SUITABILITY OF OSARA AND JAMATA RIVER SAND DEPOSITS FOR MOULDING OPERATION

BY

Ayuba ALIU

DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING

FACULTY OF ENGINEERING

AHMADU BELLO UNIVERSITY, ZARIA

MARCH, 2018

SUITABILITY OF OSARA AND JAMATA RIVER SAND DEPOSITS FOR MOULDING OPERATION

BY

Ayuba ALIU (B.Eng. Met Mats. A.B.U Zaria 2010)

P15EGML8011

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD

OF

MASTER OF SCIENCE DEGREE IN METALLURGICAL AND MATERIALS ENGINEERING

DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING

FACULTY OF ENGINEERING

AHMADU BELLO UNIVERSITY, ZARIA.

MARCH, 2018

Declaration

I declare that the work in this dissertation entitled "SUITABILITY OF OSARA AND JAMATA RIVER SAND DEPOSIT FOR MOULDING OPERATION." has been carried out by me in the Department of Metallurgical and Materials Engineering. The information derived from the literature has duly been acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Aliu Ayuba	______________________	Feb. 2018
Name of student	Signature	Date

Certification

This dissertation entitled "SUITABILITY OF OSARA AND JAMATA RIVER SAND DEPOSIT FOR MOULDING OPERATION." by ALIU Ayuba meets the regulations governing the award of the Master of Science Degree in Metallurgical and Materials Engineering of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Prof. T Ause (Chairman Supervisory Committee)	______________________ (Signature)	______________________ (Date)
Prof. O. Aponbiede (Member Supervisory Committee)	______________________ (Signature)	______________________ (Date)
Dr. A. Kasim (Head of Department)	______________________ (Signature)	______________________ (Date)
Prof. S. Z Abubakar (Dean, School of Postgraduate Studies)	______________________ (Signature)	______________________ (Date)

Acknowledgement

I give thanks to Allah subhanahu wa ta„ala for giving me the support needed over the period of my study. I would like to thank my spiritual leaders Sheikh Halifa Ahmada Rufai Shaibu, Sheikh Muhammadul Ameen, Sheikh Dr. Tijani Salaudeen and all my Muslim brothers and sisters,

I would like to thank my supervisor Prof. T. Ause and Prof. O. Aponbiede whose constant guidance from start to finish made it all possible.

My appreciation goes to my H.O.D; Dr. Awal Kasim. This research wouldn't have been possible without his merciful support and advice. I give thanks to the technical staffs of the Department, in persons of Mal. Muhammad Suleiman, Mr. Danladi and others too many to mention. I also appreciate the support of my family, friends, brothers and sisters, and all the staffs of Mabruq Global Link. I thank you all for your cooperation.

Alhamdulillah!

Dedication

I dedicate this effort to Allah subhanahu wa ta’ala without whose blessing I will not be alive and able.

ABSTRACT

This research was carried out to ascertain the suitability of Osara and Jamata River sand for moulding operation and Ajaokuta Foundry Sand was also tested along with the two sands under the same condition and their moulding properties were compared with that of American Foundrymens' Society (AFS) Standard. The Jamata River sand sample was collected from the River Niger flowing under the Murtala Bridge along Lokoja to Abuja road at a village called Jamata in Kogi State while the Osara river sand sample was collected from Osara River along Okene to Lokoja road in a village called Osara in Kogi State of Nigeria. The three sand samples were subjected to various laboratory tests under the same condition in accordance to the American Foundrymens' Society (AFS) standard of testing moulding sand by varying the water addition from 3% to 7% and bentonite which acts as a binder was also varied from 6% to 12%. The two sand deposits are about 80km apart and they are both about 60km from Ajaokuta Steel Company respectively. The result of the grain size distribution analysis of the three sand samples met with the AFS standard specification of moulding sand in that the bulk of the sand retained were on four consecutive sieves and the Grain Fineness Number (GFN) calculated from the grain size distribution results show that Osara river sand sample has GFN of 51.6 and Jamata has GFN of 65.1 while Ajaokuta Foundry Sand has 57.6. The XRF analysis shows that Osara has 82.5% SiO_2 and Jamata has 86% SiO_2 while Ajaokuta Foundry Sand has 94.3% SiO_2 which indicate that the three sands met the AFS standard. The refractoriness of the three sands samples were tested by using pyrometric cone equivalent and none of the samples sintered at 1500^0C. The permeability of the three sand samples were within the ranges of 95 to 120mmWs which shows that the three sand can be used for both ferrous and nonferrous casting according to AFS standard. The results of the mechanical test (Tensile strength, green/dry compressive strength, green/dry shear strength) for the three sand samples show that the higher the percentage of water and bentonite addition, the higher the mechanical properties. The best mechanical properties were obtained at 12% bentonite with 7% water addition and at this point the two samples met the AFS standard. The result of the research shows that both Osara and Jamata river sand can be used for ferrous and nonferrous casting operation.

Table of Content

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

CHAPTER ONE

1.0 INTRODUCTION

Foundry sand is the principal moulding material in the foundry shop where it is used for all types of casting, irrespective of whether the cast material is ferrous or non-ferrous. This is because it possesses the properties vital for foundry purposes. Its most important properties include refractory nature, which enable it to easily withstand the high temperature of the molten metal without fusing. Its chemical resistivity enables it not to chemically react or combine with molten metal and therefore can be reused repeatedly. Its permeability allow for easy flow of atmospheric air and gasses that would have been trapped to the cast during pouring thereby causing blow holes (Mathew *et al*, 2010).

The Ajaokuta Steel Company Limited was established in 1979 as an integrated industrial complex. It operates on blast furnace method of iron smelting and it is the largest steel plant in Black Africa. It started when the Federal Government of Nigeria realized the indisputable fact that the country cannot industrialize without iron and steel industry due to the requirement of steel products in manufacturing and construction industries (Nuhu, 2008).

The first phase of the plant was to turn out about 1.3 million tons of long steel products, the second phase 2.6 million tons of flat products and third phase 5.2 million tons with provisions for expansion to 10 million tons of various types of finished and semi-finished steel product including heavy plates and sections eventually, www.elendureports.com.

The auxiliary, small scale, medium scale and heavy engineering manufacturing industries are expected to emerge around Ajaokuta Steel Company Limited. This massive cluster of industries will require heavy presence of foundries to service the industries for maintenance of spare and completely knocked down parts of plants and machineries (Nuhu, 2008).

Consequently, it is important that every natural resource around the steel plant is researched on to determine its suitability for any of the industrial processes.

In this research the foundry properties of Osara and Jamata River sand and Ajaokuta Foundry Workshop sand samples were compared with the American Foundrymens' Society Standard.

Osara River exist at a longitude 6^0 19′52″E and latitude 7^0 41′ 14″N between Okene and Lokoja in Kogi State and is about 25 Km from Okene with a large deposit of sand. The people in Osara use the sand to make blocks for sales likewise the neighbouring towns Okene and Lokoja too.

Jamata Bridge is one of the longest Bridges in Nigeria and it is between Kotonkarife and Lokoja in Kogi State. It is about 1Km from Kotonkarifi towards Lokoja with a massive deposit of sand along the river (River Niger) which flows beneath the bridge.

1.1 Statement of Research Problem

Many foundry companies in Nigeria find it difficult to get suitable sand for their foundry work because most of the sand deposits have not been researched on in order to give the company's reliance and confidence in using them. Kogi State is one of the States in Nigeria with large sand deposits but very few of them have been explored. The source of silica foundry sand for Ajaokuta Steel Company foundry workshop is Burutu (close to seashore) in Delta State which is about 700km away from the company. The cost and time of transporting the sand is high.

Therefore locating a closer and suitable source of foundry sands is part of solution to the problem of the foundry management of the Steel Plant. This research seeks to characterize sands around the company to evaluate their suitability for the company foundry sand casting and other foundry companies in Kogi State at large.

1.2 Aim and Objectives

The aim of this research is to carry out the investigation of the suitability of Osara and Jamata River sands deposits for moulding operation. To achieve this aim, the following objectives were pursued;

i. To carry out the clay contents analysis, grain size distribution by using the sieve shaking method and XRF/XRD analysis of the sand samples and the bentonite (binder) used.

ii. To determine the refractoriness of the sand samples by using pyrometry cone equivalent method.

iii. To determine the permeability and mechanical properties (i.e tensile strength, green/dry compressive strength and green/dry shear strength) of the sand samples.

1.3 Justification of the Research

The research tends to find alternative sand for both Ajaokuta Steel Company and other foundries in Nigeria. It will go a long way in adding to the literature of the studies of foundry sands across the Federation (Nigeria).

Ajaokuta Steel Company uses moulding (silica) sand collected from Delta State which is too long a distance from the Company. It is equally too expensive and time consuming for the

Company. These are the reasons why this research is carried out to verify the suitability of the Osara and Jamata Sand deposit to the ferrous and nonferrous metals casting foundry usage.

One of the objectives of Sustainable Development Goal in Nigeria is to make environment conducive for the foreign and local investors in Nigeria. For these objective to be achieved all the natural resources necessary for the investors to work has to be explored to serve as an encouragement for their investment. Sand is a great resource for foundry investment. It is on these bases that this research is carried out.

1.4 Scope of Work

The scope of this work covers the testing for the foundry properties (i.e clay content test, determination of grain size distribution, chemical analysis, moisture content, permeability test, Tensile strength, green/dry compression strength test, green/dry shared strength test and refractoriness) of Ajaokuta Steel Company Foundry sand, Osara and Jamata River sand samples.

1.5 Contribution to Knowledge

1. The research work was able to establish foundry sand suitable for ferrous casting for Ajaokuta Foundry Workshop and other future auxiliary foundry companies that may be established around it.
2. To serve as a means to boost employment strategy for the people residing around the sand deposit.
3. The outcome of this research will enhance the Ajaokuta Steel company Limited's productivity and maximization of profit since it is closer and cheaper to explore as the

suitability of the sand in both close location (Osara and Jamata river sand) to the company has being confirmed by this research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Sand

Silica sand is the most commonly and widely used sand in casting. It is found on the earth's surfaces like beaches, underwater like in rivers and lakes, and subsurface deposits of different geological formations (Idenyi and Ani, 2006).

In recent years there has been a significant trend towards the use of high silica (clay free) sands at the expense of naturally bonded (high- clay) material. This change has been mainly brought about by the growing employment of synthetic resins for binding sand together (Serve, 2000).

2.2 Sand Grain Shape

Sand grains can vary in shape from angular, sub-angular to round. Ideally foundry sand should possess a sub-angular to rounded grain shape. It has already been established that angular grains which are normally the result of crushing rocks or hard-stone, are to be avoided as they have a large surface area and promote a large parking density. Angular sand therefore normally required substantial properties of foundry binders to develop reasonable strengths (Aliyu 2010).

2.3 Moulding Sand

The properties of moulding sands are influenced by the addition of additives and variation in the amount of some ingredients and additives (Ayoola *et al*, 2010). Aliyu, (2010) observed that various types of sand are used in foundries for the manufacture of moulds. He further noted that whilst naturally occurring "green" sand is suitable and the most used, other forms such as dry sand, core sand, cement bonds and shell moulding sand are also employed for specific purposes. Nuhu, (2008) stated that, the term green denotes the presence of moisture in the moulding sand and indicates that moulding sand is not dried or baked. According to Akintunde and Omole, (2008), sand suitable for moulding consists largely of grains of Silica (SiO_2) together with 5-6% clay to act as binder. Bindability of moulding sand is determined by the amount of binder present in it, and is one of the requirements for effective performance of the sand for moulding. Synthetic moulding sands, used by the foundry industries are essentially composed of pure quartz sand (free of clay or organic matter), bentonite and other additive such as pulverized coal or cereal and water. Synthetic sands are now widely used because they are amiable to much closer control of process, longer working life and also show a high degree of uniformity in composition.

For both naturally and synthetic sand mouldings, the quality of casting is influenced significantly by sand properties such as green compressive strength, dry strength, permeability, shatter index, moisture and others as stated by Mahesh *et al*, (2008). All these properties are in turn dependent on the parameter of the binder used, water and sand grain size. American Foundrymen's Society (2005) gave the satisfactory moulding property ranges for sand castings of various metal grades (Table 2.1).

Table 2.1: Satisfactory Mould Property Range for Sand Casting

Metal	Green Compressive Strength (kN/m^2)	Dry Strength (kN/m^2)	Permeability (ml/min)
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: American Foundrymen’s Society, 2005

Different types of refractory sands used for molding are:

(i) Silica sand (ii) Magnesite (iii) Zircon (iv) Silimanite (v) Olivine (vi) Graphite/carbon

Sand used in foundries must be capable of withstanding very high temperatures and should not collapse under the prevailing load.

Silica sand is mostly used in foundries because of the following.

1. It is a very good refractory material and doesn't fuse or soften even at very high temperatures, i.e. 1650°C, when in contact with molten metal.
2. They can be easily molded into intricate shapes.
3. They have sufficient porosity or permeability and allow easy escape of gases produced by molten metal and other bonding constituent.

4. They can be used repeatedly for making molds after addition of some bonding materials.
5. They are cheap and easily available.
6. They are chemically immune to molten metals.
7. They do not decay.

2.4 Properties of a Moulding Sand

2.4.1 Permeability

Molten metals always contain a certain amount of gases, which are evolved when the metal solidifies. Also the molten metal, when comes in contact with the moist sand, generates steam and water vapour. If these gases and water vapour do not find passage to escape completely through the mould they will form gas holes and pores in the casting. The mould must be permeable, that is, porous, to permit gases to pass off, or the casting will contain gas holes (Richard, 2001 and Agarwal *et al*, 2007).

For absolute determination, permeability is tested with an apparatus known as the “Permeability Meter”. This has an arrangement for allowing a controlled amount of air to pass through a sand sample. The time taken for all the air to pass through the sample is measured (Jain, 2004).

Permeability is expressed in terms of the permeability number, which is defined as the volume of air in cubic centimeter that will pass per minute through a sand sample of 1sqcm in cross section and 1cm high, at a pressure of 1g per cm^2 (Jain, 2004).

Thus, where

V = Volume of air in cubic centimeter.

H = Height of the sample in cm;

P = Pressure of air in g/cm^2

A = Cross-sectional area of the sample in cm^2

T = Time in minutes

$$\text{Permeability Number} = \frac{VH}{PAT} \qquad (2.1)$$

The principle of working and design of a permeability meter are illustrated in Figure 2.1.

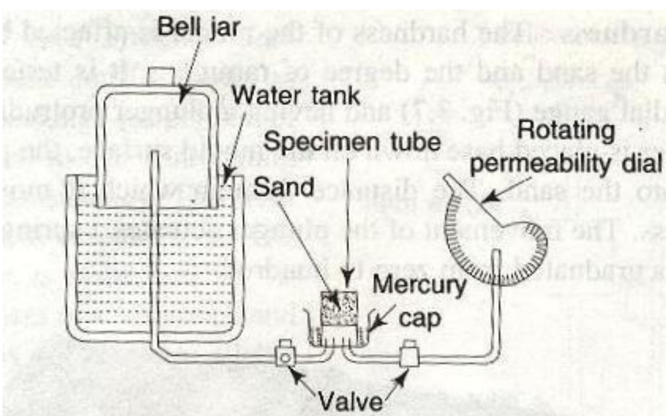

Figure 2.1: Principle of working of a permeability meter

Tokan *et al*, (2004) conducted a mould characterization of Azare foundry sand and verified that the Azare foundry sand moulding mixture at green state has a high permeability of 88%. They stated that the permeability value for casting cast iron is between 40% and 120%. Mathew and Sunday, (2010) investigated the effect of moisture content on the moulding properties of River Niger sand using Tudunwada clay as a binder and found out that the sand has the peak permeability of 420 (mm) when the percentage of water content was 4%.

Aweda and Jimoh, (2009) carried out an assessment of the properties of natural moulding sands in Ilorin and Ilesha and come out with a result that Ilorin and Ilesha sands are having a permeability index of 50 and 47.5 respectively.

2.4.2 Tensile strength of moulding sand

Tensile strength is an important concept in engineering, especially in the fields of material science, mechanical engineering and structural engineering. Tensile strength testing is commonly used to determine the maximum stress of a material that can endure while being stretched or pulled before breaking. In foundry, special type of sand is used for making mould. It is clean, uniformly sized, high-quality silica sand that is bounded to form moulds for ferrous (iron and steel) and non-ferrous (copper, aluminium, brass) metals. The molten metal enters the mould cavity and sand develops several strength zones (Mohini and Bombale, 2014).

Throughout the pouring process, sand at the mould metal interface is suddenly heated. The water inside this hot layer is vaporized and migrates between sand grains to cooler region. The thermal expansion of silica sand in the hot zone and the weakness of the wet layer can cause rupture between the two layers resulting into breaking of the mould. This has effects on the precession of the metal that was produced. For this reason, tensile strength of the type of sand use in foundry needs to be tested for, to confirm if the sand will be able to withstand the weight of the molten metal in the mould cavity without collapsing (Mohini and Bombale 2014).

2.4.3 Green and dry compressive strength

The green sand, (after water has been mixed with dry sand) must have adequate strength and plasticity for making and handling of the mould (Richard, 2001). A mould having adequate green strength will not distort or collapse even after removing the pattern from the mould box. In the absence of green strength, dimensional stability and high accuracy cannot be achieved (Agarwa, *et al* 2007).

