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Investigation of Some Moulding Properties of a Nigerian Clay-Bonded Sand

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Abstract

Moulding properties of Isasa River Sand bonded with Ipetumodu clay (Ife-North Local Government Area, Osun State, Nigeria) were investigated. American Foundry men Society (AFS) standard cylindrical specimens 50mm diameter and 50mm in height were prepared from various sand and clay ratios (between 18% and 32%) with 15% water content. The stress-strain curves were generated from a universal strength testing machine. A flow factor was calculated from the inclination of the falling slope beyond the maximum compressive strength. The result shows that the flowability of the samples increases from 18% to 26% clay content, its maximum value was attained at 26% and then it decreases from 30% to 32% clay content. The green compressive strength, dry compressive strength and air permeability values obtained from the mould samples were in accordance with standard values used in foundry practice. The x-ray diffraction test shows that the sand contains silicon oxide (SiO_2), Aluminium oxide (Al_2O_3), and Aluminium silicate ($Al_6Si_2O_{13}$). The mould samples were heated to a temperature of 1200 ^oC to determine the sintering temperature; fussion did not take place at this temperature. The results showed that the sand and clay mixture can be used to cast ferrous and non-ferrous alloys.

Keywords: Flowability, Moulding, Permeability, Refractoriness

1. Introduction

Metal casting is the production of shaped articles by pouring molten metal into moulds [1]. Metal casting has several design advantages such as size, complexity, weight saving, production of prototypes, wide range of properties and versatility. It also has comparative advantages over all other metal forming processes such as low cost, versatility in production and dimensional accuracy depending on the type of moulding and casting process employed. Metal casting can be accomplished by either expendable mould processes or permanent mould processes [2]. The common method often employed is expendable moulding involving sand casting for which the use of silica sand is popular. Silica sand (SiO_2) occurs naturally in abundance. It is cheap and suitable for repeated use and can withstand high temperatures. Due to the above properties, silica sand is well suited for moulding sand. Despite all these properties, pure silica sand requires clay to bond its particles together to make it suitable for moulding [3].

Sand casting which is perhaps the most versatile of the casting methods can be used for casting components ranging in size from very small to extremely large [4]. It is used to cast engine blocks, machine tool bases, cylinder heads, pump housings, valves etc. In order to produce sound casting, the properties of the sand being used for casting must be at optimum level. [5] stated that the quality of castings in a green sand mould are influenced significantly by its properties, such as green compression strength, permeability, mould hardness and others which depend on input parameters like sand grain size and shape, binder, water, etc. The binder which is clay; bentonite or kaoline is added to the moulding sand in right proportion for efficient use. Most samples of clay that have been reported are kaoline. It was reported that the clay samples collected from some deposits in South West Nigeria and investigated were found to be kaolinite in chemical composition and were considered suitable for making high temperature caliber refractories [6]. The sample from residual clay deposit overlying the precambrian basement complex in Ara-Ijero Ekiti was investigated to determine its compositional features and industrial applications. The clay could serve as raw material for the manufacture of quality bricks, pottery, ceramics and structural wares [7]. The physical-chemical and mineralogical studies of alluvial clay samples from the confluence of Rivers Niger and Mimi in Lokoja, Nigeria were investigated. The unified classification of the composite samples indicated that the clay had limited industrial application. However, it can find a good use in making building blocks, ceramic pots and insulation bricks. The clay may be beneficiated to enhance its porosity for application as an adsorbent [8]. It is convenient to say that most clay deposits in Nigeria are kaolinitic in nature.

The flowability of moulding sand has been studied by many researchers over the years and it is the property which enables sand to flow readily in a mould to fill up the interstices when subjected to ramming. It is influenced by moisture, permeability, grain shape, fineness and clay content [9]. According to [10], the objective of sand mulling is to achieve a uniform distribution of sand grains, since this affects permeability and surface fineness. Uniformly mixed sand gives high flowability. Controlling flowability is extremely important in overcoming surface friction between sand and pattern walls of narrow pockets within a pattern impression, or between patterns, or between patterns and flask walls [11].

