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INVESTIGATION OF THE SUITABILITY OF IYOLOKO CLAY AS A BINDING MATERIAL FOR FOUNDRY APPLICATION

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ABSTRACT

Clay is useful in foundry application. It is one of the principal moulding materials used for all type of casting whether ferrous or non-ferrous. The objective of this work is to investigate the suitability of Iyoloko clay as a binding material for foundry application. This was done by investigating the physio- chemical properties of the clay. The physio-chemical properties of the clay were determined by physical and chemical analysis. X-Ray Fluorescence (XRF) spectroscopy technique was used to determine the chemical composition of the clay. Physical analysis covers visual examination, determination of moisture content, relative plasticity, modulus of rupture, shrinkage, water of porosity and density, refractoriness, Loss on Ignition(LOI).From the physical analysis, the total shrinkage of the clay is 4%,the apparent porosity is 19.60%, The value of apparent density and bulk density for the clay are 2.24g/cm^3 and 1.80g/cm^3 respectively. The value of the water of absorption of the clay is 10.86%.The modulus of rupture of the clay is 2.38MN/m^2.The modulus of plasticity for the clay is 1.29 MN/m^2.The moisture content of the clay is 13.43%.The refractoriness of the clay is above 1600^{o}C. The value of loss on ignition of the clay is 2.43%. The Grain Finest Number (GFN) of the clay is 64.75. The chemical analysis of clay showed that the value of Alumina Al_2O_3 is 30.07 wt% and that of silica is 43.20 wt%. The result obtained from the overall experimental analysis showed that if Iyoloko clay is properly processed, it will have appreciable and reasonable physio-chemical properties that will make it suitable for used as a binding material for foundry application.

Keywords: Binding materials, clay, foundry application, physio-chemical properties.

INTRODUCTION

Clay in addition to silica sand is one of the principal moulding material used for all type of casting irrespective of whether the casting is ferrous or non-ferrous (Atanda *et al* ,2012). Clay is very useful and plays very crucial roles in the industrial development of any nation. Clay is useful in foundry applications and varies in grain shape, grain composition, relative surface, grain size, and grain distribution patterns. These properties, in addition to chemical analysis, sinter point, and expansion characteristics play an important part in the choice of clay used as a binder for moulding or core aggregate in metal casting. Clay is defined as those particles of sand (under 20 microns in diameter) that fail to settle at a rate of 25mm per minute, when suspended in water (American Foundry Society –AFS, 2005). Clay imparts the necessary bonding strength to the moulding sand so that after ramming, the moulding does not lose its shape. The higher the quantity of the clay the lower the permeability of the moulding sand.

Nigeria is endowed with a lot of clay deposits, but only few deposits are utilized for foundry application. The low utilization of clay deposits in Nigeria may be as a result of lack of adequate information about their existence and suitability for foundry application. Due to insufficient information on the foundry properties of sand and clay deposit in Nigeria, foundry raw materials such as silica sand, clay binders and additives that are used for producing effective casting via sand casting by foundry industries in Nigeria are sometimes sourced from overseas. Chukwudi (2008) from Aderibigbe, (1998) reported that virtually all silica sand and clay with required foundry properties needed in all the pyro-metallurgical industries in Nigeria were imported despite having extensive clay mineral deposits in Nigeria. The Nigerian Metallurgical industries are struggling today because of many factors among which is the short supply of clay with required foundry properties due to continue dependence on external sources of clay with required foundry properties for many of its industries (Aliyu, 1996). Obadinma (2003) reported that Nigeria imported about 27 million metric tonnes of refractory materials in 1987. This has a negative effect on the nation's foreign reserve. In order to conserve foreign reserve and key into the local content initiative of the government, there is a need to explore and exploit the available local resources for industrial application. Clay is one of such available local natural resources. Investigation of the physio-chemical properties of clay deposit is important. This will help to determine their suitability for foundry application.

