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Investigation on the Suitability of Adada River Sand and Nkpologwu Clay Deposit As Foundry Moulding Sand and Binder.

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Abstract: *This research involved analysis of chemical and mechanical moulding properties of Adadariver sand bonded with Nkpologwu clay using standard analytical and foundry test equipment. The sand contains 94.51% silica (SiO_2), 1.64% alumina (Al_2O_3), 1.46% iron oxide (Fe_2O_3) while other oxides present combined are 2.39%. Sieve analysis was conducted using electric sieve shaker and American Foundry Men's Society (AFS) grain fineness number of 45.15 was obtained. The mechanical properties of the moulding sand were determined using AFS standard techniques. The highest results obtained showed that the green compressive strength was 57.4KN/m^2 at 16% clay and 7% added water; dry compressive strength was 451% KN/m^2 at 16% clay and 8% added water; green and dry shear strengths were 32KN/m^2 and 79KN/m^2 respectively at 16% clay and 8% water contents. The shatter index is 81% at 16% clay and 8% water contents, moisture content was 6.7% at 4% clay and 8% water, and permeability was 66.5 at 4% clay and 3% water while compactibility was 45.5% at 16% clay and 8% water. The results indicate that the sand and clay can be utilized in foundry mould making.*

Keywords*: Adada river sand, Nkpologwu clay.*

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I. INTRODUCTION

Foundry industries commonly use sand casting process in production of castings. Sands, by virtue of their grades and shapes of particles are closely packed and therefore can form smooth mould surfaces. Foundry sand for metal casting is normally sourced from either natural deposits or synthetic mix of refractory sand grains, binding agents and moisture that provides requisite binding [1]. Stringent control of the properties of moulding materials is imperative for consistent production of high quality castings at minimum cost, particularly when using automated moulding lines [2]. Each of the mix constituents is important in determining the characteristics of moulding sand. The binding agent is responsible for bindability thereby determining the size of the voids created by the sand grains while moisture level determines the plasticity of the moulding sand. Silica sand is evaluated for foundry usage on the basis of its composition and physical properties [3].

The integrity of sand cast products is very significantly influenced by the properties of foundry moulding sand such as the green and dry compressive strengths, permeability, moisture content, shear strengths and others. These properties are subsequently influenced by the additions and variations in amount of additives and ingredients as well as sand grain size [4,5]. The additives include coal dust, corn flours, and clays while the ingredients referred to are binders and water.

Various types of sand are used in foundries for moulds manufacture [6]. According to Higgins [6],while naturally occurring mould "green" sand is suitable and most widely used, other forms such as dry sand, core sand, cement bonded sand as well as shell moulding sand are equally employed for certain purposes. Akintunde and Omole [7], stated that sand suitable for moulding in foundry should consist largely of silica (SiO_2) grains with 5-6% clay to act as binder. Since bonding materials are not necessarily highly refractory, the required properties of the mould sand must be achieved with minimum possible addition of the binder [8]. Plasticity and bond strength in mould sand bonded with clay are developed by adding the required quantity of water. Clays used in sand moulding for metal casting are generally of three types and depending on their chemical composition, they include montmorillonite or bentonite clays, kaolinite or fire clay and illite [4].

The effect of clay and gas content on compressive strength and gas permeability of synthetic moulding sand mixtures (Enugu sand, Enugu fire clay and Ukpo clay) has been investigated [9]. The result showed that a good combination of all working properties of the sand was achieved using either moulding sand with 8wt% fireclay and 3wt% water or 10wt% Ukpo clay, 4wt% water. Study of the foundry properties of the River Niger sand behind Ajaokuta town in Nigeria, using bentonite and kaolin as binder showed that both bentonite and kaolin gave good results but kaolin has stronger influence on bond properties of the sand [10].

Thus, many small jobbing foundries and smithy workshops within and around Nkpologwu area find it difficult to source quality moulding sand for their castings. This makes the study of utilization of Adada River sand and Nkpologwu clay as foundry moulding sand and binder important as it will address the problems facing these foundries as well as open opportunities for more foundries to spring up within that area.