The study investigates some moulding properties of clay-bonded river sand sourced from Ipetumodu in Osun State, Nigeria.

2. Materials And Methods

2.1. Material Collection

The major materials for this work are sand and clay. Sand was collected from Isasa River; the River serves as the boundary between Ayedaade and Ife North Local Government areas of Osun State, Nigeria. Clay was collected from a deposit at Ipetumodu, headquarter of Ife North Local Government area in Osun State, Nigeria.

2.2. Preparation of Binder

The collected clay sample was sun dried, pulverized and sieved using a mechanical sieve shaker with sieve size of 300μm to remove impurities and some silt materials which might affect the performance of the clay as a binder.

2.3. Determination of Some Properties of the Sand

Some properties of the sand were determined as follows;

(a) Moisture content

50g of the sand sample was measured using digital balance and dried at a temperature of 105^{o}C-110^{o}C for 2 hours to evaporate all the moisture in the sand. The sample was then weighed. The weight difference between the initial and new weight was expressed in percentage to give the moisture content of the sand.

(b) Clay Content

The dried sample from the moisture content determination was washed four times till the surface was clean. It was then dried again and weighed. The difference between the weight of the washed and its initial weight expressed in percentage was taken as the clay content.

(c) Sieve analysis and determination of Grain Fineness Number (GFN)

The sand was washed in large volume of water in a bowl several times to remove light debris and organic matter. It was then sun dried for some days to remove free water. Sieve analysis was performed using British standard with the aid of mechanical sieve shaker using the following sieve sizes: 2.0mm, 1.18mm, 850μm, 600μm, 425μm, 300μm, 212μm, 150μm, 75μm. 500g of the sand was passed through the above serial sieve and shaken for 15mins. The sand retained on each sieve and bottom pan was weighed and each expressed as a percentage of the total mass of the sand. The result obtained from the percentage retained was multiplied by the multiplying factor of each sieve. The Grain Fineness Number was determined by summing all the obtained products divided by percentage retained.

GFN $= product/(\%\ retained)$

2.4. Mineralogical composition of the sand

The mineralogical composition of IsasaRiver sand was investigated with the aid of X-Ray Diffractometer (XRD) model 10 Monochromatic CuKa radiation (wavelength= 1.5406μm) produced by Radicon limited. Fine grain of sand was obtained by passing the sand through a 425μm sieve size. The fine grain sand was exposed to the X-ray beam from an X-ray generator running at 25kv and 20mA. The scanning regions of the diffraction were 16-72^o on the 2-theta angle. X-ray diffraction curves were analyzed using a database supplied by International Centre for Diffraction Data (ICCD). The 2θ values obtained were compared with 2θ values of the compounds attached with the pattern.

2.5. Determination of Chemical Composition of the Clay

Atomic Absorption Spectophotometry method was used to determine the chemical analysis of the clay samples used. Clay does not melt but addition of hydrofluoric acid (HF) to the clay sample can melt it. Since HF is dangerous to handle, a 1.4g of flux (1.2g of Na_2CO_3 + 0.2g of boric acid) was added to the clay sample to dissolve it. During the combustion process, acetylene-NO_2 flow mixture for elements Al, Si and Ti, and acetylene-air flow mixture for Ca, Fe, Na, K and Mg, of the clay samples were obtained. The combustion process was ionized from the low energy level to high energy level. The HCl added to the mixture was used to dissolve it.

2.6. Preparation of mould samples

The sand was sieved using $425\mu m$ sieve to remove coarse particles. Various mixing ratio were prepared with clean water. It was observed that the clay binds the sand at 16% by volume and the amount of water required for the sand to bind was 15% by volume. Several mould samples of 50mm diameter and 50mm height were prepared with different percentages of sand and clay with water content of 15%. The mixing time was set at 7minunes to facilitate thorough mixing, breaking of lumps in the sand and that clay is uniformly enveloped around the sand grains. It also ensures that moisture is uniformly distributed as this affects permeability and surface fineness. The mixtures were rammed manually to considerable compaction level in the cylindrical container (mould), this enhances high flowability [10]. The mould samples were prepared with clay content between 18% and 32%. Five of the samples were used for the flowability test while eight were used for green and dry compression test.

