OPTIMIZATION OF THE MOULDING PROPERTIES OF RIVER NIGER BEACH SAND FOR FOUNDRY APPLICATIONS

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CERTIFICATION PAGE

This is to certify that Agbo, Alfred Ogbodo has satisfactorily completed the research work: Optimization of the moulding properties of River Niger Beach sand for foundry application. The work embodied in this project is original and has not been submitted or presented for any degree to any University or similar institutions.

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APPROVAL PAGE

We the undersigned hereby certify that this thesis presented by the above named candidate be accepted as fulfilling part requirements for the award of degree of Doctor of Philosophy (PhD) of Metallurgical and Materials Engineering.

Title: Optimization of the Moulding Properties of River Niger Beach Sand for Foundry Application

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DEDICATION

This work is dedicated to all lovers of truth.

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ABSTRACT

The optimization of the moulding properties of River Niger beach sand have been conducted. The chemical analysis was carried out using X-Ray fluorescence (XRF) and X-Ray Diffractometer (XRD). Particle size analysis and mechanical properties tests such as green compressive strength, green shear strength, dry compressive strength, dry shear strength, permeability, moisture content and compatibility were carried out. The result of chemical analysis of River Niger sand indicated that the sand composed of silica SiO_2 (94.49%), K_2O (1.30%), CaO (0.48%), Fe_2O_3 (1.68%) etc with 0.084% clay content. The fusion points of River beach sand were 1390^0C, 1464^0C and 1480^0C for pure silica sand, sand mixed with 5% bentonite and sand mixed with 5% Ukpor clay respectively, each with 5% water content. The sand contained quartz, sanidine, chrisotile, antigorite, phlogopite, muscovite and albite as predominant minerals with hopeite and orthoclase etc as minor minerals. Ukpor clay had Al_2O_3 (22.1%), SiO_2 (70.3%), Fe_2O_3 (2.11%) etc. The Ukpor clay also contained anhydradite, truscottite, quartz, paragonite and riebekite as its major minerals with gibbsite, heamatite etc as minor minerals. The bentonite composed of Al_2O_3 (24.60%), SiO_2 (64.10%), Fe_2O_3 (6.94%) etc. The result of the mechanical properties test conducted with a moulding mixture of 5% bentonite and 4% water content included: green strength (28.0kN/m^2), dry strength (217kN/m^2), permeability (146.64), compatibility (30.60%) etc. Under the same conditions, Ukpor clay gave the following values for green strength (23.48kN/m^2), dry strength (215.0kN/m^2), permeability (148.45 No), moisture content (2.94%) . The predicted optimum values for the moulded sand produced using bentonite content included green strength (23.66KN/m^2), dry strength(210.36KN/m^2),permeability (149.86 No) at desirability of more than 0.7.Ukpor clay had green strength(23.68 KN/m^2), dry strength (210.35KN/m^2), Permeability (149.86 No) at desirability of more than 0.7. However, when tested 1-5% of starch content, could not show any value for green compressive strength, dry compressive strength and dry shear strength respectively. The result of the particle size analysis showed that over 70.85% of the sand were retained on the following screens: 0.18mm, 0.125mm and 0.09mm respectively. The result showed that 3-5% of Ukpor clay and bentonite content with 3-4% water content are suitable for casting light grey iron, malleable iron and non-ferrous alloys.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

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. It's most important properties include the refractory nature, which enables it to withstand the high temperature of the molten metal, so that it will not get fused (Mathew, 2010). Foundry sands can be classified into two broad groups, namely natural sand and synthetic sand. Natural sand contains sufficient amount of binding material (clay) in it so that it can be used in the foundry shop as received from the River bed or pit.Therefore, no binding material is added to it except little water. Synthetic sands are artificial mixture of clean silica sand and a bonding agent such as kaolin, bentonite, etc (Kumar and Suja, 2002). The sand grains are assisted to adhere to each other by the introduction of binders. Hence they stick together and produce the cavity into which molten metal is introduced (Brown, 1994). In sand casting operations, sand is used as a moulding material to form the external shape of the cast component or as a core material to create internal cavities in castings such as engine blocks (Abdulwahab, Ochuokpa and Gauminan, 2008).

The foundry industry in Nigeria is developing, so there is need to develop appropriate moulding raw materials such as silica sand, clay, starch and other additives for effective foundry practice. Before the 1980s, all foundry workers depended exclusively on imported raw materials including the moulding sand (Ihom and Anuba, 2006). The earliest foundry shop was established by the Nigerian Railway Corporation in Lagos in 1972. It was much later that another shop was established in Kaduna by the Defense Industry Corporation in 1978.

The foundry industry is broadly classified into two groups namely: the ferrous foundry which comprises of the iron and steel foundries, while the other group is the non ferrous foundry which comprises of aluminum, copper, zinc, lead, etc foundries (Opeoluwad and Antonie, 2013). Casting processes include permanent mould casting, centrifugal casting, die-casting, investment casting, shell casting and sand casting (Beira, 1989). Sand casting is the most widely used of the casting processes. It accounts for about 80% of cast product and can be employed for both ferrous and non ferrous metals(Fatai et al, 2011) . All materials used for the producing sand mould and cores are termed moulding materials (Greer et al, 1987).

Foundry products find application in all areas of life especially in automobiles, airplane, train locomotive, and as components in other kinds of equipment/machines.