II. EXPERIMENTAL EQUIPMENT, MATERIALS AND METHODS

2.1 Equipment

Shovels, diggers, pick
Sample dividers, metal dish
Bench mounted sieve shaker
Laboratory mill (milling and mixing sand)
Moisture teller
Weighing balance
Sand rammer and ramming block
Compactability tester
Permeability meter
Universal sand strength testing machine
Shatter index tester
Oven and electric heating kiln
X-ray fluorescence (XRF) spectroscopy

2.2 Materials

Silica sand for this study was obtained from Adadariver in Npkologwu, Uzouwani Local Government Area of Enugu State, Nigeria. Also the clay used as binder was sourced from the same Npkologwu. The sand was taken from ten different locations within distances of 100 meters apart inside the river bed. The green sand was air dried for three days to allow moisture to evaporate and later oven dried at 110°C. The clay was dug from a depth of 50cm from ten different locations within distances of 10metres apart. Impurities such as stones, metals, hard lumps, organic matters were removed from the sand by sorting and sieving through 2mm mesh size.

2.3 Experimental Procedure

The clay lumps were dried in oven at 110°C and subsequently crushed, ground to pass through 200-250 mesh size. The sand samples were mixed thoroughly in a sand mixer and later a sample divider was used to obtain a representative sample for chemical and sieve analysis. The chemical analysis of the sand was conducted using x-ray fluorescence (XRF) spectroscopy while the sieve analysis was done using standard test sieve mounted on a sieve shaker.
Standard test samples were prepared using different ratios of sand and clay binder at certain quantity (percentages) of water in a sand mixer. Each test sample was used to produce AFS standard test pieces using Ridsdale laboratory sand rammer.

2.3.1 Mechanical properties tests

Green and dry compressive strengths were determined using universal sand strength testing machine. Green permeability was determined using electrical permeability meter. A steady moisture teller was used to measure the moisture content and instantaneous readings of percentage of moisture were determined using the procedure by Walker [11]. The shatter index of the specimen was determined using a shatter apparatus in accordance with the procedures stipulated by Parkes [12]. Percentage compactibility was determined using the compactability tester. The green and dry shear strengths were determined using the same universal testing machine.
The fusion point of the sample sand grains was determined using electric kiln a method similar to loss on ignition. The condition of the sand was monitored at intervals to observe the temperature the sand grains fused.

III. RESULTS, ANALYSIS AND DISCUSSION

Some satisfactory mould sand properties for various types of castings according to Dietert[13] and Mikhailer[14] are shown in Table 1.
The chemical composition of Adada river sand is shown in Table 2.

Table 1: Some Satisfactory Mould Sand Properties for various types of castings [13, 14]

Metal	Clay content (%)	Moisture content (%)	Green compressive strength (KN/m^2)	Dry compressive strength (KN/m^2)	Permeability No

Heavy steel	10-12	4-5	70-85	1000-2000	130-300
Light steel	7-12	6-8	70-85	400-1000	125-200
Heavy grey steel	10-19	6-8	70-105	50-800	70-120
Aluminum	8-10	4.5-5.5	50-70	200-550	10-30
Brass and Bronze	10-15	5-7.5	55-85	200-800	15-40
Light grey iron	8-13	4-6	50-85	200-550	20-50
Melleable iron	8-14	5-7	45-55	210-550	20-60
Medium grey iron	11-15	5-8	70-105	350-800	40-80

Table 2: Chemical Composition of Adada River Sand

Compound	SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	MnO	TiO_2	Ag_2O	Na_2O	LOI
Concentration (wt. %)	94.51	1.64	1.46	0.42	0.42	0.22	0.03	0.01	0.20	0.05	0.54

The fusion point of Adada river sand is 1403^0C.
The AFS grain distribution and grain fineness number of Adada river sand is shown in Table 3.

Table 3: AFS grain distribution and grain fineness number of Adada river sand

Sieve No	Aperture size (mm)	Sand retained on each sieve (g)	Percentage of sand retained (%)	Multiplier	Product
1	1.00	1.60	1.6	12	19.2
2	0.71	8.20	8.2	16	131.2
3	0.50	15.60	15.6	22	343.2
4	0.355	21.40	21.4	30	642.0
5	0.25	29.60	29.6	44	1302.4
6	0.18	4.80	4.8	60	288.0
7	0.125	16.40	16.4	85	1394.0
8	0.09	1.30	1.3	120	156.0
9	0.063	0.50	0.5	170	85.0
10	0.045	0.20	0.2	240	48.0
11	Pan(-045)	0.30	0.3	350	105.0
	Total	99.99	19.99		4514.00

ASF grain fineness number = product/Amount retained (%) = 4514/99.99 = 45.15
The variations of green compressive strength of Adadariver sand as a function of clay content and water is shown Fig 1.