2.7. Testing of mould samples

The following tests were carried out on the mould samples:

(a) Flowability

The flowability of the mould samples was determined using a computerized universal strength testing machine which generated a flow curve (stress-strain curve) of each mould samples. The falling slope of the curve divided by the maximum compressive strength gives the flow factor which is a measure of flowability [11]. The falling slope of the curve was calculated using the formula:

$$E = \Delta\sigma/\Delta\varepsilon \quad (1)$$

$$FF = E/Max\sigma \quad (2)$$

Where:

$\Delta\sigma = \sigma_1 - \sigma_2$

E= falling slope

σ_1= 80 %-85% of Max σ

σ_2= 70% -50% of Max σ

FF= flow factor

Max σ = maximum stress

Values were obtained for set pointsσ_1= 85 % & σ_2= 50% and σ_1= 85 % & σ_2= 60%

(b) Green compressive strength

Each of the samples was subjected to gradual load under an Instron computerized universal strength testing machine with a capacity of 50KN and at the rate of 2mm/min until failure of the mould occurred and the strength in KN/m^2 was read instantaneously.

(c) Dry compressive strength

The mould samples were heated to a temperature of 110^oC for two hours in a furnace and it was allowed to cool down at a steady rate to the room temperature before each of the samples was subjected to gradual load under an Instron computerized universal strength testing machine with a capacity of 50KN and at the rate of 2mm/min until failure of the mould occurred and the strength in KN/m^2 was taken.

(d) **Permeability**

$2000cm^3$ of air was passed through the prepared sample and the time taken by it to completely pass through the sand sample was noted. The instrument used is presented in Plate II. The permeability number was calculated using the formula:

$$P = (V \times H)/(p \times A \times T) \quad (3)$$

Where:

V = volume of air = $2000cm^3$

H = height of sand specimen= 5cm

p = air pressure in cm of water = 9.8cm

A = cross-sectional area of sand specimen =$19.63cm^2$

T = time in minutes for the complete air to pass through

3. Results And Discussions

3.1. Moisture and Clay Contents of the Sand

The moisture and clay contents of the sand are 13.92% and 4.74%.

3.2 Sieve analysis and determination of Grain Fineness Number of the Sand

The result showed that Grain Fineness Number (GFN) was 44.82. This value is in accordance with the grain fineness number used by most foundries, which is expected to be between 40 and 220. [12]. Table 1 presents the sieve analysis of the sand.

3.3 Result of the Mineralogical Composition of the Sand

The X-Ray Diffraction shows eight peaks as presented in Figure 1. Six of the peaks showed that silicon oxide, aluminum oxide and aluminum silicate were present in the sand sample.

Table 1.
Sieve analysis for determination of GFN

Sieve Size	Multiplier	Mass of empty sieve(g)	Mass of sand + sieve(g)	Mass of sand retained f(g)	% of sand retained (P)	Product (f_xP)
2 mm	10	412	413	1	0.2	20
1.18 mm	16	382	384	2	0.4	6.4
850 µm	20	355	375	21	4.2	84
600 µm	30	355	438	83	16.6	498
425 µm	40	362	587	225	45	1800
300 µm	50	317	432	115	23	1150
212 µm	70	308	344	36	7.2	504
150 µm	100	300	313	13	2.6	260
75 µm	200	321	325	4	0.8	160
Pan	350	641	641	0	0	0
Total					**100**	**4482.4**