If green sand mould is likely to loose its moisture and get dried when it comes in contact with molten metal, the mould is dried or skin-dried to withstand pressure and erosive forces of molten metal.

Strength testers are used to estimate the compressive, Tensile and Shear Strength of sand. The sand sample as prepared by a standard sand rammer.

The Table 2.1 shows the acceptable green/dry compressive strength of moulding sand according to the American Foundrymen’s Society (AFS) standard. Any sand that does not fall within the acceptable range is termed to be unsuitable for foundry usage.

2.4.4 Green and dry shear strength

During the period of removing the pattern from the mould, a shearing force is exacted on the compacted sand in the mould. Therefore a moulding sand should have good green shear strength to withstand this shear force so as to prevent the moulding sand from collapsing.

The figure below shows the principles of tensile, compressive and share strength test.

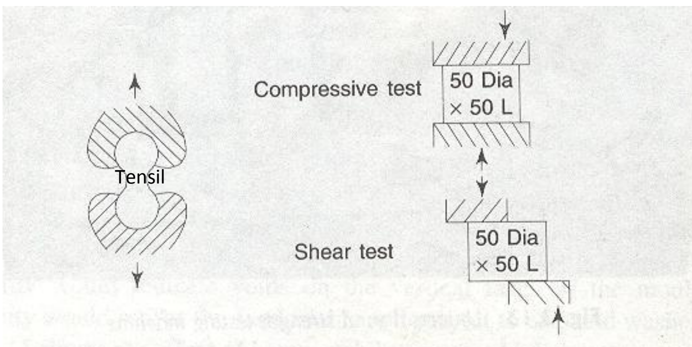

Figure 2.2: Principles of tensile, compressive and shear strength test

The sample is placed in a holder and squeezed mechanically until it breaks. The force applied in squeezing it is shown on an indicator. The force registered at the breaking point is the compressive strength of the sand. By changing the holder, the same tester may be used for testing shear and tensile strength.

2.4.6 Percentage water content of a moulding sands

The purpose of clay will not be served until the requisite amount of moisture is added to it. Clay imparts bonding action and strength in the presence of moisture (Agarwal *et al*, 2007). When water is added to clay, it penetrates the mixture and forms a microfilm which coats the surface of each flake. The molecules of water forming these films 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 thickness of this water film varies with the clay mineral. The bonding quality of clay depends on the maximum thickness of water film it can maintain (Jain, 2004).

When a mould is rammed, the sand grains are forced together on each grain, the clay coating acts in such a way that it locks the grains in position and makes them retain the position. The bonding motion is the best according to Agarwal *et al*, (2007), if the quality of water added is just micro-film. Strength is reduced, and the mould becomes weak, if the water added is in excess.

Water, present in amounts of about 1.5 to 8 percent, activates the clay in the sand, causing the aggregate to develop plasticity and strength. Water in moulding sand is often referred to as tempering water (Richard, 2001).

Aweda and Jimoh, (2009) conducted an assessment of properties of natural moulding sands in Ilorin and Ilesha and established that Ilorin and Ilesha sands were having an optimum moisture content of 5% and 6%. Fayomi *et al*, (2011) carried out a test on the suitability of local binder compositional variation on Silica Sand for foundry core-making and found out that the green sand used gave the best result when the moisture content was 6%.

Paul *et al*, (2011) carried out test on the effects of moisture content on the foundry properties of Yola natural sand and established that 5% moisture content give the optimum green compressive strength.

Mathew *et al* (2010), in their research obtained an optimum sand moulding properties at 2% and 4% water addition when they investigated the effect of moisture content on the moulding properties of River Niger sand using Tudun-Wada clay as a binder. They used 12% clay throughout their experiment.

2.4.7 Sieve analysis of moulding sand

The size and distribution of sand grains in sand is determined with the American Foundry Society (AFS) sieve analysis test (Richard, 2001).

The grain size of sand is expressed by a number called “grain fineness number”. To determine this number for a given sand sample, it is customary to use a standard sieve called the Sieve Shaker. It contains several sieves one above the other, having a varying but known number of meshes. The coarsest sieve is placed at the top and the finest at the bottom (Jain, 2004).

Grain size measurement consist of multiple sieve filtration, after which the weight average of the different fractions is performed (John, 1994).

The sample sand is placed on top of the sieves and shaken for 15 minute. After the shaking period, the sand retained on each sieve and the bottom pan is weighed and its percentage of the total sample determined (Richard, 2001).

The percentage collected in each sieve is multiplied by its own multiplying number (a given constant for each sieve) and all the products are added to arrive at the total products (Agarwal *et al*, 2007). Thus:

$$\text{Grain fineness number} = \frac{total\ product\ of\ weigth\ of\ retained\ \ X\ Mesh\ no.}{total\ sum\ of\ \%\ collected\ in\ each\ sieve} \quad \ldots\ldots\ldots\ldots 2.2$$

The grain fineness number is a concept that can be used for comparing fineness of different sands. For good compaction of sand, the amounts retained on 3 or 4 consecutive sieves should be in the range of 75-80% (Jain 2004).

Coarse – grained sands allow metal penetration into moulds and cores, resulting in a poor surface finish of the castings. On the other hand, fine-grained sands yield better surface finish, but need higher binder content and their low permeability may cause gas inclusions in the product according to (John, 1994 and John, 2000). Moreover size distribution affects the physical and technological properties as the thermal coefficient or slip ability (Peter, 2002). Consequently, the AFS fineness number is a decreasing function of the average grain size as stated by. The grain size of foundry sands fall mainly within 0.1-1.0mm (Peter, 2001 and Leone*et al*, 2010)

An excess of fine particles cause balling to occur during mulling. When water is added, the fines and clay agglomerate to form balls during mulling and thus prevent the clay and water from being thoroughly disseminated throughout the mass. The ability to mull the sand and disseminate the ingredients requires the balance of course, bulk and fine sand particles in the base sand (Richard, 2001).

The comparative sieve designation of International Standard (IS), British Standard (BS) and American Standard for Testing Materials (ASTM) sieves are given in the Table 2.2.

Table 2.2: Comparative sieve designations of IS, BS and ASTM test Sieves.

IS Sieve (Microns)	BS Sieve (Mesh)	ASTM sieve (Microns)
850	18	20
600	25	30
425	36	40
300	52	50
212	72	70
150	100	100
106	150	140
75	200	200
53	300	270

Source: Jain, 2004

The American foundry society sand standard is defined as a washed and dried Silica sand, AFS fineness number of 50± 1, with 100 percent through a 40-mesh sieve, 95 percentage through a 50 mesh and remaining on a 70-mesh sieve, and the balance retained on a 100-mesh sieve as described by Richard, (2001).

Nuhu, (2008) evaluated the foundry properties of River Niger sand behind (Geregu) Ajaokuta steel company limited and find out that the grain fineness number of the sand is 15% which is far below standard. He therefore recommends it for use in nonferrous casting because of other properties possess by the sand.

Mathew et al, (2010) worked on River Niger Sand using Tudun-Wada clay as a binder and established that the grain fineness number of the river sand is 14.412.

2.4.8 American Foundrymen's Society (AFS) clay content

For testing purpose, the American Foundrymens' Society (AFS) clay in a moulding sand is defined as "particles which fail to settle 25.4mm per minute when suspended in water. These are usually less than 20 microns in diameter" (Richard, 2001).

Binders to the moulding sands should be added in minimum required quantity as it reduces permeability. Increasing binder content to a limit increases green compression strength after which this strength remains practically unchanged with increase in binder content (Agarwal et al, 2007).

Clays (binders) are added to give cohesion to moulding sands and it provide strength to the moulding sand and enable it to retain its shape as moulding cavity. The principal mineral constituent of clays is kaolinite, it is relatively the major constituent of china and ball clays and when fired, clay has high alumina content that makes them reasonably refractory. Water exists in many forms in clay (as combined, absorbed, free or hydrated). When clay is dissolved in free water, it forms a suspension called colloidal solution. But the clay particles flocculate (clump) and settle quickly in saline water. Clays are easily moulded into a form that they retain water when dry, and they become hard and lose their plasticity when subjected to heat as demonstrated in the work of Mathew *et al,* (2010).

Umar and Bashir (2007) research show that Challawa river sand in Kano when mixed with 4% water and 20% clay can produce good synthetic sand for castings.

2.4.9 Bentonite

Bentonite is the most commonly used clay binder as it produces the strongest bond in mould sand. They are soft, creamy white powders. They are usually used for synthetic mould sand (Agarwal et al, 2007).

The specific percentage of clay required for saturation depends on purity and type of clay, base sand and additives. In most cases, however, about 8 to 12% of bentonites (either sodium or calcium bentonites) or about 20 to 25% fire clay is sufficient to produce a clay-saturated mixture with the sand fineness of 60 to 100 AFS number as stated by Richard, (2001).

A second type of sand practice involves the use of clay in amounts which are slightly but definitely less than the saturation percentage. The amounts actually carried in sand systems are about 6 to 9.0% AFS clay in bentonite-bonded sand, or about the equivalent amount of 10 to 15% fire clay. Such sands are used more for lighter castings where expansion defects, erosion of cuts, and washes are lesser problem Richard, (2001).

Bentonite is employed by industry to perform a multitude of jobs. Certain industrial applications become apparent from an understanding of composition and structure of bentonite and the properties they create. These properties are utilized directly when the material is suspended in a liquid usually water or as a dried powder or granule according to Arthur and Rober, (2011). Calcium bentonites have the greatest market as bonding agents in foundry molding sand. Their higher green strengths are unique among mineral binder, considering the small amount of bentonite necessary to impart adequate strengths. By blending calcium and sodium bentonite together, foundry-men develop favorable strength characteristics throughout all phases of the casting procedure and keep a mixture which is compatible with other sand additives such as the cellulose products as found in the work of Arthur, (2010).

Abdullahi *et al*, (2012) used 4% and 8% bentonite clay in their investigation of the effect of moisture content on the permeability of tailing sand samples gathered from Ex Tin Mines in Perak State Malaysia. The molding sand sample bonded with 8% clay was found to have maximum permeability with an optimum allowable moisture content range of 3.5-6.0% and for the sand mixture bonded with 4% clay at 3.0-3.5% moisture.

Arthur, (2010) researched on water sorption properties of Homoionic montmonillonite (bentonite) of four different sources and gave the chemical compositions of the four bentonite source as shown in the table 2.3;

Table 2.3: Chemical Analysis of the four Montmorillonites (bentonite)

Compounds	**M-1**[1]	**M-2**[2]	**M-3**[1]	**M-4**[1]
SiO_2	57.55	66.75	64.41	61.06
TiO_2	0.32	0.29	0.19	-
Al_2O_3	19.93	19.85	20.80	15.99
Fe_2O_3	6.35	2.25	3.65	4.50
FeO	0.95	-	-	0.12
MgO	3.92	6.98	2.33	2.00
CaO	1.94	3.21	0.83	0.96
K_2O	0.59	0.18	0.39	1.43
Na_2O	0.33	0.84	2.86	0.07
Ign	8.53	-	4.86	13.36
Total	100.41	100.91	100.32	99.96
H_2O-	8.51	-	-	5.88
H_2O+	7.43	-	-	13.36

Source: Arthur, 2010

He concluded that the plastic state is reached when enough water is put into the system (sand) to fill all the pore space and to supply all the montmonillonite layers with water adequate for rigid layers plus a slight additional amount. The type of cation is not the only factor which controls the properties of montmorillonite. The structure of the lattice also appears to determine the properties of montmorillonite.

Karunakaran and Jegadheesan, (2012) investigated the properties of moulding sand with waste powder from steel industry and they discovered that when they use 0% waste powder moulding sand, the permeability, green compressive and dry compressive strength were maximum at 5% bentonite added to this 0% waste powder moulding sand. The sand used by these researchers is Silica sand.

2.5 Chemical Analysis of Moulding Sand

2.6.1 XRD

XRD may be used to determine both matrix and aggregate minerals. The crystalline components of the material are to be analyzed in accordance with individual XRD equipment techniques. There are three sub-sampling techniques that may be helpful in determining the presence of minor components.

1. Acid Digestion

The acid insoluble residue may be studied under the microscope. Grains of interest may be separated out, manually, and ground for analysis. Alternatively, the residue may be sieved.

2. Manual grinding or crushing

A mortar and pestle may be used to crush the material. The resulting powder is then fed through a number of sieves and the component of interest may be studied.

3. A sample is cut into two pieces. One half is polished and studied under reflected or transmitted light, depending on procedure followed. If an area of interest is located on the polished sample, the reserved sample half may be mined for the component of interest with a fine probe (Elizabeth, 2014)

2.5.2 XRF

For XRF measurements a sample has to be additionally pulverized, homogenized and pressed into pellet with or without a binder. Usually Chromatographie cellulose, boric acid or starch are used as a binder in a proportion 1:10 by weight (in some cases a liquid binder might be used). For the emission—transmission method usually a 150 or 200 mg pellet is prepared (25 mm diameter). Although XRF is mostly used for minor and trace element analysis, major elements can be determined after proper dilution with cellulose or starch (in a proportion 1:1 by weight). Sample preparation needs to be done carefully and with the use of proper devices to prevent contamination. Therefore the devices such as mills, mortars and pulverizers should be made of agate, silicon carbide or tungsten carbide. They should be washed thoroughly with tap water, then distilled water and dried. For more complete cleaning, grinding with pure quartz sand, followed by careful washing with tap and distilled water should be applied (IAEA, VIENNA, 1997).

When dealing with samples containing heavy elements in a light (low density) matrix, which is often the case in geological samples analysis, the grain size effect can be an additional source of error in XRF analysis. The way of minimizing this effect is reduction of particle size by grinding. However, different particle size reduction occurs in most grinding procedures because the various constituents are reduced in size at different rates due to their differences in hardness, which may result in segregation. When diluents are added prior to pressing, a sample has to be mixed carefully to avoid segregation. A number of Teflon or Teflon-coated devices for homogenization are commercially available. In analysis of powdered materials, usually thick or intermediate samples are used. Thin samples are sometimes applied with the use of so-called "slurry" technique, for very fine powder (below 10 micrometer size). This technique works for water insoluble materials. A water slurry is prepared out of a few miligrams of powder and a few mililiters of water. A turbulent suspension is made followed by rapid filtration through a Nuclepore filter. This method results in fairly uniform thin layers and is applied in XRF. In the analysis of particular geological materials, and soil when concentrations of trace elements are to be determined, wet digestion might be applied (IAEA, VIENNA, 1997).

Nuhu (2008), evaluated the foundry properties of River Niger Sand behind Ajaokuta steel company limited, and came out with the analysis in which the result indicate that the sand has 71.66% SiO_2, 19.50% Al_2O_3 as the major component.

The table below shows the chemical composition of typical moulding sand for both ferrous and non-ferrous casting.

Table 2.4 XRF Analysis of Typical Mouding Sand by AFS Standard

Compounds	Weight (%) Ranges
SiO_2	81.4-92.4
Al_2O_3	3.94-8.84
FeO, Fe_2O_3	0.5-2.91
TiO_3	0.12-0.43
CaO	0.12-2.82
MnO	0.16-1.56
Alkalis (Na_2O,K_20)	1.7-4.37
Loss on ignition	0.9-5

Source: Agarwal, 2007 p 104.

2.6 Refractoriness

Refractory materials are substances or minerals that have high melting points and are difficult to fuse except at very high temperature. Refractoriness of a moulding sand is defined as the ability of molding sand to withstand high temperatures without breaking down or fusing thus facilitating sound casting. It is a highly important characteristic of moulding sands. Refractoriness can only be increased to a limited extent. They are processed at high temperature and/or intended for high temperature application. Refractoriness has been defined by the American Society for Testing and Materials (ASTM) as "the capability of maintaining the desired degree of chemical and physical identity at high temperatures and in the environment and conditions of use" (Nwagu and Tiedje, 2011).

Sani (2013), stated that molding sand with poor refractoriness may burn on to the casting surface and no smooth casting surface can be obtained. The degree of refractoriness depends on the SiO_2 i.e. quartz content, and the shape and grain size of the particle. The higher the SiO_2 content and the rougher the grain volumetric composition, the higher is the refractoriness of the molding sand and core sand.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Materials and Equipment

The materials used in this research work are Osara River sand collected from Osara River and Jamata river sand collected from under the Muritala Muhammad Bridge at a village called Jamata along the river Niger and Adjaokuta Steel Company Foundry Ltd Sand collected from the foundry workshop of the company. Bentonite clay used as binder was obtained from chemical store of the foundry workshop in Ajaokuta Steel Company Ltd and standard Ammonium hydroxide solution bought from a chemical store.

The equipment used are sieve shaking machine, permeability meter, standard sand rammer, universal sand strength testing machine, digital weighing balance, XRF (X-Ray florescence), XRD (X-Ray Diffraction) Machine, muffler Furnace in NMDC Jos and Bakers,

3.2 METHODOLOGY

3.2.1 Clay Content Analysis

The sand sample under investigation was first dried and 25g was taken into a jar. 475ml of water and 25ml of standard solution of NH_4OH (25g per liter) was added to the sample before the jar was carefully stirred for 5 min with a stirrer. The deflocculating agent (NH_4OH) acts as a coagulant of the clay particles and thereby maintains the colloids of the solution. The ammonium Hydroxide is used in this test rather than the conventional NaOH because any alteration in concentration of the standard solution of NH_4OH will not alter the result of the test.