There is considerable work done in the area of characterization of sand for use in foundry shops for mould and core production (Ihom, Jatau and Mohammed, 2006). It was in the 1970s that Enugu sands were developed for casting (Ihom et al, 2006). Today, several sand deposits have been found suitable for both mould and core production across the country and other necessary raw materials can also be sourced locally at very low cost (Ihom et al, 2006).

Clay is the general purpose binder for sand castings and a lot of work has been done in the area of developing suitable clays for sand moulds (Nwajagu,1994). Binders are introduced into the moulding and core mixtures in order to improve their properties, especially the strength (Nwajagu, 1994). While clay has been found to be satisfactorily used as a binder for moulding sands, it is largely unsatisfactory when used alone as a binder for core production. Some of the common binders for core making are vegetable oil, honey, soyabeans, cottonseed, groundnut, palm kernel, cashew nut and castor oils (Colin, 2006).

1.2 Statement of Problem

There is still the need for diversification of local materials resource base for the Nigerian foundry industry. Lack of cheap and available moulding materials hamper the rapid development of the foundry industry in Nigeria, specifically many sand deposits and binders remain uncharacterized for use in castings. Therefore, this work seeks to address this underutilization of our local foundry raw materials such as the River Niger beach sand in Onitsha, Anambra State using Ukpor clay, starch and bentonite as binder

1.3 Aim and Objectives

The aim of this research is to optimize the moulding properties of River Niger Beach sand for foundry application.

The objectives are as follows:-

1. To characterize the River Niger Onitsha beach sand located at Onitsha Anambra State, bentonite and Ukpor clay as binder.
2. To determine the grain assay of the sand.
3. To determine the strength of the starch, bentonite and Ukpor clay binded to the River Niger sand.
4. To determine the refractoriness, fusion point, moisture content, green compressive strength, green shear strength, dry compressive strength, dry shear strength, permeability, moisture content and compactibility of the mould produced from the sand, clay, bentonite and starch.
5. To optimize the moulding properties using Response Surface Method (RSM).

1.4 Scope

This work involves:

Collection of River Niger beach sand from its deposit in Onitsha, Anambra State; Collection of Ukpor clay from its deposit in UkporNnewi South L.G.A, Anambra State; determination of the chemical and physical characteristics of the clay, bentonite and sand; Production of moulding sand using silica sand, (River Niger beach), clay, bentonite and starch as binders; Mathematical modeling to analyze and optimize the data generated from the experiment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Review of Related Literature

The properties of moulding sands are influenced by the addition of additives and the amount of ingredients and additives. Among such additives are corn flours, coal dust, and saw dust, while the ingredients referred to include binders and water. Foundry industries in Nigeria use imported binders and synthetic sand for production. Higgins (1974) observed that various types of sand are used in foundries for the manufacture of moulds. Nuhu (2008) stated that the term green denotes the presence of moisture in the moulding sand and indicates that the mould 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, determined by the amount of binder present in it, is one of the requirements for effective performance of sand for moulding. A naturally occurring moulding sand needs only to be mixed with sufficient water to facilitate moulding. However, synthetic moulding sands, used by the foundry industries are essentially composed of pure quartz sand (free of clay or organic matter), bentonite, and other additives, such as pulverized coal or cereal, and water. Synthetic sands are now widely used because they are amenable to much closer control of processing, longer working life and also a high degree of uniformity in composition. For both naturally occurring and synthetic sand mouldings, the quality of casting is influenced significantly by sand properties such as green compressive strength, dry strength, permeability, mould hardness, compatibility, shatter index, moisture content and others as stated by Mahesh et al (2008). All these properties are in turn dependent on the parameters of the binder ,water and sand grain size used. Dietert, (1966) gave the satisfactory mould property ranges for sand castings of various alloy grades and it is presented in Table 2a.

Table 2a Satisfactory mould property ranges for sand castings

Metal	Green compressive strength (kN/m^2)	Dry strength (kN/m^2	Permeability (No)
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: (Dietert, 1966)

Some researchers have investigated the suitability of Nigerian clay deposits for foundry applications (Ayoola, 2010). Development of Igbokoda clay in the south western part of Nigeria as a binder for synthetic moulding sand was carried out by Loto and Omotoso (1990). Their results confirmed that Igbokoda clay had good value as a binder for synthetic moulding sand. The shatter index test in the work showed a decrease in collapsibility as the water content decreased at constant clay content. Study on evaluation of the foundry properties of River Niger sand behind Ajaokuta town in Nigeria was carried out by Nuhu (2008) in which bentonite and kaolin were used as binders. The sand gave good foundry properties when bonded with kaolin or bentonite, with kaolin having a stronger influence on the bond properties of the sand. The sand was observed to exhibit poor moulding characteristics when used without binders. According to Brownes (1971) the ratio of sand to weight of casting is about 8.1 and a tonne of casting needs about 150 tonnes of handling materials, making it imperative that the source of sand be near to a foundry for better economics. According to Walker (1935) natural sand is largely formed from the denudation of land from the decomposition of massive quartz based rock. This produces siliceous sand grain used for synthetic moulding sand (Dieter, 1966) .Siliceous sand with a specific gravity of 2.2 is the most common and most widely used base material for core and mould (Dieter,1966). It occurs in natural deposits in many parts of Nigeria on earth surface such as sand dome beaches. They are found under water bed such as Rivers, lakes and seashores. Guma (1996) characterized River Kaduna sand and found out that it has good surface characteristics, fine to almost uniform grain distribution and with a good binder and proper control. It can serve as a cheap source of good sand grain required for casting different alloys.

