter by 50mm height) for the determination of the various foundry sand properties. 160g weight of sand was compacted in the specimen tube by inserting the tube under the plunger and rammed with three drops of the sliding weight by turning the cam handle three revolutions.

The specimens for strength and mouldability tests were stripped from the tube by inverting over the stripping post and pushing the tube gently downward. While the specimens for green permeability test were tested while in the tube.

2.2.6 Green Strength Tests

a) **Green Compression Strength (GCS) Test:** The GCS test is carried out using the universal sand strength machine (USSM). A freshly prepared AFS standard 50mm diameter by 50mm height test specimen is inserted in the compression heads. The “START” button was pressed and the magnetic rider gradually moves along the reading scale. When the specimen collapsed at its maximum strength, the machine reverses and returned to zero automatically, while the magnetic rider remain in the position of the ultimate strength. The reading shown on the lower edge of the magnetic rider is recorded by reading the scale designated “Green compression strength” The failed specimen is then removed from the compression heads.
b) **Green Shear Strength (GSS) Test:** The same USSM was used for the GSS, but this time, the compression heads in the lower position of the machine is replaced with the shear test heads. The shear strength is recorded when the specimen shears by reading the lower edge of the magnetic rider on the scale designated “Green Shear Strength”.

2.2.7 Dry Strength Tests

a) **Dry Compression Strength (DCS) Test:** The freshly prepared AFS standard 50mm diameter x 50mm height test specimen was dried in a laboratory core baking oven at a temperature of 110ºC for a period of 30 minutes and then removed and allowed to cool in air to ambient temperature. After cooling, the specimen was inserted into the compression heads placed in the top position of the machine. This position increases the load applied by a factor of 5. The dry compression strength at the point when the specimen collapses multiplied by 5 is recorded by reading the scale marked “Dry Compression Strength”.
b) **Dry Shear Strength (DSS) Test:** The freshly prepared AFS standard 50mm diameter x 50mm height test specimen was dried in a laboratory core baking oven as in the case of dry compression strength. Then using the same USSM, the specimen was inserted into the shear heads fixed in the top position of the machine. The dry shear strength multiplied by a factor of 5 was recorded at the point where the standard test specimen shears by reading the scale designated “Dry shear strength”.

2.2.8 Green Permeability Test

The permeability test was carried out on the AFS standard specimen of 50mm diameter x 50mm height using the Ridsdale – Dietert electric Permmeter. The permeability meter employs the orifice method for the rapid determination of sand permeability. The specimen, while still in the specimen tube, is mounted on the small orifice of the permmeter and air at a constant pressure was applied and the drop in pressure is measured on a pressure dial-gauge, which is calibrated directly in permeability numbers. The result was recorded accordingly.

2.2.9 Percentage Mouldability Test

For the determination of mouldability, a George Fisher mouldability tester was used. In this test AFS standard specimen of 50mm diameter x 50mm height, prepared by using 160g weight of moulding sand was placed in a 7 inch

(175mm) diameter cylindrical rotary screen (8 mesh) which was supported at an angle of 7 degrees to the horizontal and rotated by a motor of known speed for a period of 10 seconds. The weight in grams of the sand passing through the screen during this interval divided by the original weight of the specimen and multiplied by 100 was recorded as the mouldability percent.

i.e., $$\textit{percentage mouldability} = \frac{\textit{final weight}}{\textit{initial weight}} \times 100\% \quad \textbf{2.1}$$

3. Results and Discussion

The quantitative and qualitative results of the tests conducted are shown in Tables 1 to 6.

Table 1: Chemical composition of Onitsha beach silica sand.

Compound	SiO_2	K_2O	CaO	Fe_2O_3	Ag_2O	TiO_2	SeO_2	BaO	HgO	MnO	GeO_2	CuO
Conc %	89.9	3.00	2.63	1.767	1.83	0.319	0.16	0.14	0.10	0.039	0.02	0.0087

Table 2: Chemical composition of Ukpor clay.

Compound	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	Ag_2O	CaO	V_2O_5	OsO_4	K_2O	SeO_2	MnO	Cr_2O_3	Ga_2O_3
Conc %	67.2	24.5	4.271	2.039	1.44	0.166	0.139	0.059	0.042	0.094	0.025	0.024	0.010

The results of chemical analysis (Tables 1 and 2) indicated that the sand is of high silica content (89.9%) while the clay is rich in silica and alumina contents (67.20% and 24.50% respectively). The clay, therefore, belongs to the aluminosilicate class.