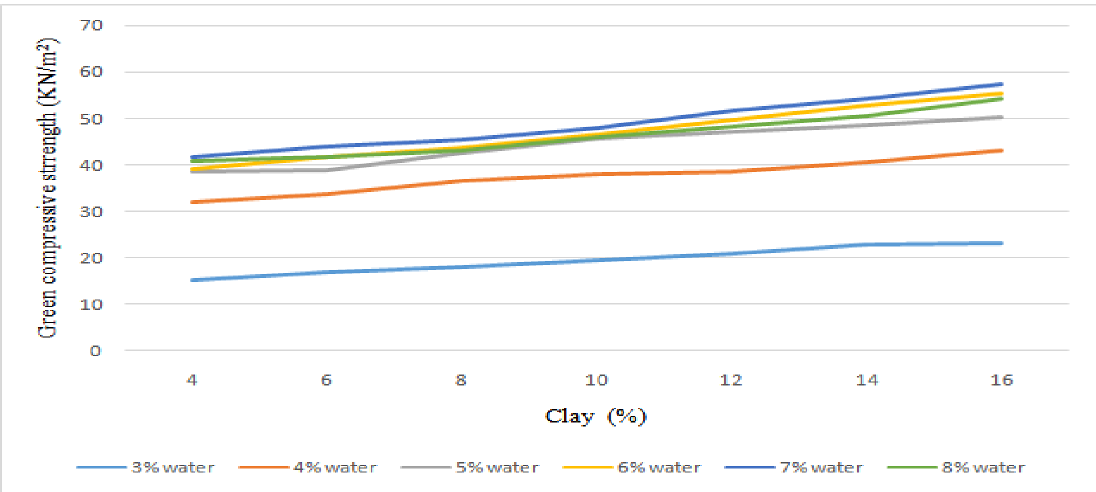

Figure 1: Green compressive strength of Adada river sand mouldas a function of % clay content at different water percentages

The variations of dry compressive strength of Adada river sand mould mixtures as a function of clay content and water are shown in Fig 2.

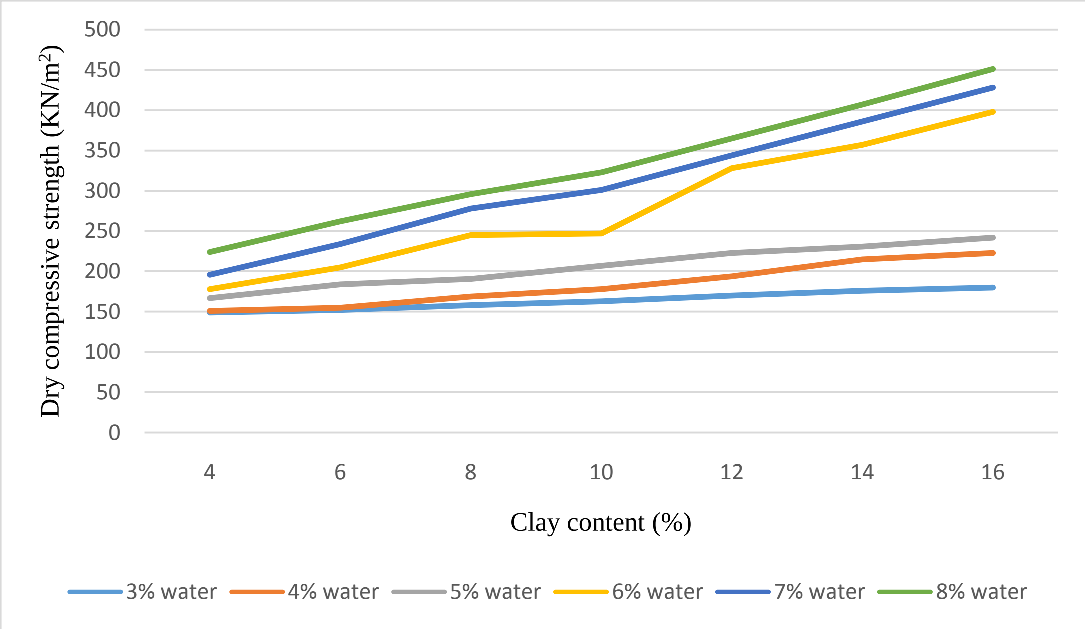

Figure 2: Dry compressive strength of Adada river sand mould as a function of % clay content at different water percentages

The variations of green shear strength of Adada river sand and Nkpologwu clay mould mixtures at different water content is shown in Fig 3.