There have been various researches in the area of developing local alternatives to foundry materials (Ndaliman 2002). But most of these works have been mostly on determining the refractory properties of various deposits of clays which are abundant in the country and are used as binder in moulding sand.Akinbode (1996) carried out an investigation on the properties of termite hills as refractory material for furnace lining and observed that the refractory properties of termite hill which include porosity, density, dimensional change and permeability were very similar to known refractory materials for furnace lining. (Abolain, Olugboji and Ugwuoke, 2004) studied the characteristics of Nigerian clays and discovered that the Barkin Ladi and Alkaleri clay samples were suitable for construction of furnaces and furnace lining. Folaranmni (2009) investigated the effect of saw dust on the thermal conductivity of clay and showed that sawdust addition made the clay suitable for oven lining as well as a good insulator.

Loto. (1990) explored the effect of cassava flour and coal dust additions on the mechanical properties of synthetic moulding sand, and found an overall improvement in the mechanical properties of the sand mixtures for both the cassava flour and coal dust additions, although with a slight tolerable decrease in toughness.

Ibitoye and Afonja (1996) investigated the viability of Ife potter's clay as a substitute for the imported bentonite and concluded that the behavior of Ife potter's clay-bonded sand and bentonite-bonded sand was comparable.

Katsina and Reyazul (2013) studied the characteristics of Beach/River sand for foundry application and observed that samples from Ughelli River, Warri River and Ethiope River could be used effectively in the foundry and the sample from Lagos bar beach required to be sieved properly to remove the coarse fractions in order to make it suitable for foundry use.

Ayoola et al (2010) investigated the suitability of Oshogbo sand deposit as moulding sand.The samples, investigated consisted of washed and unwashed sands prepared from control sample moulding sand. The result, obtained showed peak values for the green compressive strength of the washed and unwashed sand, and peak values for the permeability and shatter index of the washed sand, with set amount of binding clay bentomite and coal dust additives as well as water in both cases and thus demonstrated the possible utilization of the sand for making sand casting moulds.

Mathew et al (2010) investigated the effect of moisture content on the moulding properties of River Niger sand behind Lokoja under Murtala Mohammed bridge, using Tudum-wada clay as a binder.The result showed that River Niger sand suitable for use as foundry moulding sand and Tudun-wada clay could serve as a satisfactory alternative to bentonite for use as bindingclay formould making. The moulding mixture of Tudun-wada clay and River Niger sand with appropriate water content is suitable for ferrous and non-ferrous alloyscastings.

Aramide et al (2011) also investigated the effects of binders (bentonite and dextrin) and water on the properties of recycled foundry sand made from silica sand obtained from Ilaro sand deposit of Ogun State Nigeria.They discovered that with minimum additives of binders recycled Ilaro sand can be used.

In sand casting operations, sand is used as a moulding material to form the external shape of the cast component or as a core material to create internal cavities in castings such as engine blocks (Abdulwahab et al., 2008).

The foundry industry is broadly classified into two groups namely the ferrous foundry which comprises of the iron and steel foundries, while the other group is the non ferrous foundry which comprises of aluminum, copper, zinc, lead, etc foundries (Opeoluwod et al., 2013). Casting processes include permanent mould casting, centrifugal casting, die casting, investment casting, shell casting and sand casting (Beira, 1989). Sand casting is the most widely used of the casting processes. It accounts for about 80% of cast product and can be employed for both ferrous and non ferrous metals (Greer et al, 1987). Binders are introduced into the mould and core mixture in order to improve their properties especially the strength (Nwagagu, 1994).

Bindability of moulding sand, determined by the amount of binder present in it is one of the requirements for effective performance of sand for moulding. Synthetic sands are now widely used because they are amendable to much closer control of processing and have also shown a high degree of uniformity in composition. For both naturally occurring and synthetic sand mouldings, the quality of casting is influenced significantly by sand properties such as green compressive strength, dry strength, permeability compactibility, moisture content and others as stated by Mahesh et al, (2008).

When a casting is to be produced with through or dead-ended holes, cores are used to form these interior surfaces (Asuquo and Bobojama, 1991) and are made of sand particles bonded together to form an aggregate. It will appear that cores by this definition are limited to internal surface generation, in fact, cores are also used in shaping external surfaces of cast products. In most cases, cores are made separately in core boxes and are located in the mould cavity by impression known as core prints in the sand mould. Patterns, which are shaped to form cores as integral parts of the mould, are known as green sand cores. This method of core making is economical but it is limited to production of hollow shapes with sides normal to the parting face (Charles, 2004).

2.2 Foundry (Moulding) Sand

Large tonnages of silica sand are used in iron and steel foundries to make moulds and cores for metal castings. Molten metal is poured into a shaped cavity in a block of sand where the metal cools and solidifies. The part of the cavity that forms the external surface of the castings is called the mould. Cores of molded sand may be placed in the mould to form the internal shape and dimensions of the casting. In each application the sand particles are held together by some material called a binder (Moldenke,1930)

2.3 Types of Moulding Sand

Two types of moulding sands are distinguished on the basis of the bonding agent. Naturally bonded molding sands are those with a natural content of clay and silt sufficient to give plasticity and strength to the sand when tempered with water. The clay content generally limits the use of these sands to light iron, brass, or bronze castings.