Some of the works done on various deposits of clay and their use as binder in moulding sand according to Bala and Khan (2013) are Akinbode(1996), Abolarin ,Olugboji and Ugwuoke (2004), Folaranmi (2009) ,Umaru and Aliyu (2012), Aramide, Aribo and Folorunso (2011). However, more effort has to be made in order to investigate the suitability of more locally available clay as foundry material for the production of sound castings. The objective of this work is to investigate the suitability of Iyoloko clay as a binding material for foundry application. The scope of the work includes chemical and physical analysis to determine the chemical composition, sieve analysis, moisture content, relative plasticity, modulus of rapture, shrinkage, apparent porosity and density of the deposit. Based on the result obtained from the overall experimental analysis, the paper concluded that Iyoloko clay has appreciable and reasonable physio-chemical properties that make it suitable for used as a binding material for foundry sand. This will further enhance the import substitution policy of the government by the way of providing alternative binding materials which can be sourced locally in place of imported product thereby conserving the scarce foreign reserve for the government

MATERIALS AND METHODS

MATERIALS AND THEIR PREPARATION

The materials used was Iyoloko clay. The clay material was obtained from Iyoloko in Idah local government area of Kogi state,Nigeria.The clay materal was dug from two feets below the ground surface level.The lumbs were broken by the use of hand rammer into powdered form. The pulverized clay was dispersed in the distilled-deionised water in a pretreated plastic container and stirred vigorously to ensure proper dissolution. The dissolved clay was then filtered to get rid of unwanted materials. The filtrate obtained was allowed to settle for 48hours after which excess water was decanted. The settled clay at the bottom of the container was sun dried for seven days to get rid of excess water molecules.

EXPERIMENTAL METHODS

VISUAL INSPECTION

This was done to determine the physical appearance of the samples. It was observed that the sample has a golden ash colour.

SIEVE ANALYSIS

100g of the dried sample of the clay was poured into an Endoctts sieving machine model EFL 2000/1. The machine was electrically agitated for 15 minutes. The grains fell through the mesh sizes that are arranged in a stack above the collector tray starting from the coarse mesh of 1.400mm on top to the fine of 0.063 mesh or microns at the bottom. The particle of clay that was retained on each sieve was weighed and percentage of grain size of each sample was calculated according to American Foundry Society -AFS (2006) as cited by Freestone (2005); Ushie, Esu, and Udom (2005); Sundararajan, Ramaswany, and Raghavan (2009).

DETERMINATION PHYSICAL PROPERTIES

MOULDING OF THE TEST PIECES

The test piece were moulded into two main types of shapes; cylindrical shape with a diameter of 3.5cm and height 3.9cm, and a rectangular shape with length 9.5cm, width 2cm and height 1.5cm according to ASTM Standards Part 17 (2005) using metallic moulds. Lubricant was applied to the surface of the moulds to prevent the test pieces from sticking to the surface.

DETERMINATION OF MOISTURE CONTENT

This was determined by weighing the cylindrical test piece immediately after moulding and the weight was recorded as the wet (or green) weight, W_2. The test piece was air-dried for seven (7) days and then dried in an oven at 105°C until a constant weight was recorded. After drying, the test pieces were weighed and the dried weight recorded as W_1. The moisture content was then calculated using the formula below:

Moisture Content (%) $= \frac{W_2 - W_1}{W_2}$ (Seidu and Kutelu, 2014)

DETERMINATION OF RELATIVE PLASTICITY

The relative plasticity was determined using the cylindrical test pieces. The height of the test piece was measured by the use of vernier caliper. The height of the sample was measured at three different locations and the average value taken as the original height, H_o of the test piece. The test pieces were deformed by a manual plastometer machine. The deformation height, H_i was obtained by taking the average height value of the three different sides of the sample. The relatives plasticity was then calculated using the formula below.

Relative plasticity = $\frac{Ho}{Hi}$ (Lynne *et al*, 1980)

Where H_o - original height of the test pieces.
H_{i-} average deformation height.

DETERMINATION OF MODULUS OF RUPTURE (MOR)

The rectangular test piece was air dried for seven (7) days after which it was dried in an oven at 110°C until a constant weight was obtained. The breaking load P (kg) was determined by using the electrical transversal strength machine. A vernier caliper was used to determine the distance L (cm) between the two supports. The width B (cm) of the broken parts was recorded. The modulus of rupture was then calculated as;

Modulus of Rupture (kg/cm^2) = $\frac{3PL}{2BH^2}$ (Akwilapo and Wiik 2003)