AFS Grain fineness number (GFN) = 4482.4 / 100 = 44.82

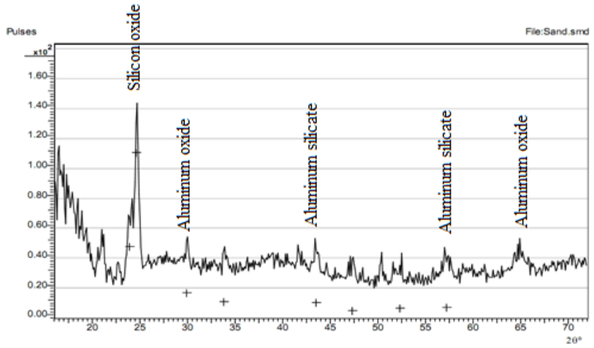

Fig. 1. XRD of the Isasa River Sand

3.4 Chemical composition of the clay

Atomic Absorption Spectophotometry method was used to determine the chemical analysis of the clay samples used. Clay does not melt but addition of hydrofluoric acid (HF) to the clay sample can melt it. Since HF is dangerous to handle, a 1.4g of flux (1.2g of Na_2CO_3 + 0.2g of boric acid) was added to the clay sample to dissolve it. During the combustion process, acetylene-NO_2 flow mixture for elements Al, Si and Ti, and acetylene-air flow mixture for Ca, Fe, Na, K and Mg, of the clay samples were obtained.The combustion process was ionized from the low energy level to high energy level. The HCl added to the mixture was used to dissolve it.The chemical composition of the clay samples is shown in Table 2.

Table 2.
Chemical composition of clay samples

Chemical composition	**% composition**
SiO_2	55.91
Al_2O_3	29.91
Fe_2O_3	1.91
CaO	0.2
MgO	0.4
K_2O	1.9
Na_2O	0.2
TiO_2	0.9

3.5 Results of the tested mould samples

3.5.1. Flow factor

The results of the stress-strain curves are presented in Figures 2-6. Tables 3 and 4 showed the results of the green strength, stress, strain, modulus and flow factor of the samples which increases from 18-26% of clay and decreases at 32% clay content both for the 85% & 50% and 85% & 60% set points respectively.