Synthetically bonded sands are artificial mixtures of clean silica sand and a bonding agent such as fireclay or bentonite. Sand with little or no natural bond generally is more refractory than naturally bonded sands and is used in steel foundries, magnesium foundries and in large grey-iron and malleable-iron foundries where extremely high temperatures are obtained. The trend today is toward increasing use of synthetically bonded sand,because it can be controlled to offer moulding properties that are dependably uniform. Uniformity becomes increasingly important as foundries become more and more mechanized (Moldenke, 1930).

2.4 General Requirements of Moulding Sands

The ideal moulding sand has been described as “a sand consisting of uniform-sized rounded grains of silica (quartz), each grain evenly coated with the thinnest necessary layer of the most refractory and fattest clay” (Moldenke, 1930). A foundry mould must have the ability to withstand the high temperature of molten metal without damage to the surfaces of contact between metal and sand. The required heat resistance varies with the type of metal being cast. For example, steel which melts at about 1510°C requires a much more refractory sand than aluminum alloys which melt at about 650°C . Silica sand used for steel casting must consist entirely of quartz grains to be infusible. The coating of clay that binds the grains together must be sufficiently low in fluxing ingredients to resist softening or change of shape at least until the metal is fully set. Larger castings require a higher refractory sand than small castings because of the longer cooling period and the sustained heat to which the sand is exposed.

Another important requirement is that the finished mould be strong enough to withstand the pressure of the molten metal without yielding. The sand must be adhesive, containing sufficient clay bond to remain intact after being rammed in the pattern.

On the other hand the mould must be sufficiently permeable to allow the steam generated on contact of the molten metal with the damp mould surfaces to dissipate quickly. This steam should pass outward through the mould and not through the molten metal. Furthermore, any gases carried in the metal and liberated at the moment of set must be able to pass through the sand.

The mould should leave the casting with a smooth surface. The coarser the grains of silica, the rougher the surface of the casting, however, fine-grained sands do not provide the best venting qualities (Moldenke, 1930).

2.5 Properties of Moulding Sand

The quality of castings produced depends largely upon the properties of the sand utilized. To ensure good castings, the sand must satisfy specifications as to refractories, bond strength, permeability, grain fineness and moisture content.

Refractoriness is defined as the ability of moulding sand to withstand high temperatures without breaking down or fusing thus facilitating production ofsound casting. (Humour, 2010). Quartz (SiO_2), the principal constituent of silica sand, is a highly refractory mineral, the fusion point of which is 1710°C ,which iswell above the pouring temperature for either iron or steel castings. The alkali-bearing minerals are more readily fusible, feldspars, for example, melt at a temperature between 1200°C and 1300°C . Thus, if metal is poured into a mould at a temperature higher than 1300°C any feldspar grains present may fuse and permit entry of metal into the mould. Fusion also is encouraged by the presence of micas and iron oxides. Consequently, the content of these impurities must be carefully regulated. Lime, soda and magnesia act as fluxes to reduce the refractoriness of the sand and should be present in only trace amounts.

Refractoriness is also influenced by grain size which determines the surface area of the quartz grains exposed to the strength. Sodium montmorillonite clays (such as bentonites) will give nearly double the dry strength of calcium montmorillonite clays.On the other hand, the wet (green) strength of sand with calcium montmorillonite is higher, and sand with very high green strength are hard to ram and may result in swollen castings (Parkes, 1950).

Grain shape also contributes to bond strength of a sand. As a rule, the finer and more angular the sand grains, the greater the bond strength of the sand because of the interlocking of grains. However, permeability is decreased, so that in most cases it is better to depend on the bonding material for cohesiveness.

Permeability: It is also termed as porosity of the moulding sand in order to allow the escape of any air, gases or moisture present or generated in the mould when the molten metal is poured into it. All these gaseous substances generated during pouring and solidification process must escape otherwise the casting becomes defective. The best permeability is obtained with moulding sand in which the grains are both rounded and uniform. Angular-grained sand tends to pack and make permeability control difficult. Furthermore, if the grains are not of uniform size, small grains may pack between large ones whether they are angular or round, decreasing porosity and thus impairing permeability.

Finer sands have a lower permeability number because of the smaller and more complex pore systems. Air and gas will pass more easily through large pores, and therefore, the coarser the sand the higher the permeability. On the other hand, the surface finish of a casting is impaired by large pores.

Despite the fact that the highest permeability can be obtained by using a uniformly sized sand, in practice a range of five or six sieve sizes of sand is used to prevent all the grains from reaching the temperature of 573^{o}C at the same time during casting. At this temperature silica undergoes change in volume, and if all the grains were to expand at the same time serious "scabbing" may occur at the top of large mould cavities (Parkes, 1950).

Any excess clay or other bonding material will tend to fill the voids and reduce permeability. The clay content should be sufficient to coat the sand grains but not so much as to close the pores.

Grain fineness. Grain size or fineness has an important bearing on the physical properties of foundry sand as shown in Table 2b, The table shows variation in properties with texture over a range of size grades of sand.