The content was allowed to settle for 10 minutes and the particles which do not settle after 10 minute was siphoned off the jar with the water. The unsettled particles are the clay content of the sand sample. Water was added again to the settled sand and then stirred again for another 5 minutes and allowed to settle for a period of 10 minutes. The particles that refused to settle after 10 minutes were clay particles remaining with the sand. Therefore the unsettled particles with the water were again siphoned off the jar. This test was repeated until the cloudy nature of the clay is not visible and the water appeared clear. At this point, the water was siphoned and the settled sand was dried in furnace to a temperature of 110^0C to allow the complete evaporation of water for a period of 1 hour. The difference between this weight and the original weight gives the weight of the clay. This procedure was carried out for the other sand samples and the results are presented in table 4.1.

3.2.2 Determination of Grain Size Distribution

The stocks of sieves were arranged according to the aperture with the largest aperture on top of the stock and the smallest aperture at the bottom (on top of pan). Some quantity of sand was dried in the air and 100g of each of the sand samples was taken on top of sieve stock and the stocks are placed on a sieve shaker and then switched on. The time was set to allow for vibration for a period of 15mins. The sieves were removed one after the other beginning with one on top. The quantities of sand remaining on each sieve are weighed. The weight was recorded. Each separate sieve weight was multiplied by the preceding sieve mesh number. The sum total of the product is divided by the total weight of samples aligned and this gives the grain fineness number of the sand. The results are tabulated in Table 4.2, to 4.4.

3.2.3 XRD and XRF Analysis of the Sand Samples

The XRD and XRF analysis of the sand three samples were carried out. The XRD analysis of the sand samples and the bentonite were carried out at the Nigerian Geological Survey Agency in Kaduna while the XRF analysis was carried out at the Chemistry Department in Ahmadu Bello University, Zaria. The results are shown in figure 4.1 to 4.3 in chapter four.

3.2.4 Refractoriness

The refractoriness of the two sand samples was conducted by following the IS 1528 (part 1), 2010 standard. Here are the procedures followed;

The sand sample under investigation was first dried and sieved with a sieve whose aperture is 212µm. Test cones sand samples was prepared by mixing each sand sample with sufficient quantity of water and dextrin (special binder specified by the manufacturer of the pyrometric cone equivalent) to make the mixture become plastic and then moulded by hand into a pyrometric cone shape made of metal. The samples were dried and fired to a temperature of 900^0C in a muffler furnace.

The produced test cone was mounted on a plaque together with standard pyrometric reference cones designed to deform at various temperatures. The furnace was checked at intervals to ensure uniformity in distribution of heat. Over a period of 2hrs the temperature of the furnace was raise to about 200^0C below the estimated temperature of refractory under test.

The temperature of the furnace is raised at the rate of 2.5^0C/min. Softening of the cone were indicated by the top bending over and the tip of the cone touching the plaque surface. The standard pyrometric cone that softening simultaneously with the test cone is taken as the reference cone. That is the test cone is considered to have the same refractoriness with that of reference cone. In this research the cone whose cone designation is ISO 150 (i.e 1500^0C) was the only one that softening and none of the two samples softening at this point. The capacity of the furnace could not be heated beyond this temperature.

3.2.5 Permeability test

Permeability test was carried out with an apparatus known as permeability meter. It has an arrangement for allowing a controlled amount of air to pass through an AFS standard sand sample. The time taken for all the air to pass through the sample is measured.

The test specimen of 5cm height by 5cm diameter size in the mould was fixed on the permeability meter. The permeability meter was turned on and the indicator dial was observed moving increasingly till it stopped moving at a point. The figure at which it stopped moving was recorded as the permeability number of the sand sample. The procedure was repeated for the other samples and results were tabulated in Appendix A to C.

3.3 MECHANICAL PROPERTIES OF THE SAND SAMPLES

3.3.1 Sand Moulding Preparation

Each sands sample, were measured with an electronic weighing machine and poured on a metallic table. The bentonite (binder) was measured and poured on top of the sand on the metallic table and then thoroughly mixed together with water carefully measured to form a complete mixture.

Mixing was done within a period of 5minutes to avoid loss of water content due to evaporation and the metallic table used was to avoid absorption of water.

The measurement was taking such that the percentage of water, sand and bentonite were varied at every test. At first the bentonite was fixed at 6% while % water was varied from 3%-7%. This is repeated by keeping the bentonite at 8%, 10% and 12% respectively. This was carried on all the three sand samples under the same condition.

It was ensured that the total weight of mixture at any change in percentage of water is 1kg which will be enough to carry out the tensile strength test, dry/green compressive strength test, dry/green share strength test and permeability test.

3.3.2 Production of Standard Samples

From the prepared mixtures, some sets of cylindrical shape samples of dimension 5cm height and 5cm diameter was obtained after ramming operation by applying three blows of mass 65N. The prepared cylindrical shaped sand samples were used to test the following; dry/green compressive strength, dry/green shear strength and permeability.

Tensile test specimens are shaped to the figure 8 shown in the plate 1. They are moulded in a split core box and compacted with three blows each weighing 6.5kg from a height of 50mm by a standard rammer shown in plate 6. After baking the specimen at 200^0C for 1-3 hours, they are cooled and tested with a universal strength machine equipped with attachment to grip them as shaped and a meter to automatically read the strength of the moulded sample.

Plate 1: Pictures of produced tensile sand samples ready for tensile strength test

Plate 2: A cylindrical moulded sand sample

a b

Plate 3: a. Picture of a coupled mould for producing tensile sample.
b. Picture of a tensile split mould for making a sand tensile sample

Plate 4: Picture of a griping device for holding a tensile moulded sample to the universal sand strength testing machine.

a b

Plate 5: a. Strip for removing cylindrical moulded sample from the mould
b. Mould for producing cylindrical moulded sand sample

Plate 6: Picture of a Standard Sand Rammer

Plate 7: Picture of a Universal Sand Strength Testing Machine

3.3.3 Green/Dry Compressive Strength Test

Standard Universal Sand Strength Test Machine equipped with a meter to instantaneously read strength (in kN/m^2) and specimen gripping attachment was used for green/dry compression strength tests. The standard universal sand strength testing machine is shown in plate 7.

The green mould specimen was fixed on strength testing machine using compression holding device as shown in plate 8. A uniformly increasing load was applied on the specimen by rotating the lever of machine clockwise until the specimen crushed. The point on the scale at which the specimen crushed was read and recorded as the green compression strength of the sample. The same procedure was repeated to determine the dry compressive strength except the AFS sand sample used for dry compressive strength was baked at 110 to 120 ^{0}C for 1-3 hours and cooled in desiccators before the test. The same procedure was repeated for the other sand samples and the results are tabulated as shown in Appendix A to C.

3.3.4 Green/Dry Shear Strength Test

The procedure used in green and dry compression strengths is the same except that compression strength holding device is changed to shear strength holding device. The point on the scale at which failure occurred on the specimen was read and recorded as the green/dry shear strength and the results are tabulated as shown in appendix A to C.

CHAPTER FOUR

4. 0 RESULTS AND DISCUSSION

4.1 The Clay Content Test

The results of the clay contents of Ajaokuta Foundry sand, Osara and Jamata River sand samples are tabulated in table 4.1.

Table 4.1: Clay contents of the three sand samples

Sand samples	Original mass (g)	Final mass (g)	Mass loss (g)	Percent clay (%)
Osara sand	25	24.8	0.2	0.8
Jamata sand	25	24.6	0.4	1.6
Ajaokuta sand	25	24.9	0.1	0.4

The results of the clay content test shown in table 4.1 indicate that Osara River sand sample has 0.8% clay and Jamata River sand sample has 1.6% clay while Ajaokuta Foundry sand has 0.4% clay content. This result was in conformity with the result of the sieve analysis displayed in Tables 4.2 to 4.3 in which there was 0.8g of silt left on the pan of Jamata River sand sample whereas Osara River sand and Ajaokuta sand samples recorded 0g silt on the pan. This revealed that the Jamata river sand sample has the highest clay content among the three sands.

4.2 Sieve Analysis of the three sand samples

The results of the sieve analysis test of the sand samples after weighing the quantities of sand collected on each sieve were entered in Tables 4.2 and 4.3.

Table 4.2: Sieve analysis of Osara River sand sample

S/No	Sieve Aperture (μm)	ASTM No	Wt Retained (g)	Product
1	500	30	-	-
2	355	44	15.9	477
3	300	52	19.7	866.8
4	250	60	25.6	1331.2
5	150	100	35.2	2112
6	125	120	1.7	170
7	106	150	2.4	48
8	75	200	0.8	120
Total			**99.3**	**5125**

AFS Grain Fineness Number (GFN) = $\frac{\sum wt\ retained\ X\ Mesh\ No.}{\sum \%wt\ Retained} = \frac{5125}{99.3} = 51.6$……….4.1

Table 4.3: Sieve analysis of Jamata River sand sample

S/No	Sieve Aperture (μm)	ASTM No	Wt Retained (g)	Product
1	500	30	-	-
2	355	44	3.6	108
3	300	52	6.1	268.4
4	250	60	14.8	769.6
5	150	100	60.5	3630
6	125	120	7.5	750
7	106	150	4.2	504
8	75	200	3.1	465
Total			**99.8**	**6495**

AFS Grain Fineness Number (GFN) $= \frac{\sum Wt\ retained\ X\ Mesh\ No.}{\sum \%wt\ Retained} = \frac{6495}{99.8} = 65.1$…………4.2

Table 4:4 Sieve analysis of Ajaokuta foundry sand sample

S/No	Sieve Aperture (µm)	ASTM No	Wt Retained (g)	Product
1	500	30	-	-
2	355	44	15.1	453
3	300	52	13.1	576.4
4	250	60	15.5	806
5	150	100	45.2	2712
6	125	120	7.5	750
7	106	150	2.3	276
8	75	200	0.8	120
Total			99.5	5693.4

AFS Grain Fineness Number (GFN) $= \frac{\sum Wt\ retained\ X\ Mesh\ No}{\sum \%wt\ Retained} = \frac{5693.4}{99.5} = 57.2$……….4.3

From Table 4. 2 the sieve analysis of Osara River sand shows that 96.4% of the sand was retained on four sieves 44, 52, 60 and 100 corresponding to aperture of 355µm, 300 µm, 250 µm and 150 µm respectively. Therefore the grain size distribution of Osara River sand met the AFS requirement for a moulding sand. It has Grain Fineness Number of 51.6 which indicates that it is within the range of AFS Grain Fineness Number 45-100 (Serve, 2000).

In Table 4. 3, the sieve analysis of Jamata River sand shows that 88.9% of the sand was retained on four sieves 52, 60, 100 and 120 corresponding to aperture of 300 µm, 250 µm, 150 µm and 106 µm respectively. Therefore the grain size distribution of Jamata River sand met the AFS requirement for a moulding sand. It has a Grain Fineness Number of 65.1 which falls within the range of AFS Grain Fineness Number 45-100 (Serve, 2000).

4.3 Chemical Analysis of the Sand Samples

The XRF analysis results of the three sand samples are shown in Table 4.4 and that of the bentonite is shown in Table 4.5. The result indicates that Jamata River sand has 87% SiO_2 while Osara River sand sample has 82% SiO_2 and Ajaokuta has 94.3% SiO_2. This was in conformity with the XRD analyses result shown in Figures 4.1 and 4.2 in which Jamata sand sample has higher quartz phase than Osara River sand sample. The result complies with the assertion of Akintunde and Omole, (2008) which stated that sand suitable for moulding consists largely of grains of Silica (SiO_2). The mineralogical phases present in Jamata River sand as shown in figure 4.1 are Quartz, Sylvite and Anatase while that of Osara River sand sample are Quartz, Sylvite, Dolomite, Albite and Orthoclase Figure 4.2. The Ajaokuta Sand sample contains purely Quartz. The comparism of the three samples with the AFS standard were also shown in the Table 4.4 which implies that the three sand samples meet up with the AFS standard which qualifies them to be used for both ferrous and non-ferrous casting.. The XRF of the bentonite used shown in Table 4.5 also indicate that the bentonite used is of good standard as compared to the AFS standard..

Table 4.4: XRF analysis of the three sand samples

Oxides	**% Composition of the sand samples**			
	AFS Standard	Osara Sand	Jamata Sand	Ajaokuta Sand
SiO_2	81.4-92.4	82.5	86	94.3
Al_2O_3	3.94-8.84	6.9	7.5	2.1
Fe_2O_3	0.5-2.91	1.5	1.5	0.3
Na_2O	1.7-4.37	1. 0	0.2	0
MgO	1.7-4.37	0.6	0.5	0.2
TiO_2	0.12-0,43	0.9	1.3	1.4
K_2O	1.7-4.37	2.8	1.4	0.1
CaO	0.12-2.82	3.1	0.8	0.1
Loss on ignition	0.9-5			

Table 4.5: XRF analysis of Bentonite used

Oxide	% Composition of bentonite	
	AFS Standard	Obtained value
SiO_2	61.5	58
Al_2O_3	22.1	17.6
Fe_2O_3	4.2	8.9
$Na_2O + K_2O$	3.12	2.4
MgO	2.27	3.9
TiO_2	0.62	1.5
CaO	1.74	6.8

4.4 The X-Ray Diffraction (XRD) Results of the Two Sands Samples

The result for the XRD for Osara and Jamata River sand samples and Ajaokuta Foundry Workshop sand are shown in Figure 4.1 to 4.3.