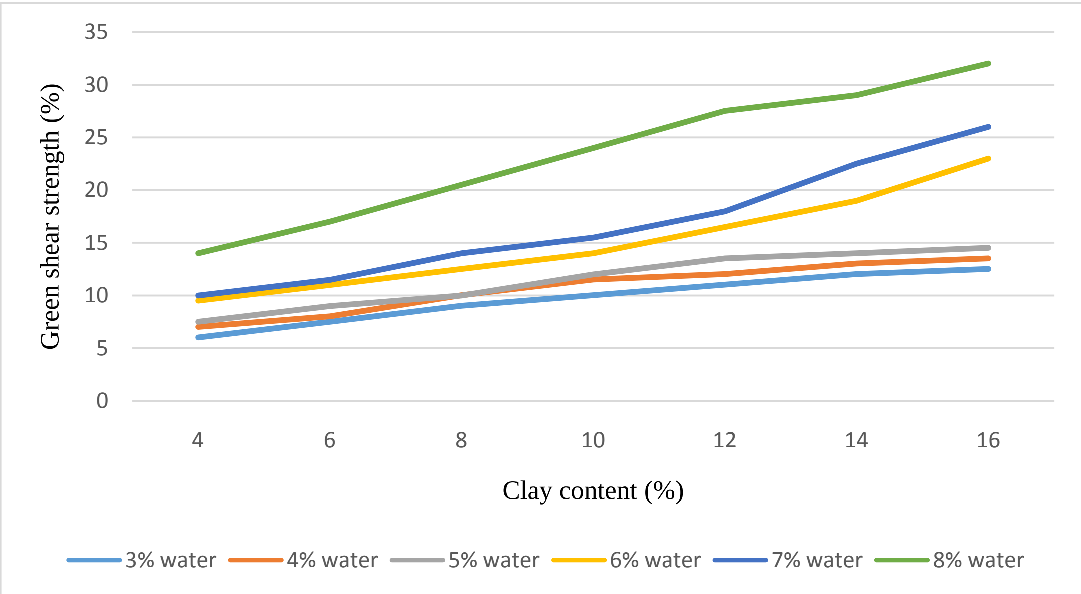

Figure 3: Green shear strength of Adada river sand mould as a function of % clay content at different water percentages

The variations of dry shear strength of Adada river sand and Nkpologwu clay mould mixtures at different water content is shown in Fig 4.

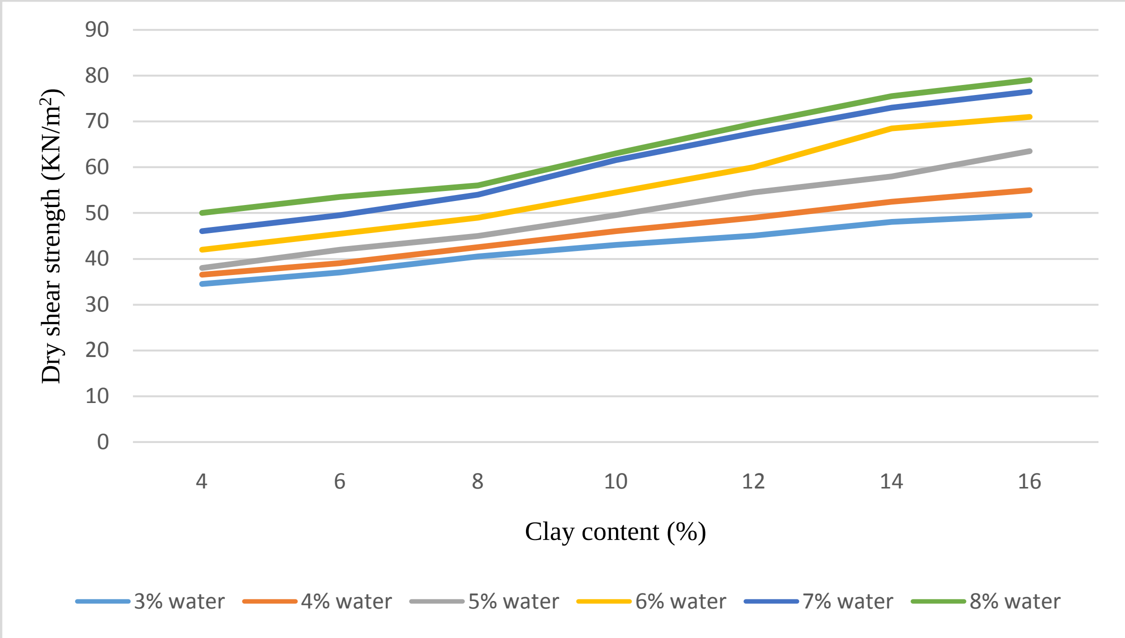

Figure 4: Dry shear strength of Adada river sand mouldas a function of % clay content at different water percentages

The variation of shatter index of Adada river sand and Nkpologwu clay mould mixture at different water content is shown in Fig 5.