The physical and chemical analysis of ground silicas of Ottawa silica company are presented in Tables 2b & 2c.

Table 2b: Physical analysis of ground silica

Grade of sand	U.S. Standard Sieve No. (Percent passing)			
285	100	140	200	325
290	99.5	97	88	68
295		98.5	92.5	71
390			96	80
398				96
				98

Source: Mclaws 1971

Table 2c: Chemical analysis of ground silica

Constituent	Composition (%)
Silica (SiO_2)	99.80
Iron Oxide (Fe_2O_3)	0.02
Aluminum Oxide (Al_2O_3)	0.06
Titanium oxide (TiO_3)	0.013
Calcium oxide (CaO)	0.01
Magnesium oxide (MgO)	0.01
Loss on iginition (L.O.I.)	0.09

Courtesy: (Mclaws 1971)

Fineness is also important because of its relationship to the surface finish of castings. The finer the grains, the smoother the work produced.Coarse grains in the mould surface allow penetration of metal between grains, thus leaving a rough surface. The highest grade of art castings is made with the finest moulding sand. Brass and bronze require fine sands. On heavy castings a fine-grained facing sand is used to give a smooth surface. On the other hand, the finer the sand, the poorer the venting.

The fineness of foundry sand is a prime indicator of quality and is expressed in terms of a grain fineness number (GFN), which represents approximately the sieve size (in meshes per inch) that would just pass a sand sample if all its grains were of equal size to the weighted average grain size. The GFN is determined in a standard AFS fineness test, which tells the foundryman not only the size of the sand grains and properties of each size, but also the proportion of clay in the sand (Parkes, 1950).

The grain fineness number is the principal test parameter for sand in the loose condition. It is a test which involves a sieve analysis using a standard set of sieves based on U.S Bureau of Standard and consists of mesh sizes of 6, 12, 20, 40, 50, 70, 100, 140, 200 and 270. In carrying out this test, a standard weight of washed and dried sand is shaken in the set of sieves for 15 minutes after which the weight of sand retained on each sieve is weighed and converted into percentage weight. This percentage is again nullified by a multiplying factor (Jain, 2008).

The grain finess is expressed as the American Foundry Society (AFS) Standard. It is expressed mathematically e.g.: AFS Grain finess number =

$$\frac{Totalproduct}{\%Totalsandretained} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

The chemical composition result of some foundry sands are presented in Tables 2d and 2e with the various sources.

Table 2d: Chemical composition of some foundry sands

Source of sand	Chemical constituents (%)									Remarks
	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	k_2O	FeO	
Key sand, New Jersey	91.11	1.040	4.77	0.25	0.18	0.12	0.09	0.14	0.15	Core sand (Weigel, 1927)
Ottawa, Illinois	99.48	0.020	0.16	n.d	0.11	0.05	-	-	-	Silica sand (Weigel, 1927)
Richland, New Jersey	86.46	1.040	6.95	0.41	0.16	0.41	0.21	0.58	0.31	Iron and nonferrous molding sand (1927)
Albany New York	75.91	3.260	9.44	0.64	1.12	0.64	1.42	2.96	1.86	Naturally bonded molding sand (1927)
Wedrora, Illinois	99.59	0.019	0.17	0.02	0.01	-	-	-	-	Silica sand (Parkes 1950)
Leighton Buzzard, United Kingdom	99.26	0.150	0.24	0.06	0.18	0.04	-	-	-	Silica sand (Parkes, 1950)
Kings Lynn, United Kingdom	99.24	0.060	0.48	-	0.12	-	-	-	-	Silica sand (Parkes, 1950)

(McLaws 1971)

Table 2e Chemical composition of some foundry sands

Constituent	Chelford	Warri River sand (%)	Ethiope River sand (%)	Ughelli River sand (%)	Lagos Bar Beach sand (%)
SiO_2	97.91	96.18	98.12	97.01	53.16
Al_2O_3	1.13	2.76	0.91	1.96	19.40
Fe_2O_3	0.50	0.06	0.16	0.13	4.70
CaO	-	-	-	-	2.66
MgO	-	-	-	-	2.08
K_2O	0.25	-	-	-	-
Loss on ignition	0.21	1.00	0.72	0.90	18.00
Total	100.00	100.00	100.00	100.00	100.00

Source: (Dietert .1954)

2.6 Types of Foundry Moulds

In foundry practice, three types of foundry moulds have found wide application. They are

(1) Non permanent mould: that is mould which can only be used once.
(2) Semi-permanent mould
(3) Permanent mould

Non-permanent mould serves to produce only one casting. On removing the casting the mould is destroyed. Preparation of non-permanent mould is done by making use of mixture of sand and clay with other additives which change the properties of the mould in the desired direction. In non-permanent mould, casting of all sizes and alloys can be got. Shell mould (prepared from sand-bokelite mixture) as well as mould produced by investment casting (lost-wax process), which shall be treated under special heading are types of non-permanent mould. Non permanent mould have found widest application because they are simplest to prepare and relatively cheap. Casting in sand-clay non-permanent mould remains the dominating technology in foundry. For example in USA about 90% of the total number of foundry industries produce castings by sand casting. In Bulgaria, 4.5% of the total quantity of castings is obtained by special casting methods. The rest 95.5% is through sand casting. In Nigeria, more than 99% of the castings produced are by sand casting, (Nwajagu, 1994).