DETERMINATION OF SHRINKAGE

Shrinkage properties were determined using the rectangular test piece. A vernier caliper was used to insert a 5cm mark on it. This was recorded as the original length, Lo (cm). The test pieces was then air dried for seven (7) days and then dried in an oven at 110°C until a constant weight was obtained. The shrinkage from the 5cm mark was then determined and recorded as the dried length L_d (cm) .The shrinkage of the test pieces from the 5cm mark was then determined and recorded as the fired length L_f (cm). The shrinkage was then calculated according to Lynne *et al,* (1980) as

Wet-dry shrinkage (%) = $100\frac{(Lo-Lf)}{Lo}$

Dry-fired shrinkage (%) = $100\frac{(Lo-Ld)}{Lo}$

Total shrinkage (%) = $100\frac{(Lo-Ld)}{Lo}$

DETERMINATION OF WATER OF ABSORPTION

The fired test pieces obtained from above were then weighed and the weight recorded as dry weight, M_1 (g). Thereafter, the test pieces were soaked in water for 24hrs, then removed , cleaned and re-weighed immediately and recorded as soaked weight, M_2 (g). The water of absorption was then calculated *(*Lynne *et al*, 1980).

Water of Absorption (%) = $\frac{(M_2-M_1)}{M_1}100$

DETERMINATION OF POROSITY AND DENSITY

After all physical properties discussed above were successfully determined, the weight of the test pieces were then determined by the use of a lever balance and recorded as M_3 (g). The apparent porosity, apparent density and bulk density were then calculated according to Akwilapo and Wiik(2003).

Apparent porosity (%) = $(M_2 - M_1)x100$

Apparent Density= $\frac{M_1}{(M_1 - M_3)}$

Bulk Density = $M_1(M_2 - M_1)$

DETERMINATION OF REFRACTORINESS

Test cones were prepared from the clay specimen, dried and placed in a furnace along with pyrametric cones designed to deform at 1200, 1300, 1400, 1500 and 1600^{o}C respectively in accordance with the American Society of Testing Materials (ASTM) (2005). The temperature was then raised at 20^{o}C per minute. The temperature of the furnace was determined by the means of an optical pyrometer. The maximum temperature available in the furnace was 1600^{o}C and the test cone did not show any sign of failure or deformation up to the temperature of 1600^{o}C meaning that the clay samples have refractoriness greater than 1600^{o}C.

LOSS ON IGNITION (LOI) TEST

Ten grams of sand is loaded into five crucibles each to add up to fifty grams of foundry sand. Each of these is measured for current weight and numbered .The Crucibles are then loaded into a muffle furnace and baked for up to four hours. At approximately half way through this baking process, the samples are removed and stirred to allow for all of the sand to be exposed to equal amounts of heat. Each of the five crucibles is measured for final weight. The final loss on ignition (LOI) is calculated using the formula below by taking average values of the five results according to the formula below (Ramrattan and Ikonomov, 2006).

Loss on Ignition equation (LOI) % = $\frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100$

DETERMINATION OF CHEMICAL COMPOSITION

The aim of the chemical analysis is to determine the various components of the clay. The chemical composition of the raw materials was determined using the X-Ray Fluorescence (XRF) spectroscopy technique. This is a non-destructive analytical method in which x-ray tube is used to irradiate the sample with a primary beam of x-rays. Some of the impinging primary x-rays are absorbed by the sample elements in a process known as the photoelectric effect.

RESULTS AND DISCUSSION

RESULT

The results of sieve, chemical and physical analysis are shown in Table1.0, 2.0 and 3.0 respectively below Weight of the sample = 100g. Table 1.0 shows sieve analysis of Iyoloko clay.

Table 1.0 Sieve Analysis of Iyoloko Clay Sand.

Sieve Serial No	Aperture Size(mm)	Sand Retained			Multiplier	Product
		Weight Retained (grams)	% Weight Retained	% Cumulative Weight Retained		
1	1,400	5.80	5.80	5.80	6	34.80
2	1,000	7.00	7.00	12.80	9	63.00
3	0,710	6.00	6.00	18.80	15	90.00
4	0,500	2.10	2.10	20.90	25	52.50
5	0,350	13.90	13.90	35.80	35	486.50
6	0,250	8.80	8.80	44.60	45	396.50
7	0,180	5.20	5.20	49.80	60	312.00
8	0,125	7.30	7.30	57.10	81	591.30
9	0,090	9.10	9.10	66.20	118	1073.80
10	0,063	11.30	11.30	77.50	164	1853.32
Total			76.50			4953.72