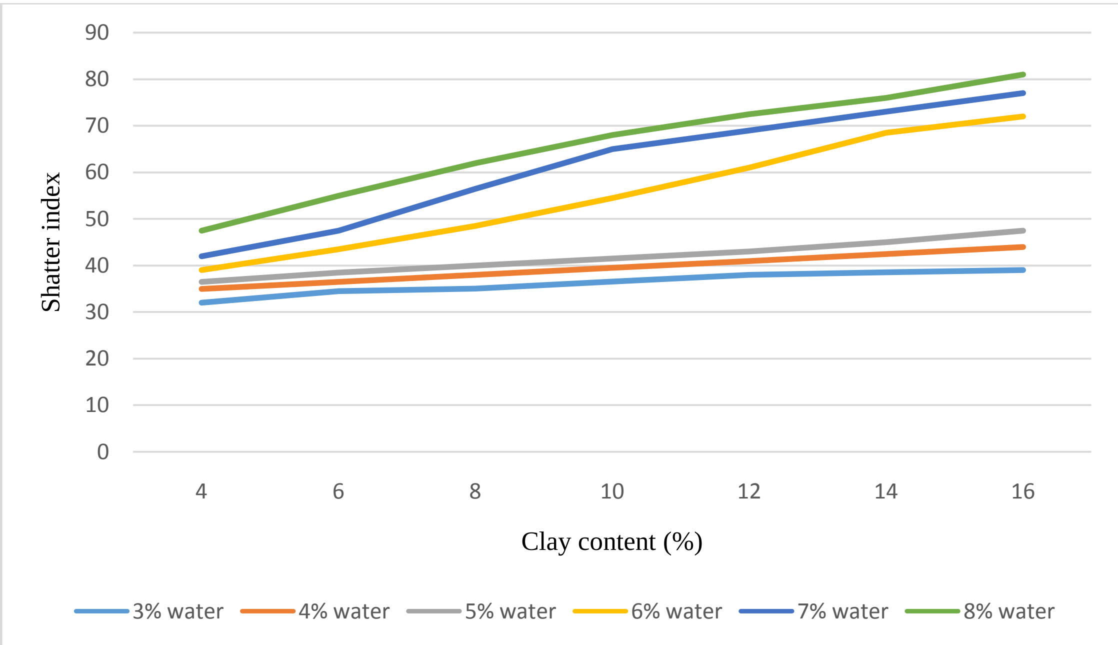

Figure 5: Shatter index of Adada river sand mould as a function of % clay content at different water percentages

The variations of moisture content of Adada river sand and Nkpologwu clay mould mixture at different water content is shown in Fig 6.