Semi-permanent moulds serve to get some tens (40-50) and rarely some hundreds of castings with a simple configuration. In this case the mould is not destroyed during removal of the casting. Semi-permanent moulds have increased strength and great care is needed during removal of the casting. They are prepared by making use of chamotte, fire clay, graphite, magnesite, asbestos etc, and are fired at 600 – 700°C. They have found application in mass production of simple shaped castings with large size.

Permanent moulds are made of metal mostly of grey cast iron and rarely of steel and copper. Their life span varies over a wide range and depends on casting temperature of the alloy.For example, in casting thick-walled grey iron casting, the metal mould withstands 250-300 castings, while on casting accumulate grades of lead alloy, the metal mould withstands thousands of castings. The metal mould has found wide application in large serial and mass production of castings, mainly of non-ferrous alloys. They are used also in centrifugal casting, continuous casting and pressure die casting (Nwajagu, 1994).

2.7 Cores in Foundry Production

There is a great need to be familiar with the utilization, design and production of suitable cores because cores are crucial to achieving efficient production of cast products with hollow cavities. In fact there are no ways of doing this without the use of cores,if excessive foundry wastes and machine scraps were to be eliminated (Charles, 2004). Some of these cores are specialized and intricate as in those employed for producing engine blocks and cylinder heads. Cores for these applications are oil-bonded sand cores using basic oils such as linseed oil and are baked in an oven to achieve the requisite properties (Colin, 2006).

Cores are generally made of core sand grains and binders. A well formulated mixture gives good green strength and adequate cured strength to prevent collapse during usage. Green strength is a basic core making requirement and its level determines the ease with which the core mixture may be moulded into shape and handled for subsequent curing processes without failure. The final strength and hardness of coresare developed when the bonded mixture is cured (Colin,2006)

Cores are separate shapes of sand that are generally required to form the hollow interior of the casting or a hole through the casting. Sometimes cores are also used to shape those parts of the casting that are not otherwise practical or physically obtainable by the mould produced directly from the pattern.

2.8 Purpose of Core

Cores form the internal cavities of the casting, or extra sections of the mould for castings that external projections or negative draft, which, if included in the pattern, would prevent the pattern from being removed from the mould.

Multiple cores may also be used in complex castings (Humair, 2010)

2.9 Silica Sand for Core Production

Silica sand is the main constituent of sand cores. Silica sand applicable for core production contains from 80 to 90% silicon dioxide and is characterized by high thermal stability. It impacts refractoriness, chemical resistivity and permeability to the core (Jain, 2008). Sand can be specified according to average size and shape of sand particles. Sand grains could be fine, medium or coarse, as regards size, or round, semi-angular or compounded as regards shape (Jain, 2008). Fine sand is desirable for small and intricate castings because the grains lie close hence the mould has reduced permeability. Medium sized sand is used for bench work and light floor work, while coarse sand is used for large casting with high permeability to permit gases to escape (Jain, 2008).

Granular particles of various sizes and shapes provide variable interstices (space between grains) and hence are directly responsible for permeability and compactness of the sand. Granular particles have higher strength but lower permeability, whereas round grains have higher permeability but lower strength (Jain, 2008).

This work, therefore seeks to optimize the moulding properties of River Niger beach sand for possible foundry application using bentonite, Ukpor clay and cassava starch as binders.

2.10 Properties of Binders of Sand Cores

Binders are materials, which after drying or baking, bond the sand grains together to effectively maintain a formed shape and minimize peeling off and crumbling of sand. Binders check the erosive effect of the streaming metal on cores during casting by improving their properties especially the strength (Asuquo and Bobojama, 1991) and (Nwajagu, 1994). Hence they must meet several requirements of which the most important include the following:

- Uniform distribution in the mixture and ensuring the needed total and surface strength in wet (green) and dry states.
- Good collapsibility of the mixture that is, contribute to easy knockout of the core from the casting.
- Required porosity and hygroscopy
- Yieldability and flowability in the green state and high strength in the cured condition
- Desired refractoriness of the mixture
- Absence of stickiness to the surface of the patterns and core boxes during the production of core
- Harmlessness to the operating personnel, that is it will not produce toxic gases or be offensive to the skin
- Cheapness and abundance.

2.11 Classification of Binders

Binders are classified based on two features. The first is the nature of a bonding agent which can be organic or inorganic. The second is based on the nature of curing which can be irreversible or reversible (Collin, 2006).

Organic binders are of greatest importance and are divided into two classes, namely:

(a) Anhydrous binders which do not dissolve in water and

(b) Hydrous binders which are soluble in water.

Organic binders in each of these classes give low green strength to the mixture, good flowability in the green state and high strength in the dry state. The green strength of such cores can be increased by adding clay, dextrin, bentonite, palm oiletc. Such mixtures are used to produce thin-walled shaped cores (Collin, 2006). Common organic binders include vegetable oils such as imported linseed oils and locally produced oils such as shear butter oil, palm oil, groundnut oil,etc (Jain, 2003).

Early work on suitability of local vegetable oils for core production is credited to (Adewara and Aponbiede, 2003) and the results obtained showed some limited potentials for their use. Other binders which are petroleum oil based, comprise of petroleum oil dissolved in white spirit, composite binders, which are mixtures of the several binders such as vegetable oils and resin dissolved in white spirit. Oil binders are added to sand mixture in amount of 1.5 to 2% and at a drying temperature of between 200 to 220^{o}C (Abdulwahab et al, 2008).