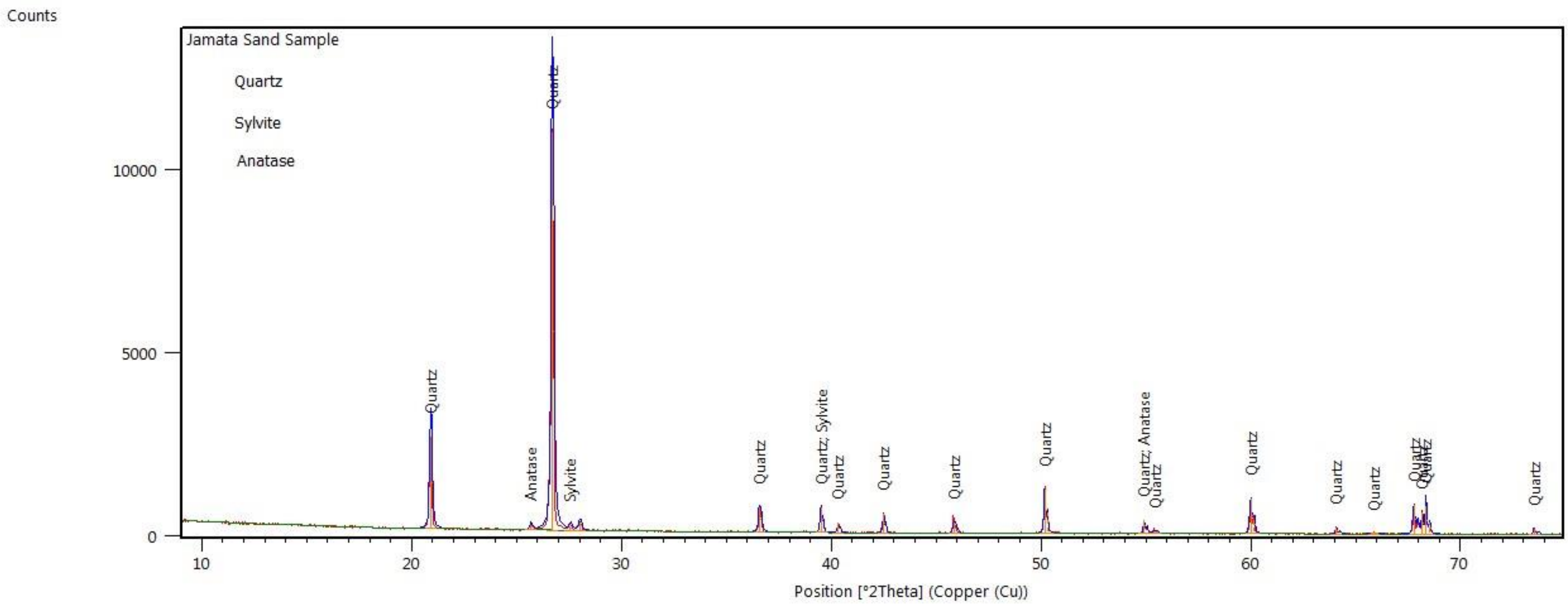

Figure 4.1: XRD result of Jamata River sand sample

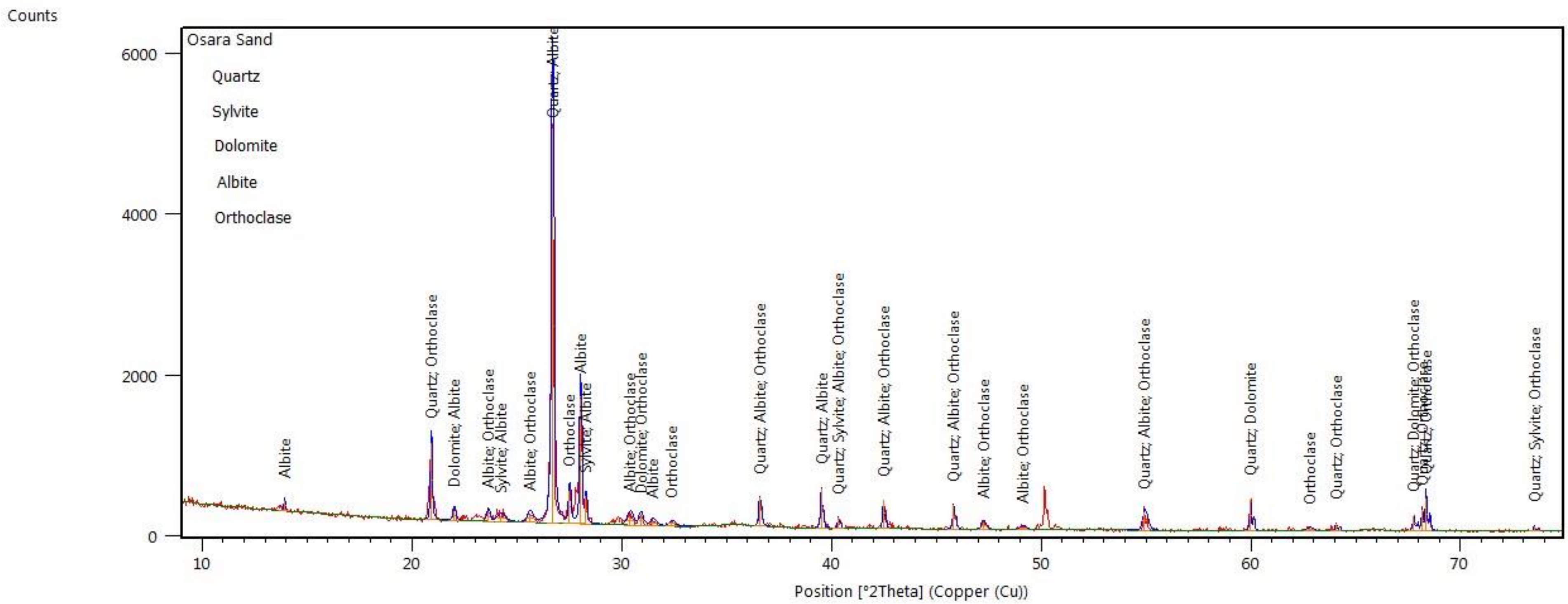

Figure 2: XRD result of Osara sand sample

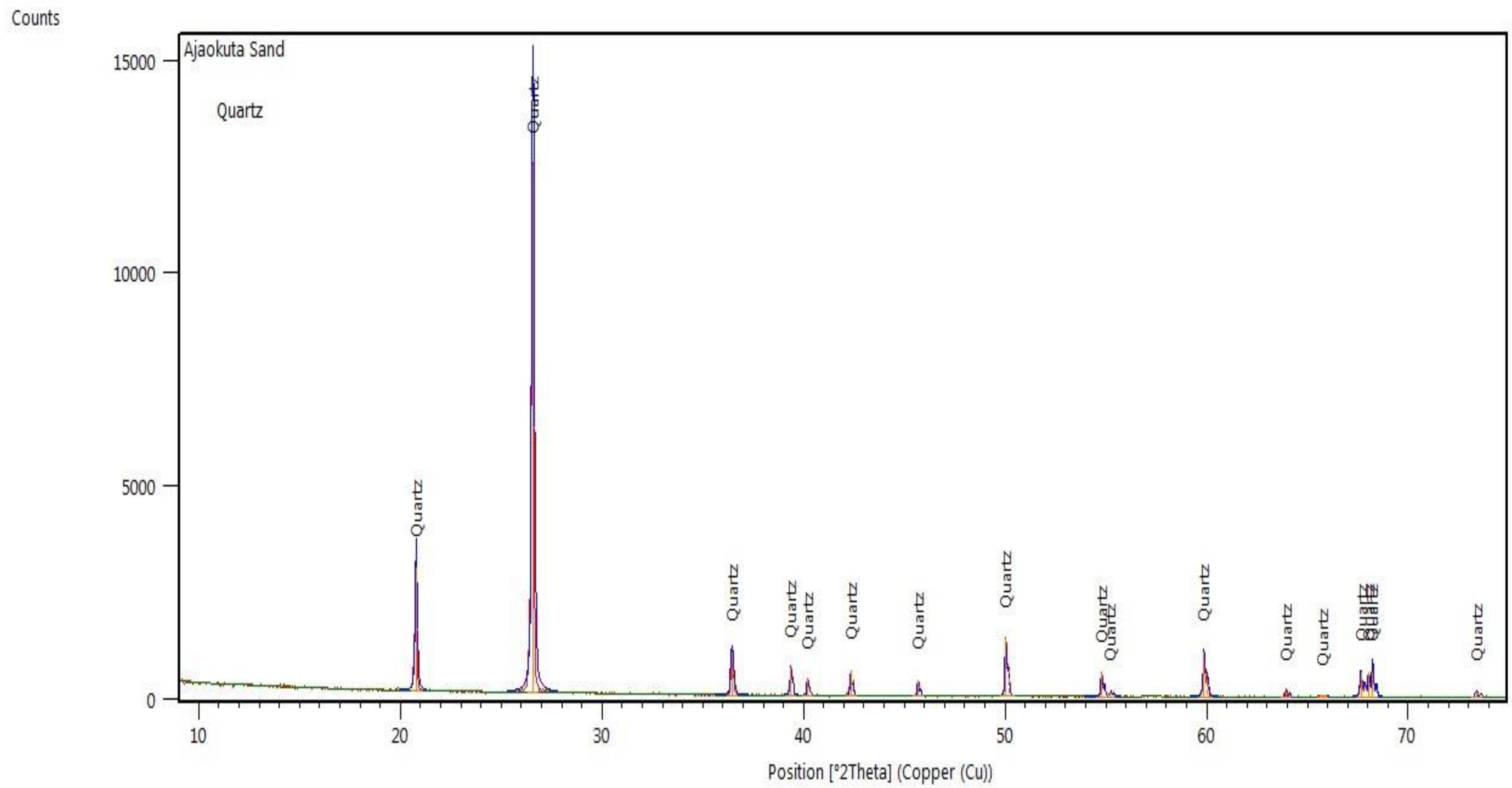

Figure 4.3: XRD result of Ajaokuta Foundry Workshop Sand

From the result displayed in Figure 4.1 to 4.3, it shows that the peak of the quartz for Jamata River sand sample is 14500 and Ajaokuta sand is 15500 while that of Osara River sand sample was 700. These results conform to the XRF result of the three sand samples in Tables 4.4 where Ajaokuta has 94.3% SiO_2, Jamata sand has 86% SiO_2 and Osara sand has 82.5% SiO_2. The XRD results also indicate that the Ajaokuta Foundry sand is purely quartz; Osara sand sample has quartz, sylvite, dolomite, albite and orthoclave minerals while Jamata river sand sample has quart, sylvite and anatase minerals. The presence of the minor minerals reduced the percentages of quartz (SiO_2) content of Osara and Jamat River sand samples..

4.5 REFRACTORINESS OF THE TWO SAND SAMPLES

Table 4.6 Refractoriness of the sand samples

Sand Samples	**Refractoriness (^0C)**
Osara	Above 1500
Jamata	Above 1500
Ajaokuta	Above 1500

The results show that none of the test cone of the three sand samples produced sintered or deform at 1500^{0}C. The available furnace at the National Metallurgical Development Center (NMDC) in Jos where this test was carried out couldn't be heated beyond 1500^{0}C. This obtained value indicates that the three sand samples can be used for both ferrous and nonferrous casting.

4.6 The Effect of % Water and Bentonite Addition on The Permeability of the Three Sand Samples

The tables of the result for the permeability test of Osara and Jamata River sand and Ajaokuta Foundry workshop sand samples were recorded in Appendix A to C and the figure of the result were shown in Figure 4.4 to 4.6.

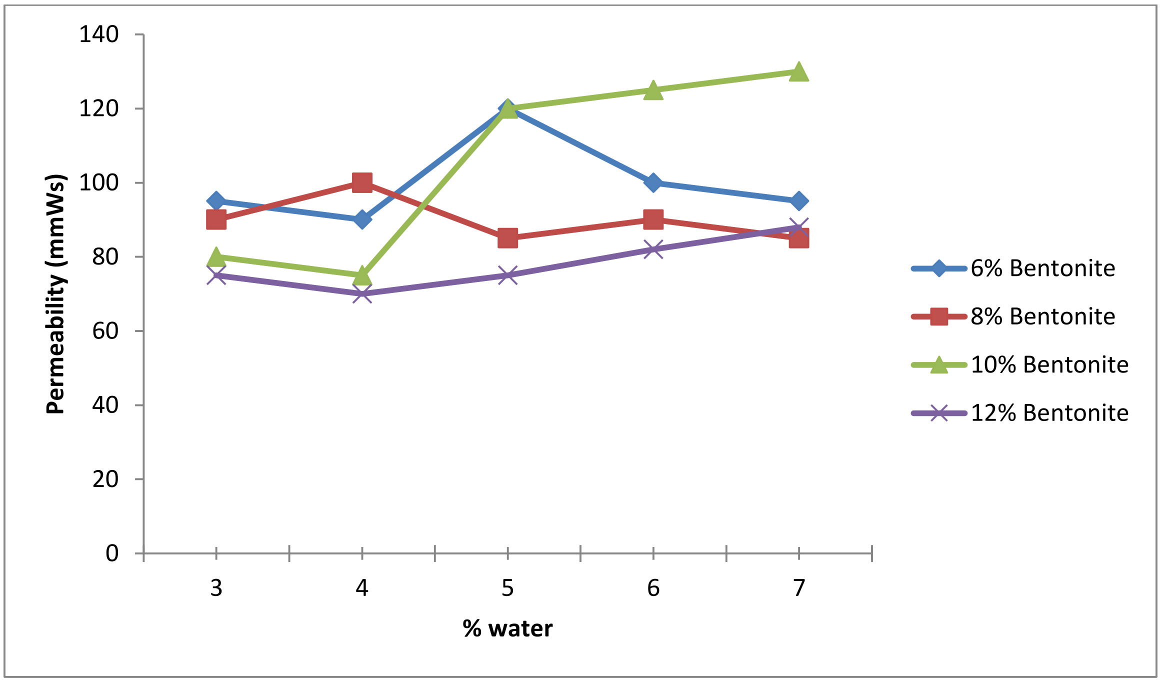

Figure 4.4: The Permeability of the Jamata River Sand sample.

From Figure 4.4, the maximum permeability of Jamata River sand sample is obtained at 10% bentonite with 7% water addition. It can be seen from the Figure 4.4 that the lowest permeability is at 12% bentonite addition. This is because the saturation point for the bentonite have been exceeded, therefore the excess bentonite addition will only block the interstitial space between the sand particle where air would have flown out of the mould easily.

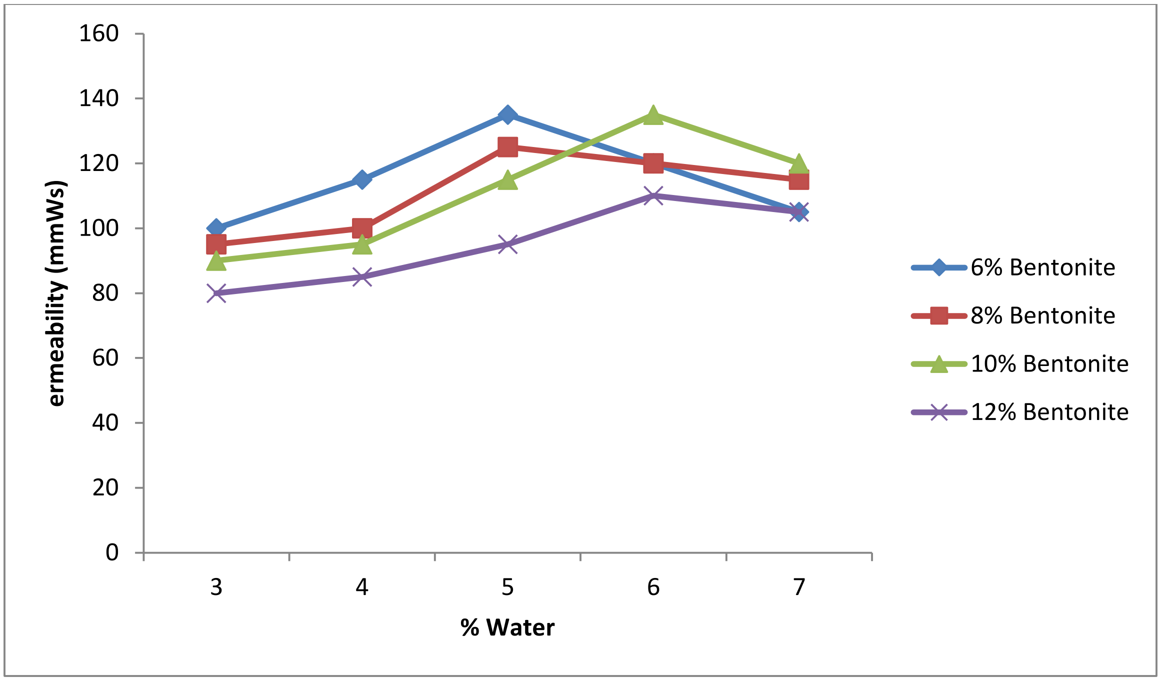

Figure 4.5: The Permeability of the Osara River Sand sample.

From Figure 4.5, the maximum permeability of Osara River sand sample is obtained at 10% bentonite with 6% water addition. It can be seen from the Figure 4.5 that the lowest permeability is at 12% bentonite addition. This is because the saturation point for the bentonite have been exceeded, therefore the excess bentonite addition will only block the interstitial space between the sand particle where air would have flown out of the mould easily.

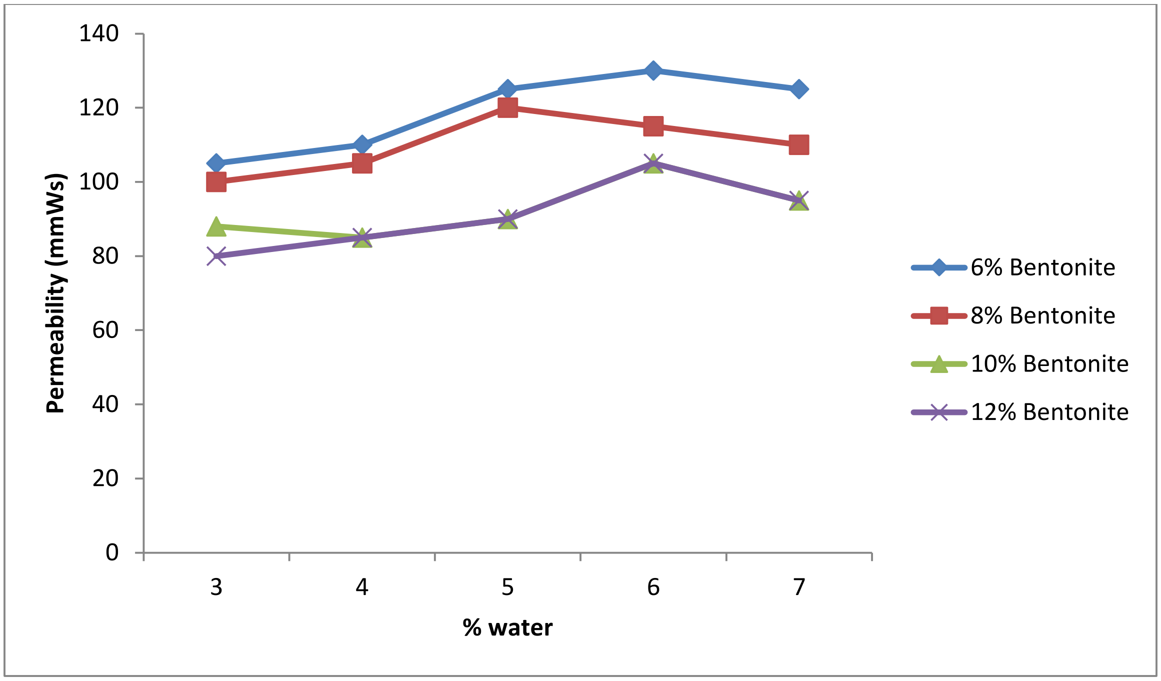

Figure 4.6: The Permeability of the Ajaokuta Foundry Sand sample.

From Figure 4.6, the maximum permeability of Ajaokuta foundry sand sample is obtained at 6% bentonite with 6% water addition. The next value that follows this is 8% bentonite with 5% water addition which should be better considered because of other factors (Mechanical propeeties).

Generally from Figure 4.4 to 4.5, it is discovered that the permeability of the Osara and Jamata River sand samples were best at 6% water addition and 10% bentonite but the Ajaokuta foundry sand sample from Figure 4.6 has its best permeability at 6% bentonite with 6% water addition but it is better to recommend 8% bentonite because of other factors to be considered. Any further increment leads to decrease in the permeability of the sand samples. From Table 2.1 at these values the three sand samples met the AFS standard of 90 to 120 mmWs for high steel casting.

4.7 Effect of % Water and Bentonite Addition on the Tensile Strength of the Three Sand Samples

The tables of the result for the Tensile Strength test of Osara and Jamata River sand and Ajaokuta Foundry workshop sand samples were recorded in Appendix A to C and the figure of the result are shown in Figure 4.7 to 4.9.