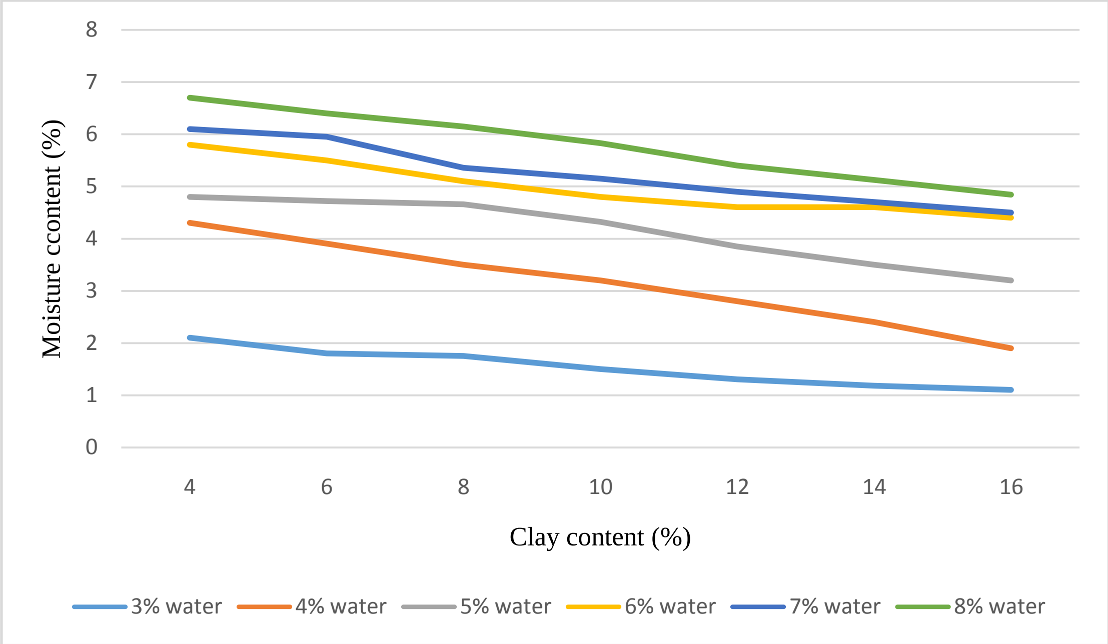

Figure 6: Moisture content of Adada river sand mould as a function of % clay content at different water percentages

Variations of permeability of Adada river sand and Nkpologwu clay mould mixtures at different water content is shown in Fig 7.

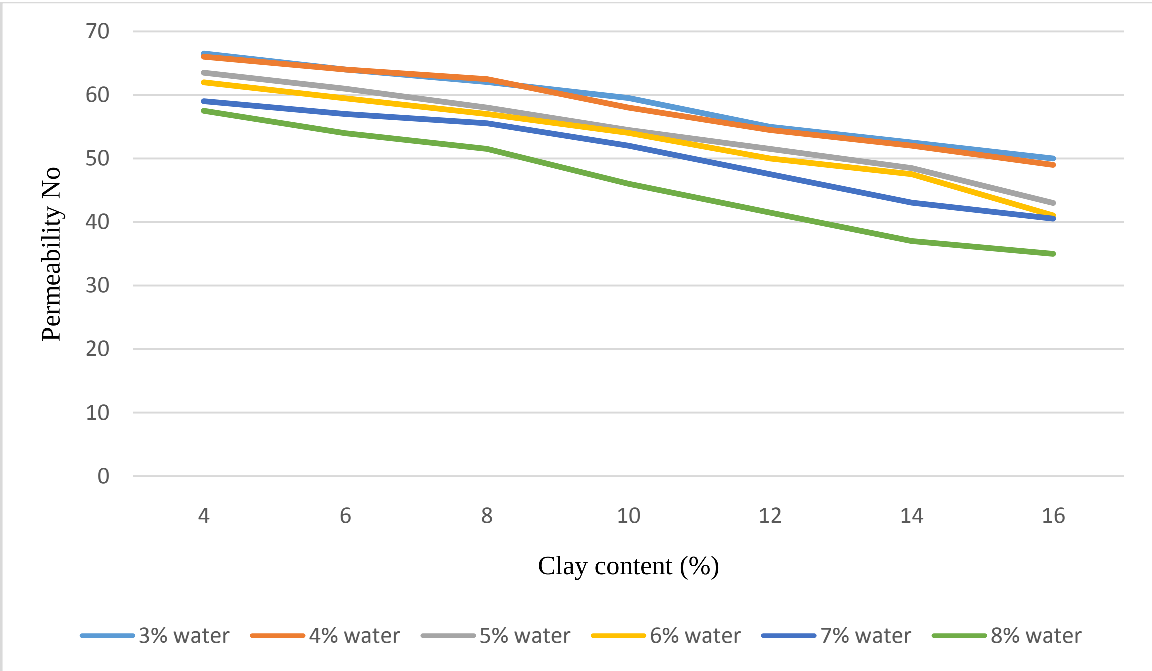

Figure 7: Permeability No of Adada river sand mouldas a function of % clay content at different water percentages

The variations of compactability of Adada river sand and Nkpologwu clay mixtures at different water content is shown in Fig 8.