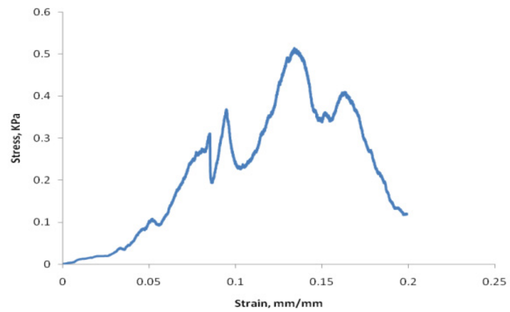

Fig. 2. Stress-strain curve at 18% clay content

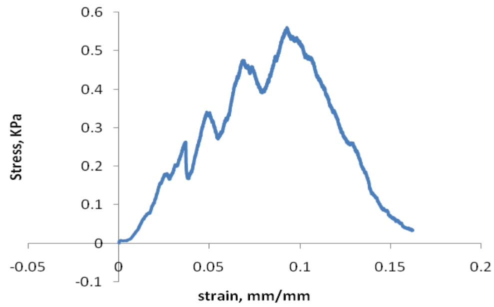

Fig. 3. Stress-strain curve at 22% clay content

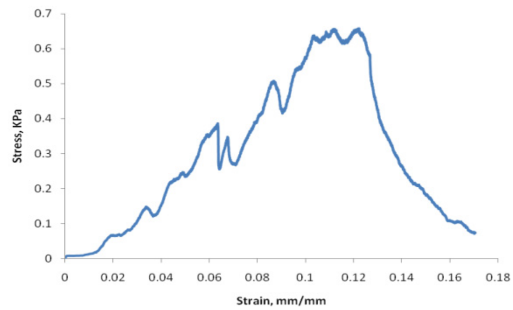

Fig. 4. Stress-strain curve at 26% clay content

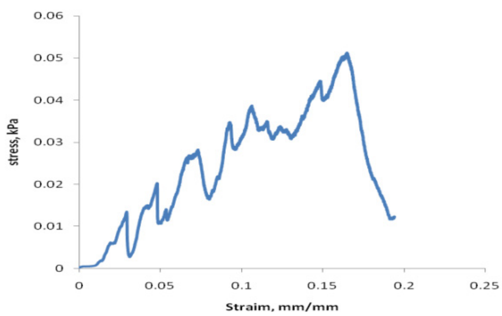

Fig. 5. Stress-strain curve at 30% clay content

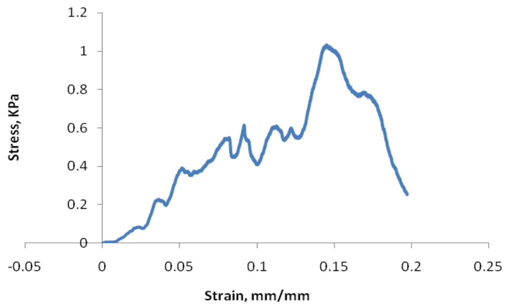

Fig. 6. Stress-strain curve at 32% clay content

Table 3.
Flowability table at 85% and 50% set points

Clay Content (%)	Max Green Strength	$\Delta\sigma = \sigma_1 - \sigma_2$	$\Delta\varepsilon$	$E = \Delta\sigma / \Delta\varepsilon$	FF = E/Max σ
18	51.41	17.99	0.0475	378.8	7.37
22	56.71	19.85	0.0140	1417.8	23.33
26	65.83	23.04	0.0100	2304.0	34.99
30	79.90	29.97	0.0125	2397.6	30.00
32	100.31	35.10	0.0295	1189.9	11.86

Table 4.
Flowability table at 85% and 60% set points

Clay Content (%)	Max Green Strength	$\Delta\sigma = \sigma_1 - \sigma_2$	$\Delta\varepsilon$	$E = \Delta\sigma / \Delta\varepsilon$	FF = E/Max σ
18	51.41	12.852	0.035	367.2	7.1
22	56.71	14.174	0.008	1771.8	31.2
26	65.83	16.460	0.005	3292.0	50.0
30	79.90	21.980	0.008	2747.5	34.4
32	100.31	25.070	0.0253	990.9	9.9

The increment in flow factor is as a result of the increase in the clay content which enhanced binding of the sand grains, compactibility and improved ability of the sand grains to flow in the mould. The decrease in flow factor is as a result of the steepness of the falling slope of the stress-strain curve. The variations of the clay contents with flow factor for set point 85% & 50% and 85% & 60% are shown in Figures 7 and 8 respectively.

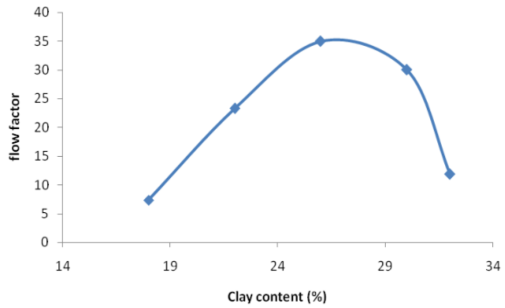

Fig. 7. Variation of clay content and flowability for set point 85% and 50%

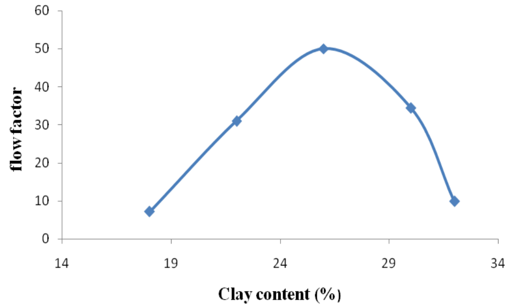

Fig. 8. Variation of clay content and flowability for set point 85% and 60%

It was observed that the flow factor (FF) increases with increasing clay content. This is due to the added clay filling up the interstices which naturally exist between sand grains. The maximum of FF was achieved at 26% clay content and then decreased from that point to 32% clay content. The decrease may be attributed to oversaturation of clay content leading to hindered flow of the sand due to stickiness property of the clay. The interstices of the sand are already filled up at this level of clay content.