From the Table 1.0 above, the Grain Finest Number (GFN) of Iyoloko clay can be determined by the following calculation.

$$\text{Grain Finest Number (GFN)} \quad \frac{\text{Total Product}}{\text{Total sum of \%weight retained}} = \frac{4953.72}{76.50} = 64.75$$

Table 2.0 shows Chemical Analysis of Iyoloko Clay

Table2.0 Chemical Analysis of Iyoloko Clay

S/No	Constituent	Percentage present
1	SiO_2	43.20
2	AI_2O_3	30.07
3	ZnO	0.0025
4	MgO	0.03
5	MnO	0.002

Table 3.0 show test result of physical properties of Iyoloko clay

Table 3.0 Test Result of Physical Properties of Iyoloko Clay

Parameter	Value
Wet-dry shrinkage (%)	3.20
Dry-fired shrinkage (%)	0.83
Total shrinkage (%)	4.0
Apparent porosity (%)	19.60
Apparent density (kg/cm^3)	2.24
Bulk density (kg/cm^3)	1.80
Water of absorption (%)	10.86
Modulus of rupture for fire(MN/m^2)	2.38
Modulus of Plasticity	1.29
Moisture content (%)	13.43
Refractoriness	> 1600^{o}C
Loss on Ignition(LOI)	2.43%

DISCUSSION

Table 3.0 shows the result of shrinkage, apparent porosity, apparent density, bulk density, water of absorption, modulus of rupture for fire, modulus of plasticity, making moisture, refractoriness and loss of ignition (LOI).The result of total shrinkage of the clay which is the sum of wet dry shrinkage and dry fired shrinkage is 4%.This value is in line with the recommended range of 2-10% recommended by Chester (1973).The value of apparent porosity for the clay is 19.59%.This falls within the range of 10-30% recommended by Chester (1973). The value of apparent density and bulk density for the clay are 2.24g/cm^3 and 1.80g/cm^3 respectively. Typical value of bulk density for refractory material suggested by Gilchrist (1997) is 1.90g/cm^3.The result of densities of the clay is still within the value suggested by Gilchrist (1997). The value of the water of absorption of the clay is 10.86%.The modulus of rupture of the clay is 2.38MN/m^2, this is in line with the range of 2MN/m^2 and 4 MN/m^2 suggested by ASTM standard part 17 (2005).The modulus of plasticity for the clay is 1.28 MN/m^2.The making moisture of the clay is 13.43%.this indicate that the making moisture of the Iyoloko clay is within the standard value of 1-13% (Mitchell and Stentiford, 1973).

The clay sample did not show any sign of failure at temperatures of 1600^{o}C. This means that the refractoriness is very high and fall within the internationally accepted range of 1580^{o}C – 1750^{o}C (Abifarin, 1999**)**. This eventually showed that the clay has high and good refractoriness qualities and can withstand the high temperatures the clay will be subjected to in operation. The value of loss on ignition of the clay is 2.43% which is in line with Brown (2000), who stated that LOI must be below 3%.
Table 1.0 shows the result of sieve analysis. From the analysis, the Grain Finest Number (GFN) of Iyoloko clay is 64.75.The value of the GFN is in line with Foseco Ferrous Foundryman's Handbook which stated that AFS grain fineness number for foundry sands usually fall into the range of 35-90
Table 2.0 shows the chemical composition of the Iyoloko clay. The value of Alumina Al_2O_3 is 30.07 wt% and that of silica is 43.20 wt%.The result indicated that Iyoloko clay falls under Alumina-Silica type of clay. This further confirms Aderibigbe (1998) statement that the major clay deposit in Nigeria has Alumina-Silica raw materials with alumina content of less than 45%.

CONCLUSION

In this work, the suitability of Iyoloko clay as a binding material for foundry application was investigated. Based on the result obtained from the overall experimental analysis, it was discovered that Iyoloko clay has appreciable and reasonable physio-chemical properties that make it suitable for used as a binding material for foundry application. Iyoloko clay can also be processed to an appreciable level for used as refractory clay materials for ramming and refractory lining for furnaces, kilns, crucibles, ladles, soaking pits etc. This will enhance the import substitution policy of the government by way of replacing the imported foundry materials with the available local one thereby conserving scarce foreign reserve for the government. The clay can equally be exported to earn the much desired foreign exchange for the country.

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