The purity of sand grains influence their refractoriness. It is evident that silica is the predominant component in the sand sample. This is desirable since high percentage of silica in moulding sand, usually enhance its refractoriness, thermal stability and chemical inertness [6, 7]. It have also been noted that the presence of oxides of alkali metals in high proportions cause objectionable lowering of the fusion point of foundry sand from 1690°C to about 1200°C [8]. Where maximum refractoriness is required, as in steel moulding, high purity silica sand are used.

Table 3: Sieve analysis and AFS grain fineness number (GFN) of Onitsha beach silica sand.

S/N	Sieve Aperture (μm)	% Sand Retained	BS Sieve No	Product
1	1400	2.48	12	0.00
2	1000	1.40	16	16.80
3	710	4.32	22	69.12
4	500	13.82	30	304.04
5	355	25.91	44	777.30
6	250	28.55	60	1256.20
7	180	16.96	85	1017.60
8	125	5.84	120	496.40
9	pan	0.44	-	52.80
Total		**99.72**		**3990.26**

$$GFN = \frac{\textit{Total Product}}{\textit{Total \%Sand Retained}} = \frac{3990.26}{99.72} = 40.01 \quad \textbf{3.1}$$

The result of the sand grain size analysis showed that more than 99% of the bulk sand was retained on the first few consecutive sieves. Thus, the sand deposit met the American Foundrymen's Society (AFS) Standard specification for sand casting [7, 9]. The grain fineness number (GFN) and average grain size of the sand deposit are 40.01 and 421.70μm respectively. This grade of fineness number is suitable for the sandcasting of most types of alloy steels and nonferrous metal as this belongs to the group of fineness number that has wide range of application in sandcasting. The average grain size of the sand falls within the common foundry sand range of 150-400μm [6]. It should be noted that while average grain size and AFS grain fineness number are useful parameters, choice of sand should be based on particle size distribution, as the size distribution affects the quality and properties of casting produced.

Table 4: Effects of moisture content on the properties of moulding sand.

Moisture Content (%) / Properties	2	3	4	5	6	7	8
GCS (KN/m^2)	35.20	35.00	43.40	30.10	27.30	25.90	20.30
DCS (KN/m^2)	82.60	101.50	294.00	395.50	374.50	361.90	360.50
GSS (KN/m^2)	14.00	14.00	24.50	17.50	14.00	14.00	13.30
DSS (KN/m^2)	70.00	73.50	175.00	437.50	374.50	206.50	73.50
Green Permeability	7.60	8.60	9.80	10.00	12.00	8.20	7.10
Mouldability (%)	97.50	98.80	95.18	80.30	58.54	37.37	18.14

Table 5: Moulding composition by weight (variation of moisture content).

Moisture content (%)	Weight of Moisture (g)	Weight of sand (g)	Weight of Binder (g)
2	20.57	840.00	168.00
3	31.18	840.00	168.00
4	42.00	840.00	168.00
5	53.05	840.00	168.00
6	64.34	840.00	168.00
7	75.87	840.00	168.00
8	87.65	840.00	168.00

Table 6: Standard property ranges for sand casting of different alloys [10].

Metal	GCS (kN/m^2)	Permeability (No)	DCS (kN/m^2)
Heavy steel	70 - 85	130 - 300	1000 - 2000
Light steel	70 - 85	125 - 200	1000 – 4000
Heavy Grey iron	70 -105	70 - 120	350 - 800
Aluminum	50 - 70	10 - 30	200 - 550
Brass and Bronze Ligh	55 - 85	15 - 40	200 - 860
t Grey Iron	50 - 85	20 - 50	200 - 550
Malleable iron	45 - 55	20 - 60	210 – 550
Medium Grey Iron	70 - 105	40 - 80	350 - 800

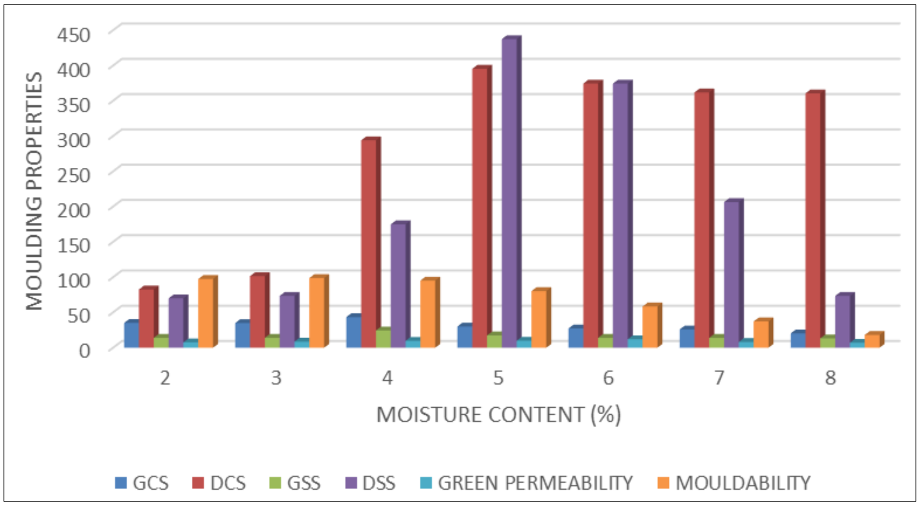

Fig 1: Effect of moisture content on the properties of moulding sand.