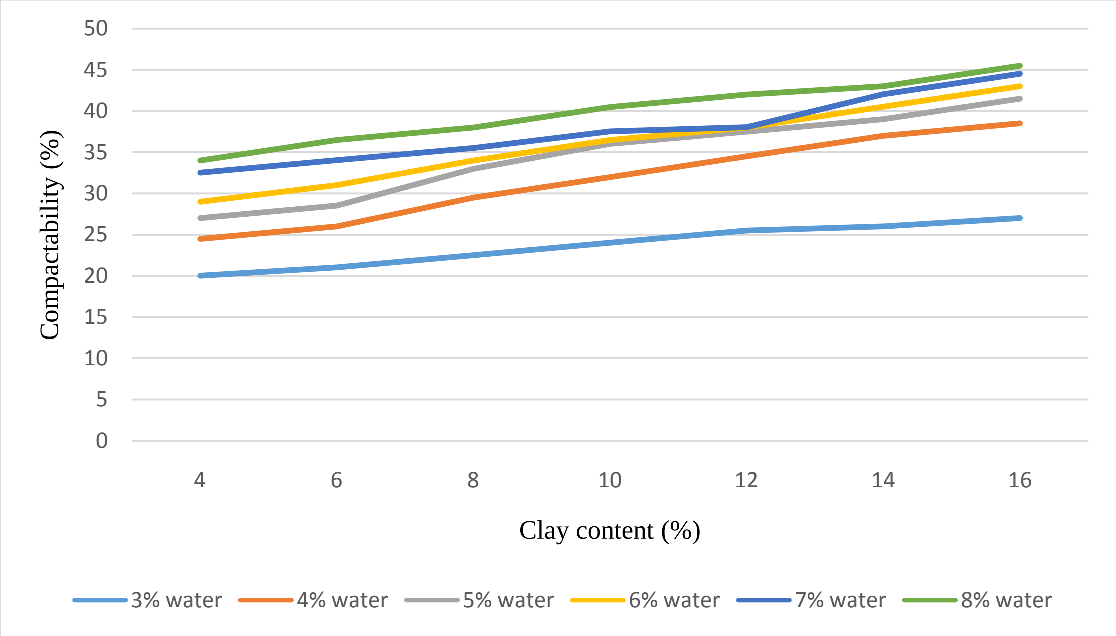

Figure 8: Compactability (%) of Adada river sand mouldas a function of percentage clay content at different water percentages

3.1 Chemical and grain size analysis

The chemical composition of the sand sample, Table 2, shows that the major constituent is silica (SiO_2) with 94.49% followed by alumina (Al_2O_3) with 1.46%, iron oxide (Fe_2O_3) with 1.48%. Other substances such as oxides of calcium, potassium, sodium, titanium among others occurred in small proportions. The values of the chemical constituents are in line with the recommended foundry mould sand chemical compositions in literature [15].

The grain sand distribution of the Adada river sand is shown in Table 3 and figure 1. Rechard et al [16], as well as AFS [4], showed that the grain size distribution affects many of the sand properties. Table 3 depicts that 96% of the sand grains lie between 0.710mm to 0.125mm, showing a well-defined grading. According to Ukachi [17], the characteristic shape of the sand grain is an important factor in sand. Nwajagu and Okafor [18] as well as Mikhailov [14] noted that highly concentrated small grain structures enhance fine surface finish casting.

A method to rapidly express the average grain size of a particular foundry sand is by grain fineness number GFN. The grain size and distribution of foundry sand determines its fineness. Large particles in sand are known as sand grains while fine particles are foundry sand clay. There is very important relationship between the clay in the foundry sand and the physical properties of sand grains. Knowing the grain fineness of foundry sand is a very important parameter guiding the amount of bonding material needed in developing the desirable properties for a new foundry sand. The grain fineness number of Adada river sand is 45.15, and this falls within the standard value range of 35-90 [19]. Therefore this sand may be suitable for non-ferrous dry sand castings as well as some cast iron castings and some alloy steels, as this belongs to the group of fineness number that has wide range of applications [20].

3.2 Green and dry strengths (compressive and shear)

Green compressive strength is a measure of the ability of the sand mould to withstand metallostatic pressure during casting and solidification of cast. The variations of green compressive strength of mould sample with increase in percent clay content of the mould mixture is shown in Fig.2. The green compressive strength increased with increase in percentage clay as well as increase in added water content. At 4% clay content, the green compressive strength increased from 15.20KN/m^2 with 3% added water to 41.60KN/m^2 with 7% added water and then decreased with addition of more water. At other percent clay content, the green compressive strength increased as water percentage increased and reached maximum at 7% water content. Further increase in the percentage water content above 7% led to decrease in the compressive strength. The value reduced to 40.80KN/m^2 at 4% clay content and 8% added water. This reduction in green compressivestrength with increase in water suggests the presence of excess moisture in the sand mould. The water addition of not more than 7% is adequate for obtaining sound cast products with this sand.