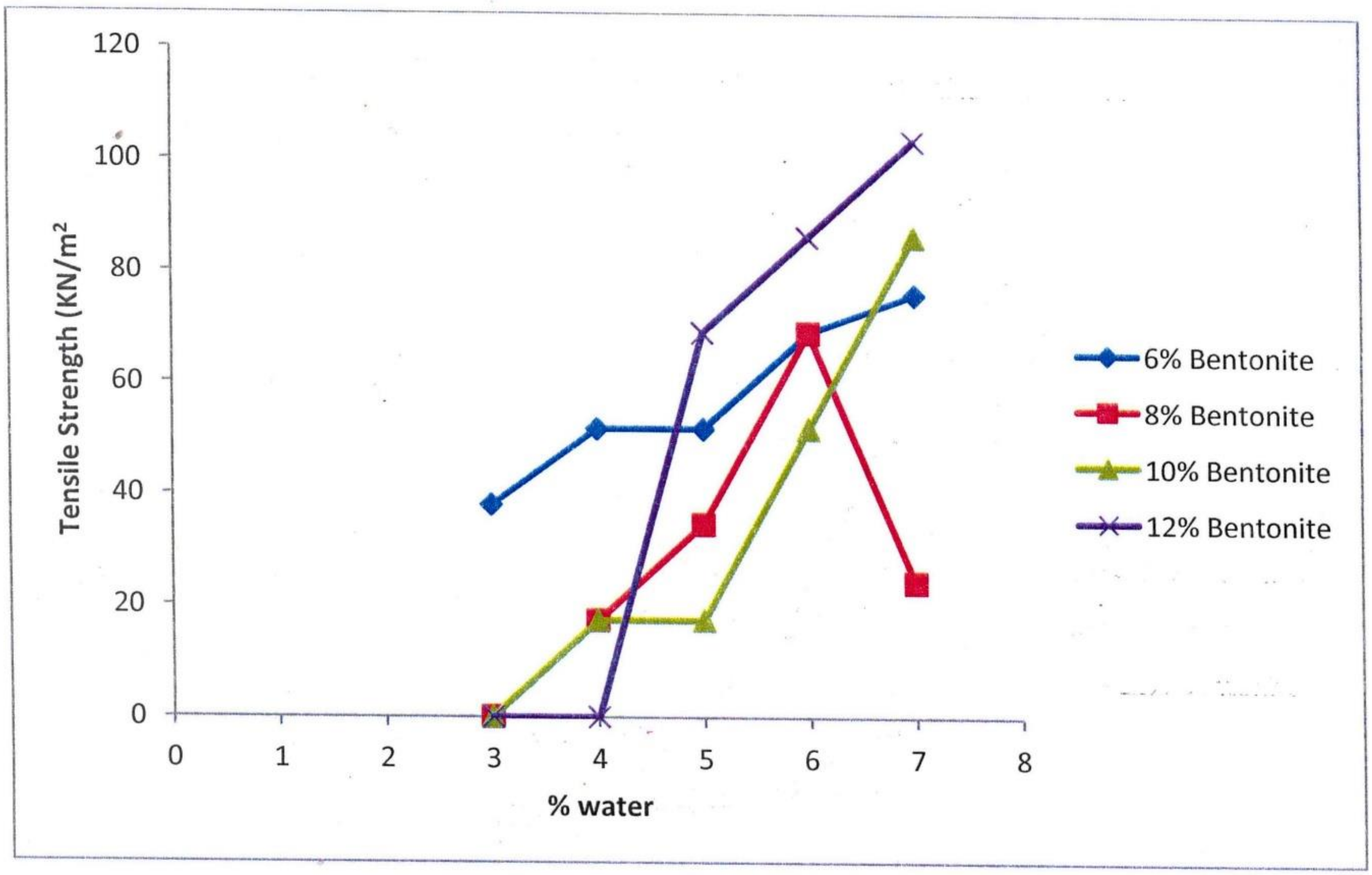

Figure 4.7: The Tensile Strength of Jamata River sand

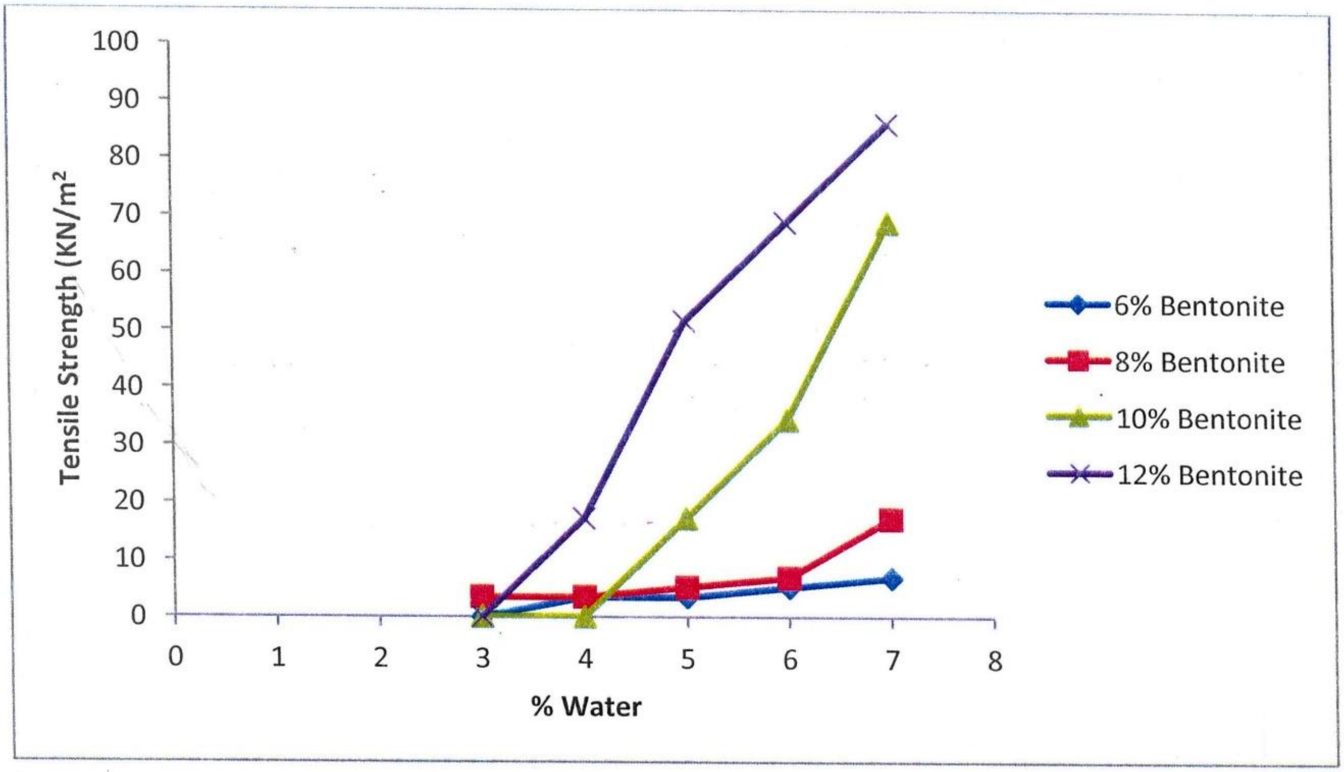

Figure 4.8: The Tensile Strength of Osara River Sand

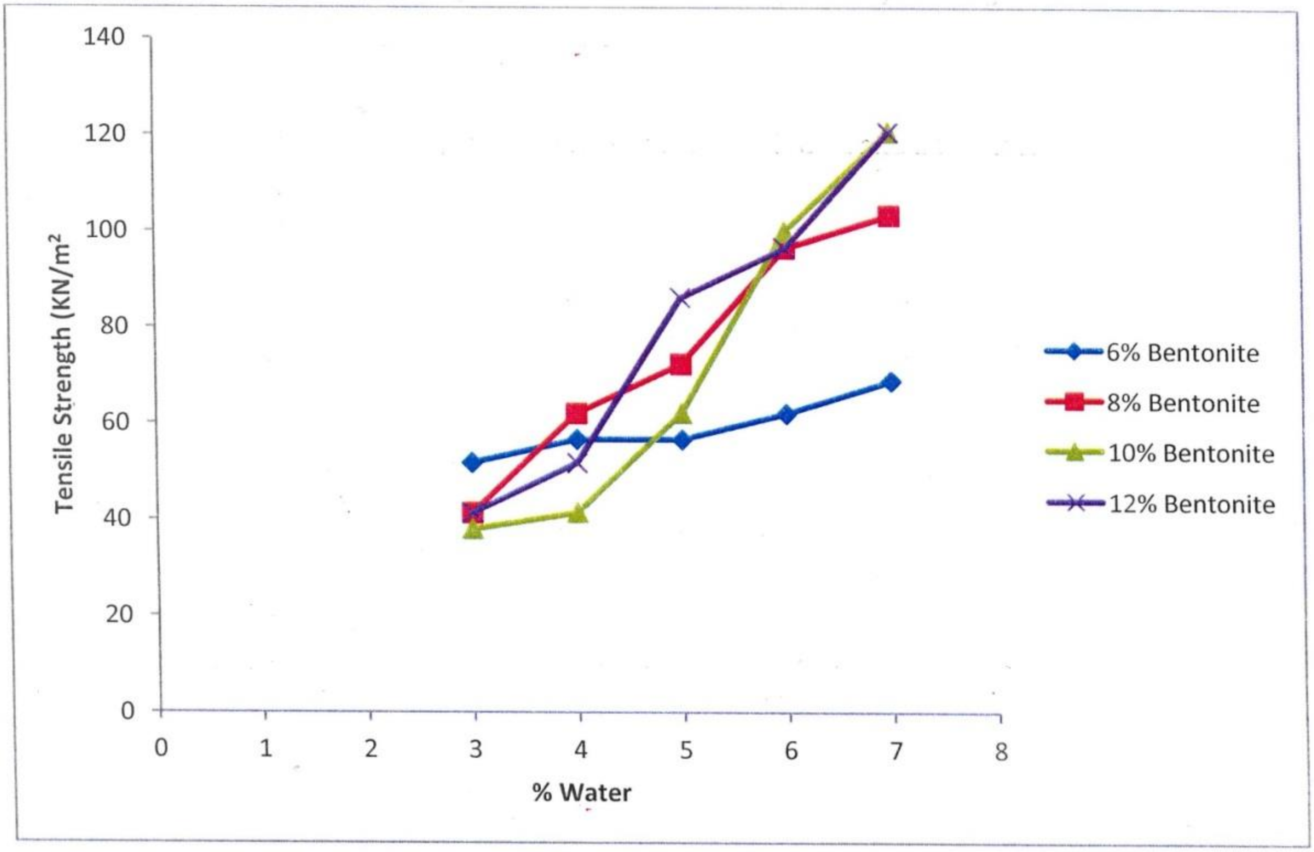

Figure 4.9: The Tensile Strength of Ajaokuta Foundry Sand Sample

In Figure 4.7 and 4.8, it can be noticed that Osara and Jamata river sand sample could not be moulded at 3% and 4% water addition at 6% and 8% bentonite. This is because the two sand samples couldn’t acquire plasticity that is good enough for tensile strength at this level. But generally, the three sand samples show increase in tensile strength with increase in percentage water and bentonite addition.

4.8 The Effect of % Water and Bentonite Addition on the Green Shear Strength of the Three Sand Samples.

The tables of the result for the Green Shear Strength test of Osara and Jamata River sand and Ajaokuta Foundry workshop sand samples were recorded in Appendix A to C and the figure of the result are shown in Figure 4.10 to 4.12.

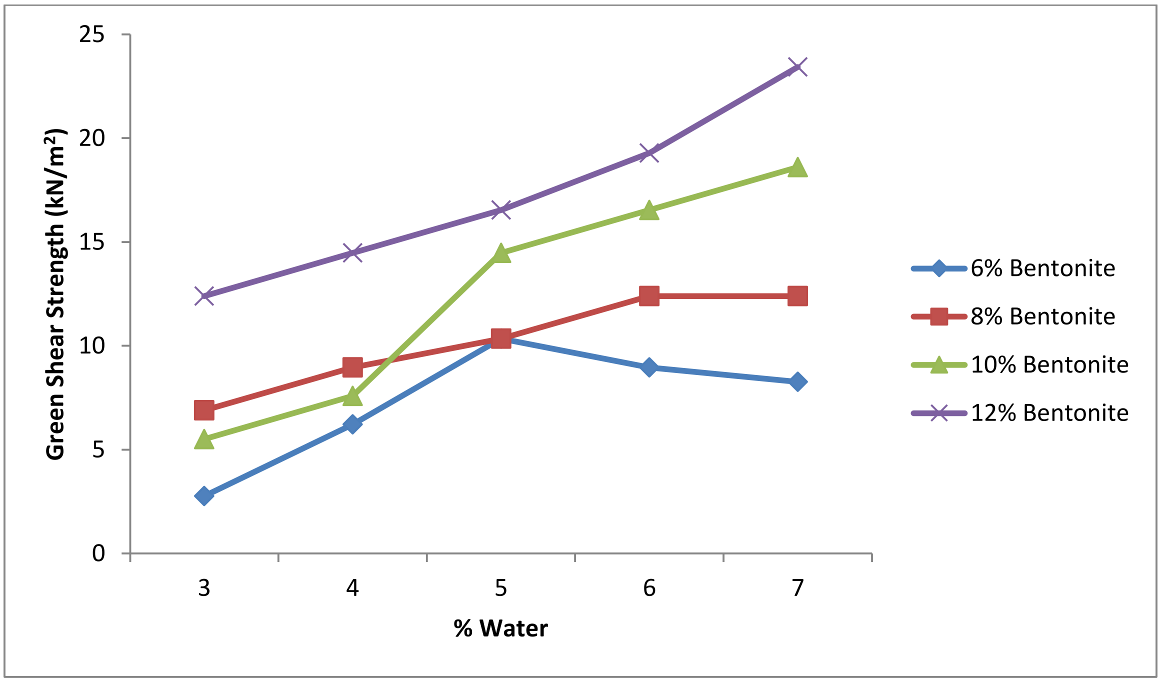

Figure 4.10: The Green Shear Strength of Jamata River Sand Sample

Figure 4.10, shows that the higher the percentage water and bentonite addition the higher the green shear strength of the Jamata river sand sample. The maximum green shear strength of the sample is recorded at 12% bentonite with 7% water addition.

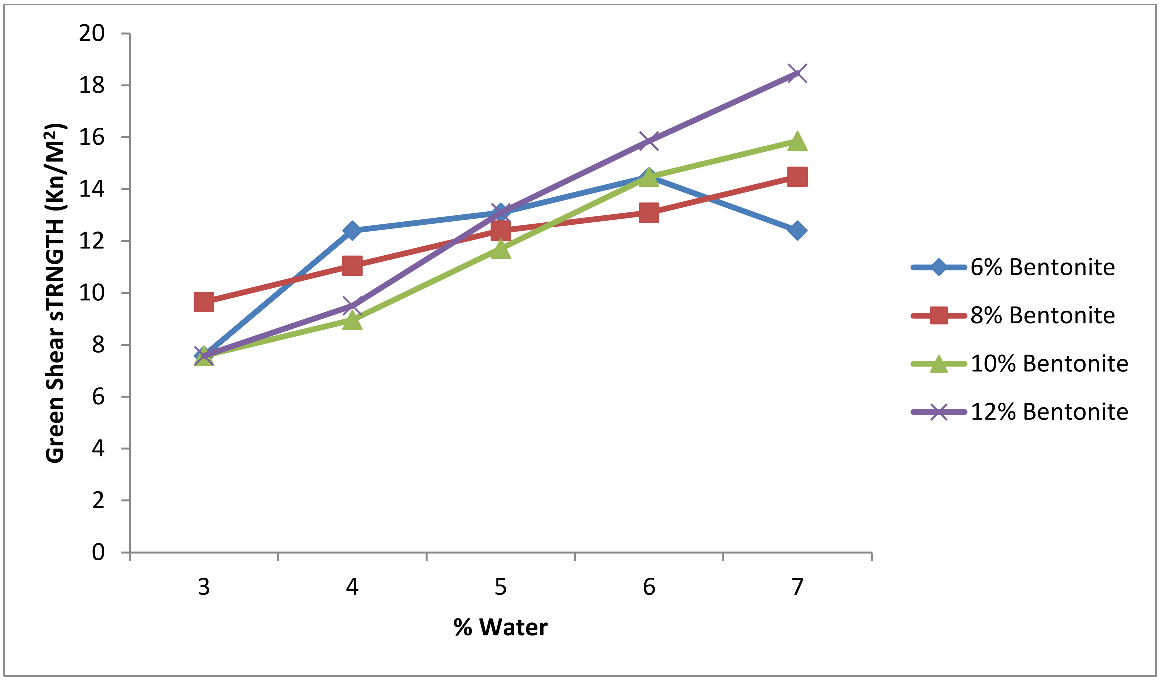

Figure 4.11: The Green Shear Strength of Osara River Sand Sample

Figure 4.11, shows that the higher the percentage water and bentonite addition the higher the green shear strength of the Osara River sand sample. The maximum green shear strength of the sample is recorded at 12% bentonite with 7% water addition.