Organic air-drying binders are water-soluble and are mixed up with clay. Clay gives the required green strength while the binders give the dry strength. Examples are lignin, dextrin and molasses. Lignin is a by-product of the sulphite liquor of the paper-pulp industry and supplied as powders or as liquids. Dextrin is the product obtained from starch by the action of a weak acid during low heating. It is used in combination with other binders and also for the preparation of glues. Molasse is a liquid waste, separated from raw sugar manufacture. Molasses-bonded cores show good yieldability.

Synthetic binders which, do not require core drying process, are now in use for production of sand-bonded cores. These are thermosetting and thermoplastic resins. Thermoplastics melt on heating and undergo reversible curing on cooling . Thermosets first soften when heated and set as a result of irreversible chemical processes. The advantage of these binders is that the process of curing goes on very fast and results in a strong and elastic film. This process speeds up the process of production of cores.

Examples of synthetic binders are: furan resin which is phenol formaldehyde resin with addition of furfuryl (alcohol). It finds wide application in the production of cores in hot boxes. Carbamide resins, which are products of urea and formaldehyde are soluble in water and used in the production of quick-drying and `self-curing binders. After drying, carbamide resin-bonded cores become non-hygroscopic and collapse easily. Carbamide resin based binders find use in rapid manufacture of cores in hot boxes and for the preparation of cold-curing sand mixtures (Giesseren, 2004).

There is a good number of natural material that posseses adequate bonding qualities to compel their use in foundries (Asuquo and Bobojama, 1991). The major materials in the inorganic binders' class are clays, cement, water glass and plaster of Paris (P.O.P.). Clays generally display bonding properties along with thermo-chemical stability. For these reasons, they serve as binders in preparing moulding sands causing casting to be readily packed up. With the right proportion of water, clay becomes the principal source of strength and plasticity of the moulding and core sand. It is suitable for both natural and synthetic sands. The common clay minerals are kaolin, moutmorillonite and illite.

Water glass is a hydrous solution of silicates of sodium or potassium of varying composition, $Na_2O.SiO_2XH_2O$. Water glass as a binder is used in three modifications depending on the process used in hardening the mixture. Moulding and core mixtures containing water glass are not necessarily self bonding, therefore as a general rule, other binding agents such as clay are added. The hardening is brought about by the dehydration of water glass when the mould and core are dried. Cement is another inorganic binder in common use. It is a hydraulic binder which becomes hardened in air and under water after mixing.

Irreversibly curing binders undergo complex chemical transformation during hardening as a result of polymerization or polycondensation of the substance. Reversibly curing agents such as bitumen, pitches and resin restore the properties after cooling and others such as dextrin peptic gel do so under the effect of a solvent.

2.12 Core Types and Materials

Core may be classified into three broad types depending on their material make-up and method of use as follows; green sand cores,drysand cores and thermochemically cores sand (Asuquo and Bobojama, 1991).

2.13 Green Sand Cores

Cores in purely green state find little application because of inherent danger of increasing scab and blow hole formation. For optimum performance, green-sand core must be thoroughly rammed, well bonded and adequately vented. Cores are bonded for the purpose of increasing their strength and rigidity. However, to be acceptable for use they must possess a minimum strength of about 4KPa (Asuquo and Bobojama, 1991). Green cores are produced from the same sand as that used for mould making. Bentonite with a minimum moisture content of 3.5% and dextrin admixture are common material for cores. The green cores have their surfaces coated with surface active materials which tend to increase their non-wetability and resistance to scab and blow formation.

Green sand cores are normally used where the core has no sharp corner and where the thermal shock generation is not strong. Pieces of wires in the form of grid serve as good bonding materials for small cores. Large cores need iron or rods which are broken off during the cleaning of the casting. However, core grids should reduce the yielding of core during stripping. Core venting is as important as grid reinforcement. Venting being for the purpose of allowing the gas and steam generated during casting to escape without undue accumulation of pressure on the system. Venting can be done with venting wire. Some times a string can be inserted into the core which may be removed later on or in the case of dry cores, may be burnt off during drying (Asuquo and Bobojama, 1991)

2.14 Dry Sand Core

For the production of large castings, the green cores are not suitable. Dry sand cores are used when large castings are involved. Good clay mixtures form the basis of dry sand cores and this is quite different from the mould materials. Suitable binders such as oils and resins are added to the sand-clay mixture to help increase the strength of the cores. The binders melt on heating and re-solidify upon cooling whereby they form a strong and hard phase that cause strengthening. The venting of dry sand core is done by filling up with cinder and coke. Since these are combustible fillers, they get burnt and escape as gases leaving vents or permeable holes in the core (Jain, 2008).

2.15 Thermo-chemically Cured Cores

These cores derive their properties through chemical or thermo-chemical means. The basic core mixtures for these types of core are organic or inorganic binders plus curing or hardening agents. Where curing initiation is difficult, catalysts may be incorporated to enhance chemical reaction. Core mixtures are hardened on the basis of either self-curing (cold setting) or thermally accelerated curing which needs very short time intervals. Though this type of core production is prone to high cost, health hazards from the chemicals, it has advantages such as high productivity, better dimensional accuracy and cleaner surface, better adaptability to mechanization and automation and reduction of drying time.