The green strength, dry strength (compression and shear) and green permeability increased to a maximum value at 4%, 5% and 6% moisture content respectively, and then decreased with moisture increase. Water is added to the synthetically and naturally bonded moulding sand to develop its adhesive characteristics inorder to enhance the moulding sand plasticity. The trend is in agreement with recent findings [10, 11, 12, 13]. These trends are due to the fact that as moisture increased, the bonded particles of the sand mould become loose resulting to easier escape of gases, weakening of bond strength and resistant against abrasion. The excess moisture was responsible for the poor binding properties obtained above the peak values.

The permeability increased due to the swelling action of the clay particles, thereby pushing the sand particles further apart, making more room for air passages. Beyond the point where the clay become saturated with water, the moisture merely filled void volume resulting in decrease in permeability.

The mouldability increased to 98.80% at 3% moisture content then steadily decreased as the moisture increased. Above 5% moisture addition the moulding sand exhibited a very low percentage mouldability. At this point the clay have swollen and become saturated with water that it could not conform to moulding processes any longer. Therefore, the most favourable moisture content for River Niger sand (Onitsha deposit) bonded with 16% Ukpor clay content is within the range of 4% and 5%. This result agrees with the conclusion made by Nwajagu and Okafor (1989) and Guma (2012).

Table 7: Summary of Statistical Analysis of the Effects of Mositure Content on the Properties of Moulding Sand.

Response	Name	Units	Analysis	Min	Max	Mean	Std. Dev.	Ratio	Model
R_1	GCS	KN/m^2	Polynomial	20.3	43.4	31.0286	7.55419	2.13793	Linear
R_2	DCS	KN/m^2	Polynomial	82.6	395.5	281.5	133.209	4.78814	Quadratic
R_3	GSS	KN/m^2	Polynomial	13.3	24.5	15.9	4.03567	1.84211	Fifth
R_4	DSS	KN/m^2	Polynomial	70	437.5	201.5	150.783	6.25	Quadratic
R_5	Green Permeability	No	Polynomial	7.1	12	9.04286	1.68311	1.69014	Quadratic
R_6	Mouldability	%	Polynomial	18.14	98.8	69.4043	32.1684	5.44653	Fifth

Table 8: Optimization Solution for the Effects of Moulding Sand Variables on the Properties of Moulding Sand.

Moisture Content	GCS	DCS	GSS	DSS	Green Permeability	Mouldabilty	Desirability
4.557	32.279	320.920	22.309	315.369	10.489	88.148	0.658

The responses of the variables in table 7, showing the summary of statistical analysis and models, were generated by Design Expert 10.0.2.0 software. While table 8 show the optimization result based on the models obtained for each variable. All the variables were set at maximum range to achieve maximum responses and optimal results.

4. Conclusion and Recommendations

4.1 Conclusion

The effect of variation in moisture content with the properties of synthetic moulding sand has been investigated in this research work and the following conclusions are made:

1. Moisture content of River Niger sand (Onitsha deposit) bonded with Ukpor clay should be maintained between 4 to 5% to obtain a better combination of moulding sand properties.
2. The grain size analysis showed that more than 95% of the bulk sand was retained on the first few consecutive sieves. Thus, River Niger silica sand (Onitsha deposit) met the AFS standard specification for foundry sand. The grain fineness number (GFN) and average grain size of the sand deposit, all fall within the range recommended for wide application in sand casting.
3. The results of chemical analysis for the silica sand and the clay samples indicated that both have the required purity for enhanced refractoriness, thermal stability and chemical inertness of moulding sand.

4.2 Recommendations

In the course of this investigation, some pertinent recommendations are made and further research areas have been identified.

1. Onitsha deposit of River Niger sand and Ukpor clay are recommended for use as ingredients for synthetic foundry sand preparation.
2. That moisture content of River Niger sand (Onitsha deposit) bonded with Ukpor clay should be kept at 4% minimum to obtain a most favourable combination of moulding sand properties.

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