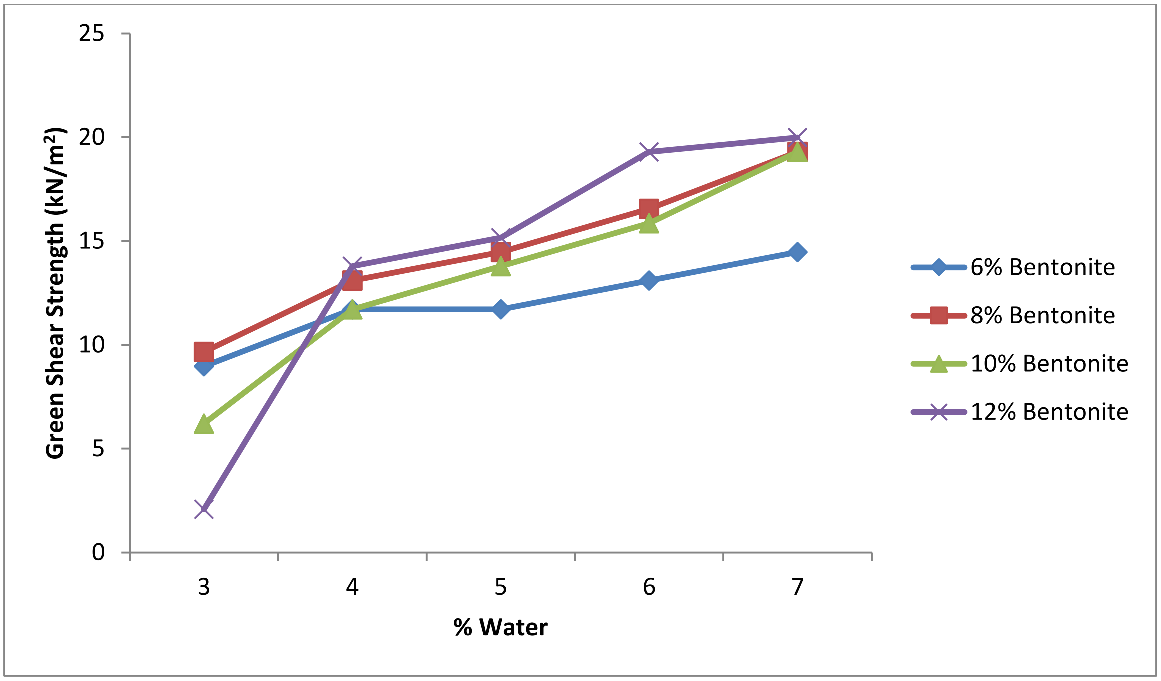

Figure 4.12: The Green Shear Strength of Ajaokuta Sand Sample

Figure 4.12, shows that the higher the percentage water and bentonite addition the higher the green shear strength of the Ajaokuta sand sample. The maximum green shear strength of the sample is recorded at 12% bentonite with 7% water addition.

Generally, the Green Shear Strength of the three sand samples increase with increase in percentage water and bentonite addition and the maximum Green Shear Strength were obtained at 12% bentonite with 7% water addition.

4.9 The Effect of % Water and Bentonite Addition on the Green Compressive Strength of the Three Sand Samples

The tables of the result for the Green Compressive Strength test of Osara and Jamata River sand and Ajaokuta Foundry workshop sand samples were recorded in Appendix A to C and the figure of the result are shown in Figure 4.13 to 4.15.

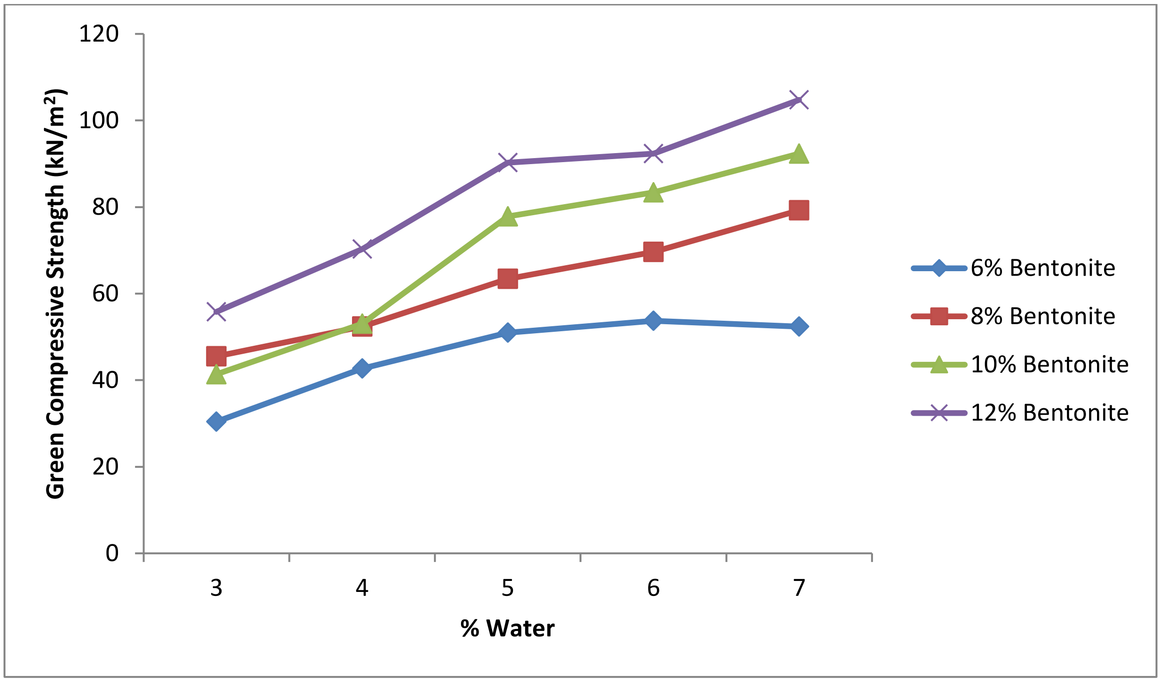

Figure 4.13: The Green Compressive Strength of Jamata River Sand Sample

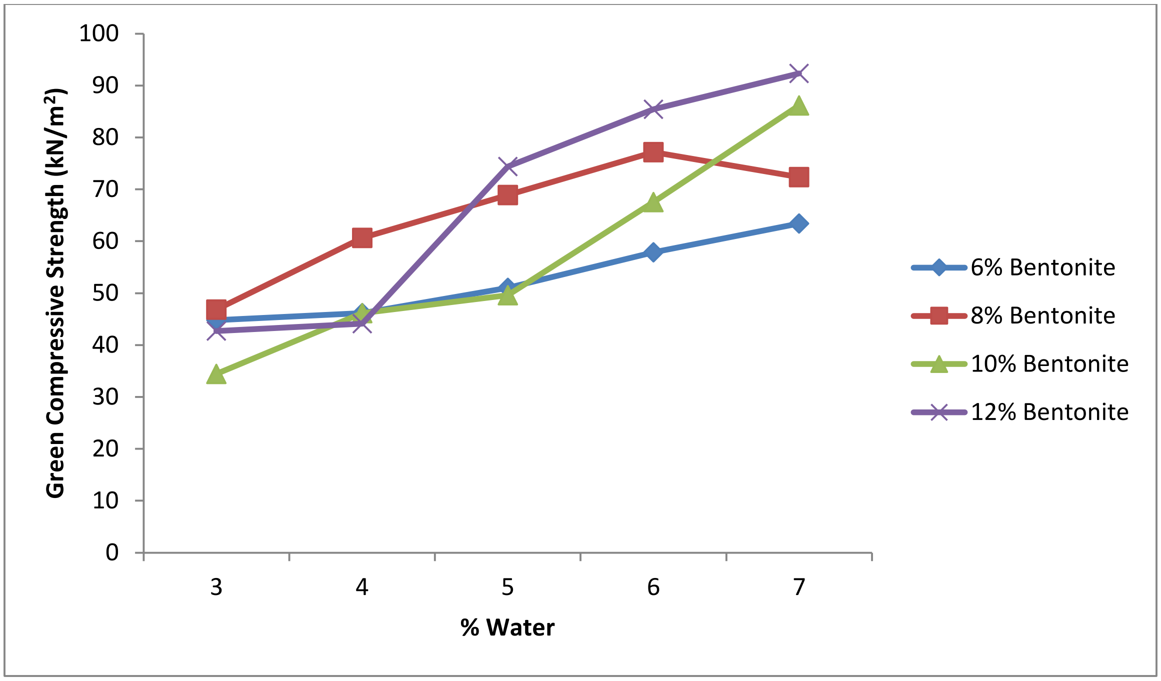

Figure 4.14: The Green Compressive Strength of Osara River Sand Sample

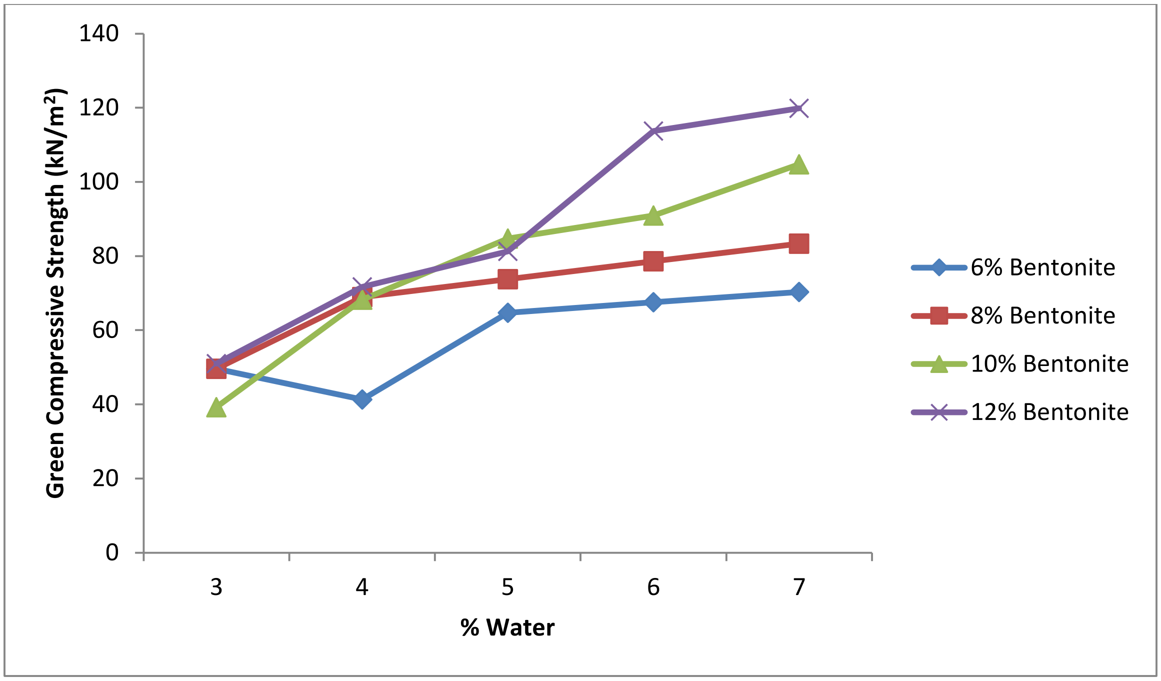

Figure 4.15: The Green Compressive Strength of Ajaokuta Foundry Sand Sample

Figure 4.13 to 4.15 show the variation of green compressive strength with varying percentage water addition at 6%, 8%, 10% and 12% bentonite addition. There is a uniform increase in the green compressive strength of the sand samples at every increase in percentage water addition. The three sand samples under investigation meet up with the AFS standard when this research result is compared to the AFS standard in table 2.1.

4.10 The Effect on % Water and Bentonite Addition on the Dry Shear Strength of the Two Sand Samples

The tables of the result for the Dry Shear Strength test of Osara and Jamata River sand and Ajaokuta Foundry workshop sand samples were recorded in Appendix A to C and the figure of the result are shown in Figure 4.16 to 4.18.