The dry compressive strength increased with increase in percentage clay content as well as increase in added water, Fig.3. The increase in dry compressive strength with increase in added water at all the percentage clay contents indicates that themould mixture can absorb more moisture. It shows that at added water of 6-8%, the sand mould in dry condition can withstand the pressure intensity of above 350KN/m^2 at about 14 to 16% clay content. Within the same 6-8% water and at 10% clay content, the dry sand mould can withstand pressure intensity above 250KN/m^2. This makes the dry moulding sand to be a suitable process for large casting.

The green and dry shear strengths are shown in Figs. 4 and 5 respectively. The green and dry shear strength increase with increasing clay content as well as increasing percentage of water. There was a rapid increase in green shear strength at 8% water while dry shear strength also increased rapidly at 6-8% water content

3.3 Shatter index

The shatter index of the mould samples of Adada river sand and Nkpologwu clay is displayed in Fig.6. The shatter index increased with increase in clay content as well as increase in water addition. At low water content of 3-5%, there was gradual increase in shatter index to a maximum of 47.50% at 16% clay and 5% water contents respectively. At 6-8% water content the shatter index increased rapidly as the clay content increased from 6 to 16%. At 6% clay the shatter was43.5% at 6% water and 55% at 8% water. At 16% clay, the shatter index was 72.00% at 6% water and 81.00% at 8% water. The increase in shatter index with increase in water content may be due to water activation of the clay and thereby toughening the mould to resist being shattered. Low values of shatter index leads to friability of the mould during pattern withdrawal. Too high values of shatter index are also not good as it makes mould breakage after casting difficult. The shatter index obtained in the tests are good for various ferrous and non-ferrous castings.

3.4 Moisture content

The moisture content is a very important parameter that requires consideration in determining the suitability of any moulding sand for casting. It ensures ease of moulding as well as good quality mould and casting. As shown in Fig.7, at any given percentage water addition, the moisture content decreased with increase in the clay content. This is because as the clay content of the mould mix is increased, more water is absorbed from the sand to wet the clay thereby reducing the moisture in the sand mould. The moisture content of the sand mould at 6%, 7%, and 8% added water fall within the satisfactory sand property range of (4-6%) for various types of castings as shown in Table 1.

3.5 Permeability

The green permeability number of a moulding sand is dependent on the moisture content and the degrees of fineness of the sand [15]. When the green permeability of the moulding sand is inadequate, explosions and casting defects results during casting. As shown in Fig. 8, at a given added water, the green permeability decreased with increase in the clay content of the specimen. Also the permeability decreased as the percentage added water increased. The result of experimental green permeability of the mould specimens showed that the sand samples had good green permeability for cast iron and non-ferrous metals casting.

3.6 Compactability

The ability of sand sample to be moulded in form is a measure of its compactability. The samples tested showed that the compactability has a direct relationship with increase in water and claycontents of the mould, Fig.9. The highest compactability of 58.50% was obtained at 8% water and 16% clay contents.

IV. CONCLUSION

This study has shown that Adada river sand collected at Nkpologwu has high silica content with physio-chemical properties that are suitable for non-ferrous and some ferrous alloy castings. It responded well to Nkpologwu kaolin clay binder that gave good mechanical properties of sand mould specimens. The amount of Nkpologwu clay employed as binder as well as the amount of added water greatly influenced the moulding properties of the sand.

The green and dry compressive strengths increased with increase in clay and water contents. A decrease in green compressive strength was observed at 8% water content and 16% clay after attaining a maximum of 57.4KN/m^2 at 7% water and 16% clay. The green and dry shear strengths increased with increasing clay and water percentages throughout the experimental limits.

The shatter index of the mould samples of Adada river sand and Nkpologwu clay increased linearly as the clay and water contents increased and reached a maximum of 81.00% at 16% clay and 8% water contents. The moisture content was observed to increase as the water percentage increased but decreased as the percentage clay increased. The moisture content of the mould samples at 6-8% added water fall within the satisfactory mould propertiesrange of 4-8% as shown in Table 1 [13,14]. The green permeability decreased gradually as both percentages of clay and water increased, but fell within acceptable standards.

The grain size analysis shows that 96% of the sand grains lie between 0.71 to 0.125mm, Table 3, showing a well-defined grading. The grain fineness number (GFN) of Adada river sand is 45.15, and this falls within the standard value range of 35-90 recommended for wide applications in metal sand castings. Thus, there is close agreement in the values of properties obtained from this study with established standard properties values for sand castings. Therefore, with some control this moulding sand can meet particular foundry sand requirements in its usage for casting types of metals or their alloys. Further work should be done on this sand to determine its moulding properties using bentonite as binder.

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