3.5.2. Green compressive strength

The result of the Green compressive strength is presented in Figure 9 and it shows the variation of clay content and green compressive strength. It was observed that the green strength increases between 18%-26% until it reaches 28% where a decrease was observed and then increases again between 30%-32%. The green strength was between 51.33 kN/m^2-103.14 kN/m^2 which is in accordance with the satisfactory ranges for sand castings [2].The result is an expected behavior of sand-clay mixture. Clay becomes sticky with the addition of water. The stickiness increases with water content to an optimum level after which the stickiness begins to reduce. This optimum level was not reached in this work. The behavior at 28% clay content was unexpected.

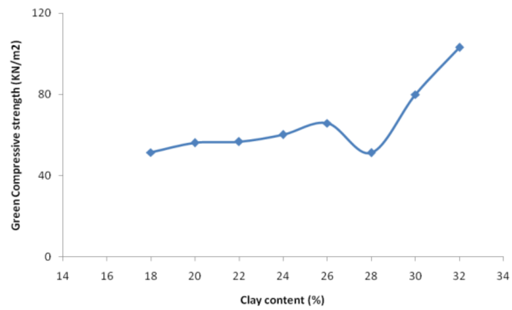

Fig. 9. Variation of clay content and Green compressive strength

3.5.3 Dry compressive strength

The result of the dry compressive strength presented in Figure 10 shows graphically the variation between the clay content and the dry compressive strength. The result shows that as the clay content increases, the dry compressive strength also increases. The range of value obtained from the test is also in accordance with satisfactory mould range for sand casting. The observation was due to consolidation of clay-clay particle contact through surface diffusion to form rudimentary neck around the interstices [13]

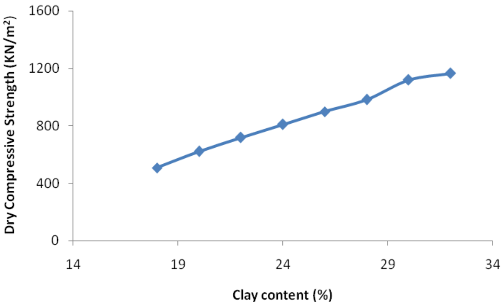

Fig. 10. Variation of clay content and dry compressive strength

3.5.4 Refractoriness test

This test was carried out to determine the temperature at which the sand grains of each of the mould samples would fuse. The test samples were placed in furnace and the temperature was raised to 1200^0 C. The samples were then observed to check for fusion. Sand grains of the samples did not fuse at this temperature and this shows that they can still be heated beyond this temperature but the maximum limit of the furnace used is 1200^0C. The result is similar to that presented by [14].

3.5.5 Permeability

Permeability is a function of gases or liquid passing through a medium. The result of the permeability test is shown in Figure 11 which shows graphically the variation of clay content and permeability. It was observed that the permeability decreases with increasing clay content. This may be attributed to the clay filling up the interstices/gap between adjacent sand grains.

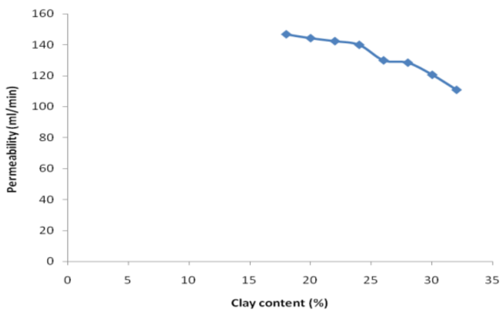

Fig. 11. Variation of clay content and permeability

4. Conclusions

The result of the x-ray diffraction test shows that the sand contains the following compounds; silicon oxide (SiO_2), Aluminum oxide (Al_2O_3), and Aluminum silicate ($Al_6Si_2O_{13}$). Ipetumodu clay can be used as a binder for moulding. There is close agreement between the values of the green compressive strength, dry compressive strength and permeability obtained from this research when compared with established values. The results show that the sand and clay mixture can be used to cast ferrous and non-ferrous alloys, aluminum, brass and bronze, light grey iron.

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