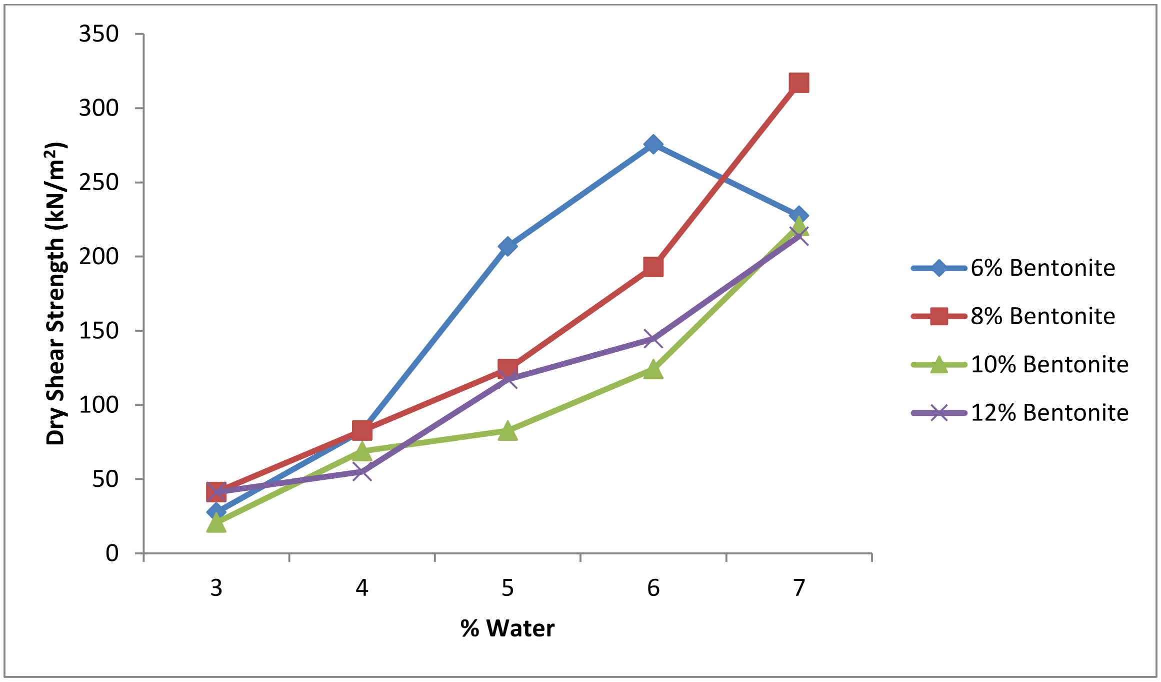

Figure 4.16: The Dry Shear Strength of Jamata River Sand Sample

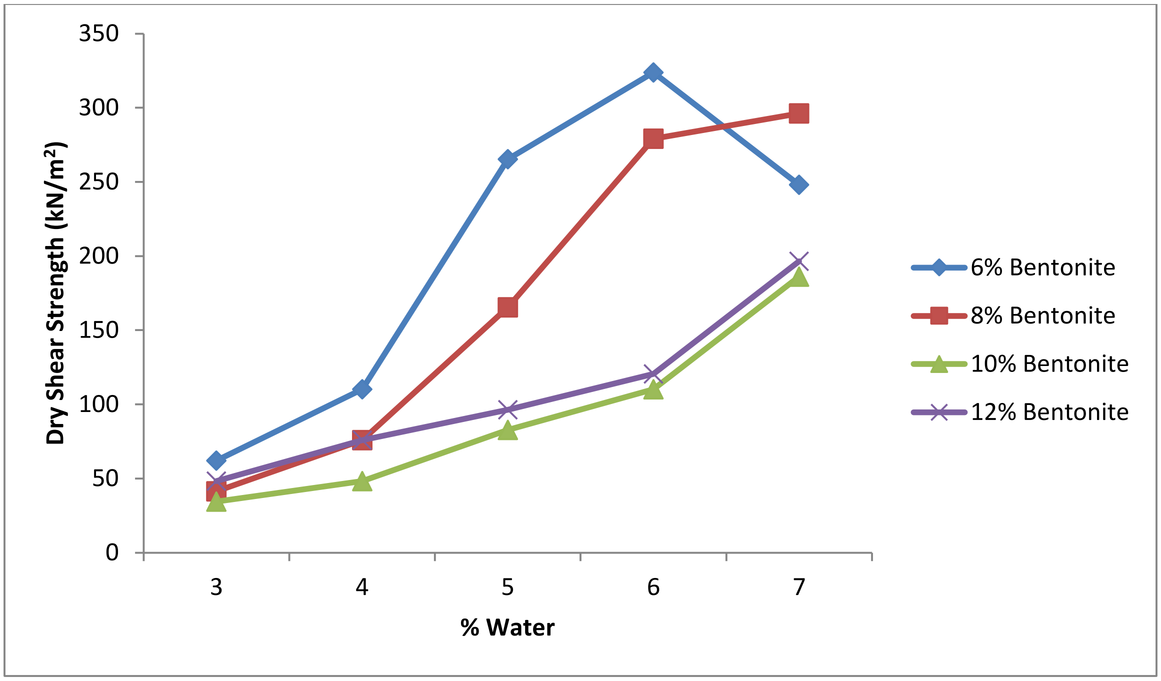

Figure 4.17: The Dry Shear Strength of Osara River Sand Sample

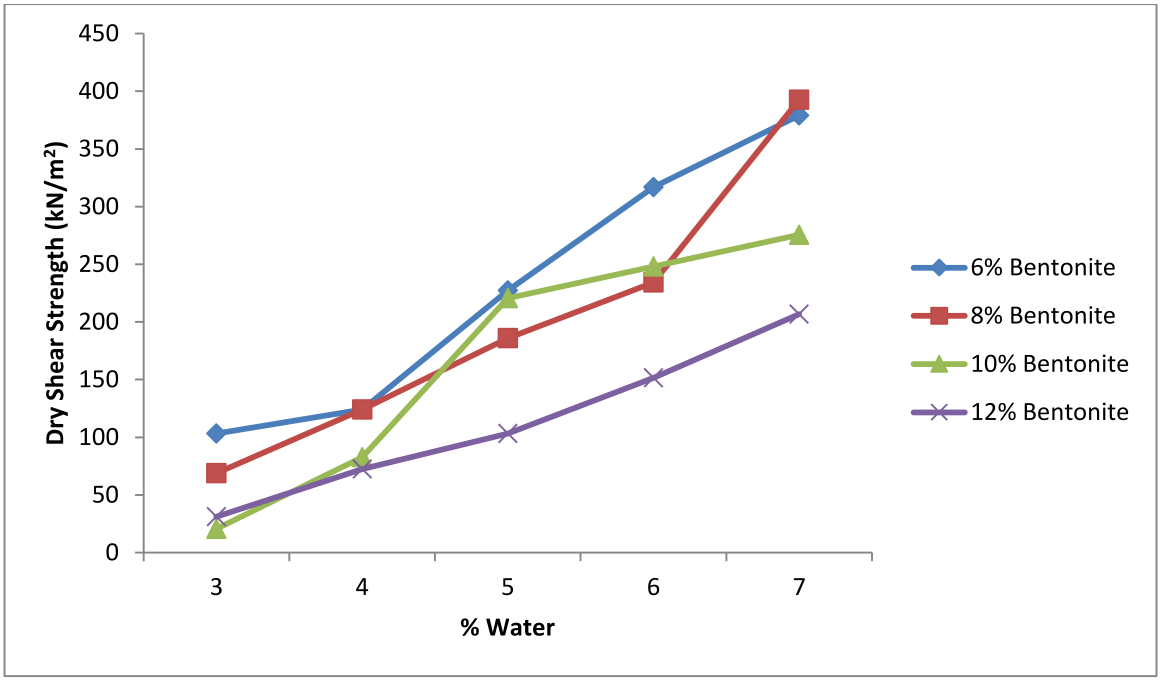

Figure 4.18: The Dry Shear Strength of Ajaokuta foundry Sand Sample

The Dry Shear Strength of the three sand samples almost decreases with increase in percent water and percent bentonite addition as shown in the Figures 4.16 to 4.18. But in Figure 4.16 and 4.17, the Osara and Jamata sand samples has the peak of their Dry Shear Strength at 6% bentonite with 6% water addition and their values decrease at 7% water addition. This means that if 6% bentonite is to be used during moulding process of Osara and Jamata River sand, the water addition shouldn't be more that 6%.

At 8%, 10% and 12% bentonmite the dry shear strength increases with increase in percentage water addition. This is because there was enough bentonite to bring about maximum and good plasticity at those percent water additions. The three sand samples meet up with the AFS Standard requirement for the dry shear strength with compared with the AFS standard in table 2.1.

4.11 The Effect of % Water and Bentonite Addition on the Dry Compressive Strength of the Three Sands Samples

The tables of the result for the Dry Compressive Strength test of Osara and Jamata River sand and Ajaokuta Foundry workshop sand samples were recorded in Appendix A to C and the figure of the result was shown in Figure 4.19 to 4.21.

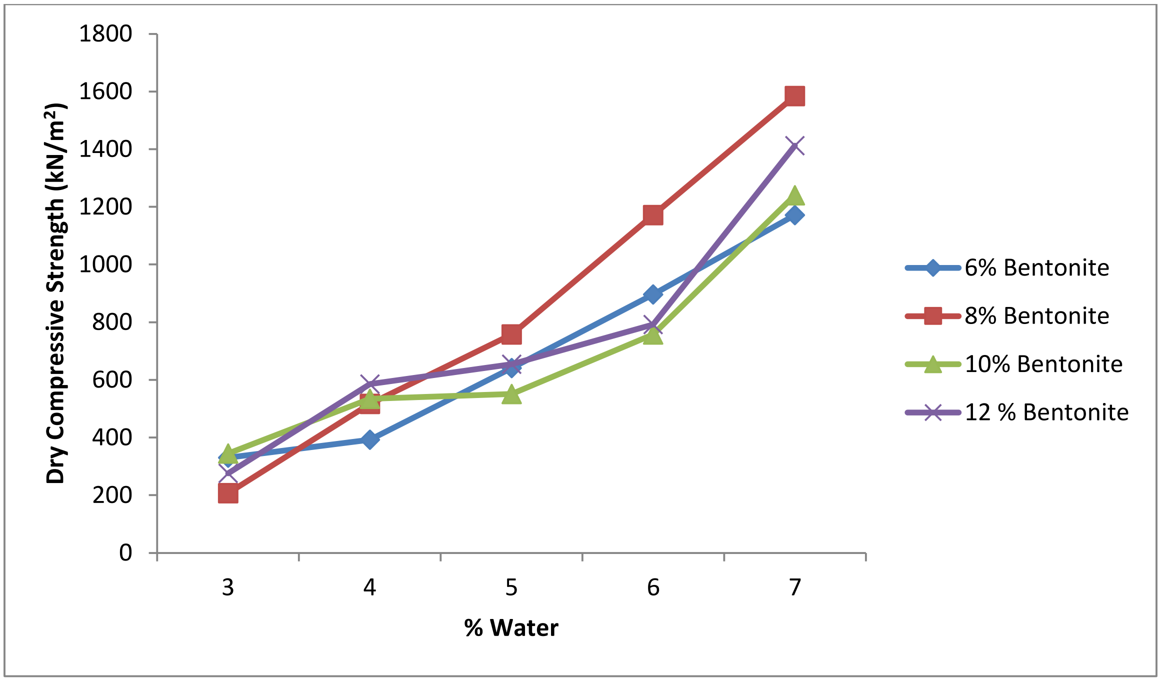

Figure 4.19: The Dry Compressive Strength of Jamata River Sand Sample

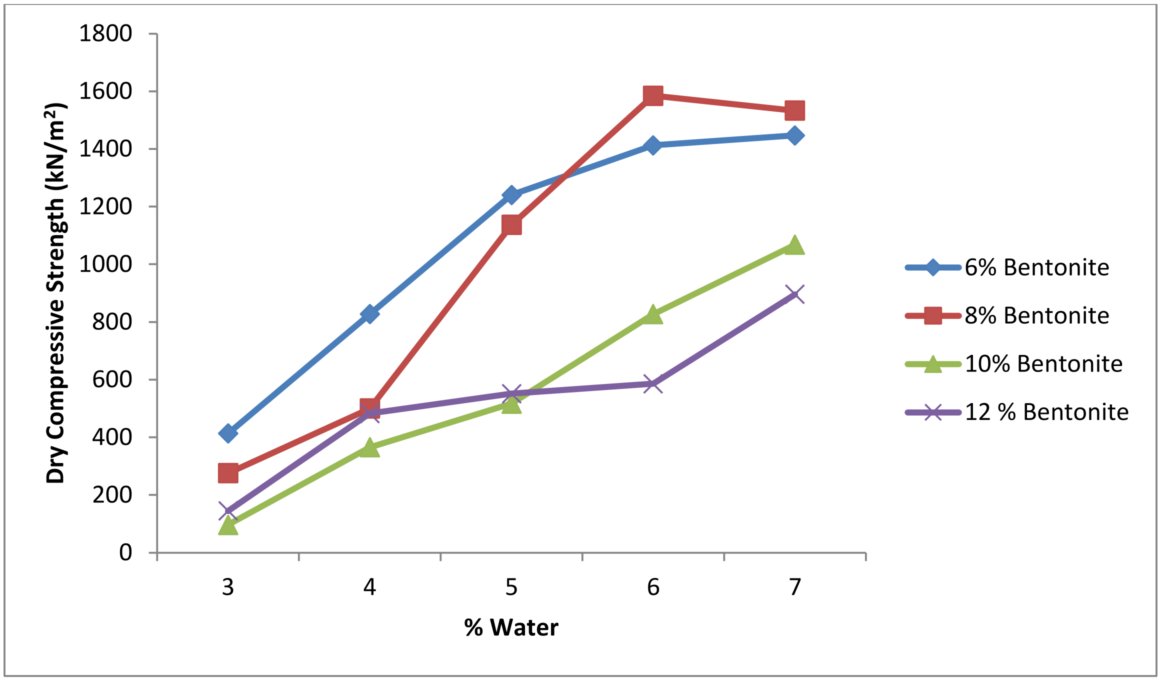

Figure 4.20: The Dry Compressive Strength of Osara River Sand Sample

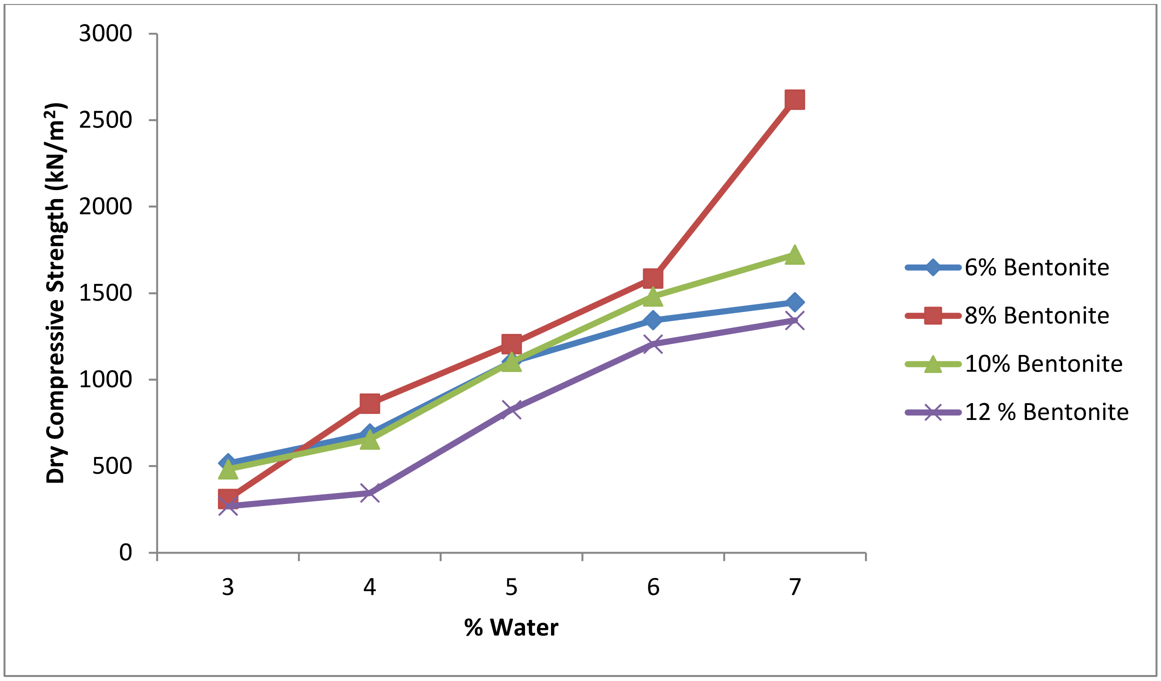

Figure 4.21: The Dry Compressive Strength of Ajaokuta Foundry sand Sample

Generally the dry compressive Strength of the three sand samples was best at 8% bentonite and 7% water addition. They all conform to the AFS Standard pacification when compared to the AFS standard in table 2.1.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the results of the tests and analysis carried out, the following conclusions were drawn.

1. The three sand samples namely Osara and Jamata River sands and Ajaokuta Foundry sands contains tolerable amount of clay content (0.8%, 1.6% and 0.4%) which is up to the accepted standard for use in casting both ferrous and nonferrous metal in the foundry according to the AFS Standard.
2. The grain fineness number of Osara river sand is 51.6, Jamata River sand is 65.1 and Ajaokuta Foundry sand is 57.3. It shows that the three sand samples falls within the acceptable AFS Grain fineness number which is greater than 45 according to Richard 2001.
3. The permeability of the three sand samples were within the ranges of 95 to 120mmWs also shows that the sand can be used for both ferrous and nonferrous casting according AFS standard and any casting produced by them would have a minimum defect due to porosity and boreholes.
4. The refractoriness of the sand samples was discovered to be greater than 1500^0C. The exact refractoriness of the sand samples could however not be determined due to limited capacity of the furnace used. Meanwhile the AFS Standard is 1550^0C.
5. The mechanical properties of the three sand samples shows that they can compete favorably with the AFS standard and they could be exploited for both ferrous and

nonferrous casting for small and large scale foundries accordingly. Osara and Jamata River sand can therefore be used as substitute for Ajaokuta foundry workshop sand.

5.2 RECOMMENDATION

1. From the result of this research it is hereby recommended that if Jamata river sand deposit is to be used for ferrous casting, 8% bentonite with 7% water addition, or 10% bentonite with 5 to 7% water addition, or 12% bentonite with 4 to 7% water addition is recommended. So also if Osara river sand deposit is to be used for ferrous casting, 8% bentonite with 6 to 7% water addition, or 10% bentonite with 7% water addition, or 12% bentonite with 5 to 7% water addition is recommended.
2. Where a very fine surface finishing is required, it is recommended that Jamata River sand should be used because of its grain fineness value.
3. Since Jamata and Osara river sand have a competitive foundry properties with that of the Ajaokuta foundry Sand and AFS Standard values, it is hereby recommend that the two sand can be used as substitute in the Ajaokuta Steel Company Foundry Workshop rather than going as far as Delta State to get a moulding sand from the sea shore. Other foundry workshop especially those located within Kogi State are also advised to explore this opportunity to use these two sands for foundry works.
4. More of this kind of research should be carried out on other sand deposits around Kogi State because of its potential of becoming one of the best Nigerian industrial States.

REFERENCES

Abdullahi A., Sulaiman S., Baharudin B.T.H.T., Ariffin, M.K.A. Vijayaram. T. R. (2012), "Effect of Moisture Content on the Permeability of Tailing Sand Samples Gathered from Ex Tin Mines in Perak State Malaysia". Advances in Mechanical Engineering, ISSN: 2160-2619 Volume 2, Number 4,

Adebayo A. V and Aremo B. (2011), "Influence of Mould Heat Storage Capacity on Properties of Grey Cast Iron."Journal of Materials and Materials Characterization and Engineering.Vol.10, No.4, Pp387-396.

Agarwal R. L, Banga T. R and Manghnani T., (2007)."Foundry Technology". 5th Edition, Published by RomeshChanderKhanna for Khanna Publishers 2-B, Nath Market, NaiSarak, Delhi-110006.

Akintunde M. A and Omole S. O.,(2008). "Physico-chemical Assessment of Ijapo Clay deposit as Binder for Moulding in Foundry". The pacific Journal of Science and Technology, vol. 9, No 2, Pp 578-582

Aliyu I, (2010), "Characterization of Etsako Sand Deposit for Foundry Operation". Thesis submitted to the Department of Metallurgical and Materials Engineering, A B U Zaria. Unpublished

American Foundry Men's Society (2005) "Modern Casting", 3rd Edition,
Des Plaines III [u,a]

Arthur G. C and Robert W. Doehler,(2011)."Industrial Application of Bentonite." American Colloid Company, Skokie, Illinois

Arthur W. W,(2010)."Water Sorption Properties of HomoionicMontmorillonite." Published Article, Illinois State Geological Survey.

Aweda J. O and Jimoh Y. A, (2009).“Assessment of properties of natural moulding sands in Ilorin and Ilesha, Nigeria.” Journal of Research Information in Civil Engineering, vol.6, No. 2,

Ayoola W. A, Adeosun S. O, Oyetunji A. and Oladaye A. M, (2010). “Suitability of Oshogbo Sand Deposit as moulding Sand”. The Kenya Journal of Mechanical Engineering. Vol. 6, Pp35-41

Beeley P. R. 2001. Foundry Technology, 2nd edition, London, Butterworth-Heinemann

Brown I., John R., (1994). The FOSECO foundry handbook, 10th edition. Published by Foseco international limited.

Chokkalingam B. and Mohamed Nazirudeen S. S, (2009).“Analysis of Casting Defect through Defect Diagnostic Study Approach.” Annals of the Faculty of Engineering, Hunedoara. Journal of Engineering. Tome VII. Fascicule 2, ISSN 1584-2665.

Choudary R. B, (2007). “Materials Science and Metallurgical for B. Tech, AMIE and Diploma Courses.”Rhanna Publishers 2B, Nath Market, NaiSarak, Delhi, India. Pp 267-268

Elanchezhian C. and Vijaya R. B, (2006).“Manufacturing Technology-I”Published by: Laxmi Publications (P) Ltd 113, Golden House, Daryaganj, New Delhi-110002.

Elizabeth S. Goins (2014). “Standard Practice for Determining the Components of Historic Cementitious Materials”. Material Research series, *National Centre for Preservation Technology and Training USA.* www.ncptt.nps.gov/products

Higgins R. A., (1993). “Engineering Metallurgy”. Vol. 1: Applied Physical Metallurgy, Sixth Edition. ISBN 0 340 56830 5. Published by J W Arrowsmith Ltd, Bristol

Hlavac J., (1982). Melting Temperature of Refractory Oxides, Journal of Pure and Applied Chemistry, vol. 54, No. 3, Pp 681-688. Doi:10.1351/pac 198254030681

IAEA-VIENNA, (1997), Sampling, storage and sample preparation procedures for X ray fluorescence analysis of environmental materials, ISSN 1011-4289

Idenyi, N. E and Ani N. M (2006) "Characterization of Abakaliki and Ugbawka Rice Husks" Technical proceedings of 22nd NMS, Annual Conference, Pp89-94

IS 1528-1 (2010): Methods of Sampling and Physical Tests for Refractory Materials, part 1: determination of pyrometric cone equivalent (pce) or softening point [mtd15: Refractories]

Karunakaran P and Jegadheesan C., (2012)."Investigation of the Properties of Moulding Sand with Waste Powder from Steel Industry." European Journal of Scientific Research, vol. 77 No.1, Pp5-13. ISSN 1450-216X

Kenneth, G. Budinski, (2000). "Engineering Materials Properties and Selection." 3rd Edition, Prentice Hall Englewood Cliffs, New Jersey USA. Pp 422-444.

Jain, R. K, (2004); Production Technology, Khanna Publishers, Delhi, Pp138-254

John R. B,(1994)."Foseco Foundryman Handbook." 10th Edition, Brutterworth, Heiman Publication. ISBN: 0-7506-1939-2.

John R. B,(2000)."FosecoFoundryman Handbook." 10th Edition, Brutterworth, Heiman Publication. ISBN: 0-7506-4284-x.

Leone C., Caprio G. and De Iorio I., (2006)."Interpreting Acoustic Emission Signs by Artificial Neutral Networks to Predict the Residual Strength of Pre-fatigued GFRP Laminates", Composites Science and Technology, Vol. 66, No 2, Pp 233-239.

Mathew S. and A,Sunday A. L, (2000)."Effect of moisture content on the Moulding Properties of River Niger Sand Using Tudun-Wada Clay as a Binder." AU J.T. 13(3): 170-174.

Mahesh B., Parappagoudar D. K, Pratihar A. and Datta G. L, (2008).“Forward and Reverse Mappings in Green Sand Mould System Using Neutral Networks”. Elsevier Science, vol. 8, Pp239-260.

Mohini M. M and Bombale U. L (2014), “ Electronic System for Testing Tensile Strength of Foundry Sand” *International Journal of Research in Engineering and Technology* Vol. 3, eISSN: 2319-1163 | pISSN: 2321-7308

Moore R. E, (2001). “Refractories, Structure and Properties”. Encyclopedia of Materials Science and Technology, Pp 8079-8099.

Nuhu A. A, (2011).” Natural Honey and Nigerian Gum Arabic as composite Binder for Expendable Foundry Cores”. AU J.T. 15(2): Pp70-76

Nuhu A. A,(2008).“Evaluation of the foundry properties of River Niger Sand BehindAjaokuta Steel Company Limited, Ajaokuta, Nigeria.” American Eurasian Journal of Scientific Research 3 (1): 75-83, ISSN 1818-6785

Nuhu A. A and Abdullahi A. T, (2004) “Assessment of foundry properties of steel casting sand moulds bonded with grade 4 Nigerian acacia species (gum Arabic)” *International Journal of Physical Sciences Vol. 4 (4), pp. 238-241, April, 2009*

Nwagu U. C and Tiedje N. S,(2011)“Foundry Coating Technology.” A review Journal of Materials Sciences and Application, vol. 2, Pp1143-1160

Olakanmi E. O, Aiyeru S. G, Idalu P. I, (2010). Effect of cereal binder, moisture and clay contents on the functional properties of clay-bonded core and moulding sands. *South African Journal of Industrial Engineering* Volume 21 No. 2

Paul A. I, Johnson A., Emmanuel E. A., Joy O. (2011). “Effects of Moisture Content on the Foundry Properties of Yola Natural Sand.”Leonardo Electronic Journal of Practices and Technologies ISSN 1583-1078 P85-96

Peter B.,(2002).“Foundry Technology”, 2^{nd} Edition, Butterworth Heiman Publication. ISBN: 0-7506-4567-9

Richard W. Heine,(2001).“Principles of Metal Casting.”30^{th} Reprint. Published by McGraw-Hill Book Company

Rundman K. B.,(2000), Metal Casting, Reference book for MY4130, P. 11-16

Sani A., Bashir G, B. G. Danshehu and A. D. Isah (2013). “Studies on the Chemical and Physical Characteristics of Selected Clay Samples”. *International Journal of Engineering Research & Technology,* 2(7): Pp171-183

Serve F. L. Le (2000); “Sands and Sand Preparation”. Castings, Production Engineering Services, Macmillan Press Ltd,. Norwich, UK. Pp 35-41

Sheidi H. M and Ajuwa C. I,(2008).“Investigation on Properties of River Niger Sand for Sound Casting, River Niger, Bacita, Nigeria.” Journal of Engineering and applied sciences 3 (3): Pp 214-216, ISSN: 1816-949x.

Umar, A.A and A. Bashir, 2007. Development of an optimum mix of moulding materials for casting purposes using Challawa River bed sand. Journal of Engineering and Technology, BUK, pp: 18.

Titov N. D, and Stepanov Y. U, Ivanov, P. S, (translator).“Foundry Practice”Mir Publishers, Moscow, USSR, Pp 49-101.

Tokan A., Adelemoni E. A. A and Datau S. G, (2004).“Mould Characteristics of Azare Foundry Sand.”JORMAR 1(1), Pp 67-80, ISSN 1597-3204.

Y. Chang and H. Hocheng. (2001).“The flowability of bentonite bonded green molding sand.” Journal of Materials Processing Technology vol 113, 238-244.

APPENDIX A

TABLE OF THE MECHANICAL PROPERTIES AND PERMEABILITY OF JAMATA RIVER SAND SAMPLE

Table A1: The mechanical and permeability properties of Jamata River Sand sample at 6% bentonite

Test	**3%water=30g 6%clay= 60g 91%sand=910g**	**4%water=40g 6%clay=60g 90%sand=900g**	**5%water=50g 6%clay= 60g 89%sand=890g**	**6%water=60g 6%clay= 60g 88%sand=880g**	**7%water=70g 6%clay= 60g 87%sand=870g**
Tensile Strength (kN/m^2)	37.90	51.68	51.68	68.90	75.79
Green Shear Strength(kN/m^2)	2.76	6.21	10.34	8.96	8.27
Green Compressive Strength(kN/m^2)	30.38	42.72	50.99	53.74	52.36
Dry Shear Strength(kN/m^2)	27.56	82.68	206.7	275.60	227.37
Dry Compressive Strength(kN/m^2)	330.72	392.73	640.77	895.70	1171.3
Permeability	95	90	120	100	95

Table A2: The mechanical and permeability properties of Jamata River Sand sample at 8% bentonite

Test	3%water=30g 8%clay= 80g 89%sand=890g	4%water=40g 8%clay=80g 88%sand=880g	5%water=50g 8%clay= 80g 87%sand=870g	6%water=60g 8%clay= 80g 86%sand=860g	7%water=70g 8%clay= 80g 85%sand=850g
Tensile Strength(kN/m^2)	-	17.23	34.45	68.90	24.12
Green Shear Strength(kN/m^2)	6.89	8.96	10.34	12.40	12.40
Green Compressive Strength(kN/m^2)	45.47	52.36	63.39	69.59	79.26
Dry Shear Strength(kN/m^2)	41.34	82.68	124.02	192.92	316.94
Dry Compressive Strength(kN/m^2)	206.70	516.75	757.90	1171.3	1584.70
Permeability	90	100	85	90	85

Table A3: The mechanical and permeability properties of the Jamata River Sand sample at 10% bentonite

Test	**3%water=30g 10%clay= 100g 87%sand=870g**	**4%water=40g 10%clay=100g 86%sand=860g**	**5%water=50g 10%clay= 100g 85%sand=850g**	**6%water=60g 10%clay= 100g 84%sand=840g**	**7%water=70g 10%clay= 100g 83%sand=830g**
Tensile Strength(kN/m^2)		17.23	17.23	51.68	86.13
Green Shear Strength(kN/m^2)	5.51	7.58	14.47	16.54	18.60
Green Compressive Strength(kN/m^2)	41.34	53.05	77.86	83.37	92.33
Dry Shear Strength(kN/m^2)	20.67	68.90	82.68	124.02	220.48
Dry Compressive Strength(kN/m^2)	344.50	533.98	551.2	757.90	1240.20
Permeability	80	75	120	125	130

Table A4: The mechanical and permeability properties of the Jamata River Sand sample at 12% bentonite

Test	3%water=30g 12%clay=120g 85%sand=850g	4%water=40g 12%clay=120g 84%sand=840g	5%water=50g 12%clay= 120g 83%sand=830g	6%water=60g 12%clay= 120g 82%sand=820g	7%water=70g 12%clay= 120g 81%sand=810g
Tensile Strength (kN/m^2)			68.9	86.13	103.35
Green Shear Strength (kN/m^2)	12.40	14.47	16.54	19.29	23.43
Green Compressive Strength(kN/m^2)	55.81	70.28	90.26	92.33	104.73
Dry Shear Strength(kN/m^2)	41.34	55.12	117.13	144.69	213.59
Dry Compressive Strength(kN/m^2)	275.6	585.65	654.55	792.35	1412.45
Permeability	75	70	75	82	88

APPENDIX B

TABLE OF THE MECHANICAL AND PERMEABILITY PROPERTIES OF OSARA RIVER SAND SAMPLE

Table B1: The mechanical and permeability properties of Osara River Sand sample at 6% bentonite

Test	3%water=30g 6%clay= 60g 91%sand=910g	4%water=40g 6%clay=60g 90%sand=900g	5%water=50g 6%clay= 60g 89%sand=890g	6%water=60g 6%clay= 60g 88%sand=880g	7%water=70g 6%clay= 60g 87%sand=870g
Tensile Strength (kN/m^2)	0.00	3.45	3.45	5.17	6.89
Green Shear Strength(kN/m^2)	7.58	12.40	13.09	14.47	12.40
Green Compressive Strength(kN/m^2)	44.79	46.16	50.99	57.88	63.39
Dry Shear Strength(kN/m^2)	62.01	110.24	265.27	323.83	248.04
Dry Compressive Strength(kN/m^2)	413.4	826.8	1240.2	1412.45	1446.9
Permeability	100	115	135	120	105

Table B2: The mechanical and permeability properties of Osara River Sand sample at 8% bentonite

Test	**3%water=30g 8%clay= 80g 89%sand=890g**	**4%water=40g 8%clay=80g 88%sand=880g**	**5%water=50g 8%clay= 80g 87%sand=870g**	**6%water=60g 8%clay= 80g 86%sand=860g**	**7%water=70g 8%clay= 80g 85%sand=850g**
Tensile Strength (kN/m^2)	3.45	3.45	5.17	6.89	17.23
Green Shear Strength(kN/m^2)	9.65	11.04	12.40	13.09	14.47
Green Compressive Strength(kN/m^2)	46.85	60.63	68.9	77.17	72.35
Dry Shear Strength(kN/m^2)	41.34	75.79	165.36	279.05	296.27
Dry Compressive Strength(kN/m^2)	275.6	499.53	1136.85	1584.7	1533.03
Permeability	95	100	125	120	115

Table B3: The mechanical and permeability properties of Osara River Sand sample at 10% bentonite.

Test	3%water=30g 10%clay= 100g 87%sand=870g	4%water=40g 10%clay=100g 86%sand=860g	5%water=50g 10%clay= 100g 85%sand=850g	6%water=60g 10%clay= 100g 84%sand=840g	7%water=70g 10%clay= 100g 83%sand=830g
Tensile Strength(kN/m^2)			17.23	34.45	68.9
Green Shear Strength(kN/m^2)	7.58	8.96	11.71	14.47	15.85
Green Compressive Strength(kN/m^2)	34.45	46.16	49.61	67.52	86.13
Dry Shear Strength(kN/m^2)	34.45	48.23	82.68	110.24	186.03
Dry Compressive Strength(kN/m^2)	96.46	365.17	516.75	826.8	1067.95
Permeability	90	95	115	135	120

Table B4: The mechanical and permeability properties of Osara River Sand sample at 12% bentonite

Test	3%water=30g 12%clay=120g 85%sand=850g	4%water=40g 12%clay=120g 84%sand=840g	5%water=50g 12%clay= 120g 83%sand=830g	6%water=60g 12%clay= 120g 82%sand=820g	7%water=70g 12%clay= 120g 81%sand=810g
Tensile Strength(kN/m^2)		17.23	51.68	68.9	86.13
Green Shear Strength(kN/m^2)	7.58	9.50	13.09	15.85	18.46
Green Compressive Strength(kN/m^2)	42.72	44.10	74.41	85.44	92.33
Dry Shear Strength(kN/m^2)	48.23	75.79	96.46	120.58	196.37
Dry Compressive Strength(kN/m^2)	144.69	482.30	551.20	585.65	895.70
Permeability	80	85	95	110	105

APPENDIX C

TABLE OF THE MECHANICAL AND PHYSICAL PROPERTIES OF AJAOKUTA SAND SAMPLE

Table C1: The properties of the Ajaokuta Sand sample at 6% bentonite

Test	**3%water=30g 6%clay= 60g 91%sand=910g**	**4%water=40g 6%clay=60g 90%sand=900g**	**5%water=50g 6%clay= 60g 89%sand=890g**	**6%water=60g 6%clay= 60g 88%sand=880g**	**7%water=70g 6%clay= 60g 87%sand=870g**
Tensile Strength (kN/m^2)	51.68	56.57	56.57	62.01	68.9
Green Shear Strength(kN/m^2)	8.96	11.71	11.71	13.09	14.47
Green Compressive Strength(kN/m^2)	49.61	41.34	64.71	67.52	70.27
Dry Shear Strength(kN/m^2)	103.35	124.02	227.37	316.94	378.95
Dry Compressive Strength(kN/m^2)	516.75	689.00	1102.40	1343.55	1446.9
Permeability	105	110	125	130	125

Table C2: The properties of the Ajaokuta Sand sample at 8% bentonite

Test	3%water=30g 8%clay= 80g 89%sand=890g	4%water=40g 8%clay=80g 88%sand=880g	5%water=50g 8%clay= 80g 87%sand=870g	6%water=60g 8%clay= 80g 86%sand=860g	7%water=70g 8%clay= 80g 85%sand=850g
Tensile Strength(kN/m^2)	41.34	62.01	72.35	96.46	103.35
Green Shear Strength(kN/m^2)	9.65	13.09	14.47	16.54	19.29
Green Compressive Strength(kN/m^2)	49.61	68.90	73.72	78.55	83.37
Dry Shear Strength(kN/m^2)	68.90	124.02	186.03	234.26	392.73
Dry Compressive Strength(kN/m^2)	310.05	861.25	1205.75	1584.70	2618.20
Permeability	100	105	120	115	110

Table C3: The properties of the Ajaokuta Sand sample at 10% bentonite

Test	3%water=30g 10%clay= 100g 87%sand=870g	4%water=40g 10%clay=100g 86%sand=860g	5%water=50g 10%clay= 100g 85%sand=850g	6%water=60g 10%clay= 100g 84%sand=840g	7%water=70g 10%clay= 100g 83%sand=830g
Tensile	37.90	41.34	62.01	99.91	120.58

Strength(kN/m²)					
Green Shear Strength(kN/m²)	6.20	11.71	13.78	15.85	19.29
Green Compressive Strength(kN/m²)	39.27	68.21	84.75	90.95	104.73
Dry Shear Strength(kN/m²)	20.67	82.68	220.48	248.04	275.60
Dry Compressive Strength(kN/m²)	482.30	654.55	1102.40	1481.35	1722.50
Permeability	85	95	95	110	120

Table C4: The properties of the Ajaokuta Sand sample at 12% bentonite

Test	**3%water=30g 12%clay=120g 85%sand=850g**	**4%water=40g 12%clay=120g 84%sand=840g**	**5%water=50g 12%clay= 120g 83%sand=830g**	**6%water=60g 12%clay= 120g 82%sand=820g**	**7%water=70g 12%clay= 120g 81%sand=810g**
Tensile Strength(kN/m^2)	41.34	51.68	86.13	96.46	120.58
Green Shear Strength(kN/m^2)	2.07	13.78	15.16	19.29	19.98
Green Compressive Strength(kN/m^2)	50.99	71.66	81.30	113.69	119.89
Dry Shear Strength(kN/m^2)	31.01	72.35	103.35	151.58	206.70
Dry Compressive Strength(kN/m^2)	268.71	344.50	826.80	1205.75	1342.55
Permeability	80	85	90	105	95

APPENDIX D

SUMMARY OF THE OPTIMUM PROPERTIES OF THE TWO SAND SAMPLES

	Osara River sand sample properties						Jamata River sand sample properties					
	Tensile strength kN/m^2	Green Compressive strength kN/m^2	Green Shear Strength kN/m^2	Dry Compressive Strength kN/m^2	Dry Shear Strength kN/m^2	Permeability mmWs	Tensile strength kN/m^2	Green Compressive strength kN/m^2	Green Shear Strength kN/m^2	Dry Compressive Strength kN/m^2	Dry Shear Strength kN/m^2	Permeability
Peak value	86.13	92.33	93.02	1067.95	196.37	135	103.35	104.73	23.43	1412.45	213.59	130
% water addition	7	7	7	6	7	6	7	7	7	7	6	6
% Bentonite Addition	12	12	12	10	12	10	12	12	12	12	10	10