2.16 Baking Methods (Organic Binders)

Cores prepared using organic binders are mostly set using a catalyst. They are of two groups. The first contains synthetic resin and catalyst (Nwajagu, 1994). The setting time is from a few minutes to hours depending on the type of binder and quantity of the catalyst. Cores of different sizes can be prepared and moulding can be done without flask. The second group of mixture is used for making cores which after ramming are blown with a gaseous catalyst which sets the resin. The mixtures are characterized by short setting cycle and are used in serial and mass production of cores (Nwajagu, 1994).

2.17 Bake Methods (Synthetic Binders)

These cores are made from mixtures containing 1.5-3.0% furan or phenol resins and 0.1-0.5% catalyst relative to the quantity of quartz sand which is 100% (Nwajagu, 1994). The setting time is between 15 minutes to 3 hours. The maximum strength of the mould and the cores are obtained few hours after setting.

2.18 Cold-box Method

This method is of various types and is based on the composition of the core mixture production method. The common cold-box methods are:

(a) Ashland method which utilizes core binders that are in liquid form and are made from equal quantities of phenol resin and polyisocryrite while the catalyst is the vapour from triethylamine carried by the compressed air. Ramming is by the shooting of the core mixture. The core prepared in this way is blown with a catalyst while still in the core box. Under the action of the catalyst, hydroxyl group of the phenol resin combines with isocyanides group of the polyisocyanide, resulting to the formation of polyurethane resin.The methodis highly poisonous and explosive and the core must be blown under a closed system (Colin, 2004).

(b) Fascold method which uses two sand core mixtures, the quartz sand and liquid resin (phenol or furan) mixture being the base material while quartz sand and catalyst (concentrated acid) mixture forms the hardener. The two mixtures are obtained separately in mixers and are mixed together and homogenized later in the reaction chamber. Mixing in this chamber is only for a short time because setting of the mixture starts immediately. After this, the mixture is shot into the core box. After 30-40 seconds, the core is removed from the box.

(c) Gisag method which uses formaldehyde resin and catalyst. The mixture is obtained by mixing the sand and catalyst in a mixer before the resin is added. After stirring the mixture at high speed for about 10 seconds, the homogenized mixture is shot into the core box. Setting of the core in the box takes place in 15 to 30 seconds (Colin, 2004).

2.19 Warm-box Method

The core mixtures used for the core production by this method are similar in composition to those used in hot-box process and consists of 1-2% additions of furfuryl alcohol-bihydromethyl furan (57-58%) and furfuryl alcohol (39-40%). Complex catalysts, which comprise of carbamide and sulphate salts, form about 25% of the core mixtures. The process takes place at relatively low temperatures (120-180^{o}C) and sets in about 90 seconds (Nwajagu, 1994).

2.20 Hot-box Method

In this case, phenol, carbamide, furan modified and other resins are used and in quantities ranging between 1 to 4%. The cores are made using machines, in metal core boxes and are heated by electric or gas heaters to cure them. After heating in the box, the mixture is held for sometimes for full setting of the resin. The core boxes are heated to between 180 and 340^{o}C while the setting time is from a few seconds to some minutes (Nwajagu, 1994).

2.21 Pep-set Method

This method is based on using a mixture containing phenol resin, polymering resin and a setting agent. As a result of the interaction of the anhydrous phenol resin (dissolved in aromatic solvent with high boiling point) and polymerizing resin (dissolved in the same solvent) solid urethane resin is formed. Amine is used as catalyst. The polymerizing resin and phenol are introduced into the mixture in equal quantity (0.5-0.7%). The amine is introduced in the quantity of 3-12% relative to resin depending on the desired setting rate. Pep-set method allows the core to be removed quickly from the box since the setting time of the mixture is 3-10 minutes. The life of the mixture is equal to a half of the setting time. The mixtures are prepared using dry sandand are easily subjected to reclamation (Jain, 2008).

2.22 SO_2 Process

This process, also known as Hardox SO_2 or SO_2-fast, is based on the setting of the thermal-reactive resin and SO_2 in the presence of an oxidizing agent. Typical core mixture for the SO_2 process contains 0.8-1.4% synthetic resin and an organic oxidizing agent, such as hydrogen peroxide. The oxidizing agent based on hydrogen peroxide is cheap but has small life time (5-6 hours). About 0.1-3% SO_2 gas is fed in a stream of inert gas into the core mixture. The blowing time depends on the mass of the core and varies from 0.2 to 30 seconds at a gas pressure of between 0.25-0.4MPa.

The reaction between SO_2 and the peroxide takes place instantaneously causing setting. Setting take place with evolution of heat which helps in attaining the needed strength very quickly. After setting, the core is cleaned of the remaining SO_2 by blowing with dry air (cold or hot) depending on the desired setting rate. Hot blowing is done at a temperature of between 70-150^{o}C and at a pressure of about 0.25MPa. Cores produced by the SO_2-process have long life and are of good handling ability.

2.23 Cryogenic Core Making Method

This method, also known as effective process, involves the solidification of the mixture by freezing. The composition of the mixture is quartz sand, 2-6% water and 1.5-2.5% binder. The mixture freezes under the action of liquid hydrogen (-196^{o}C) and liquid CO_2 (-50^{o}C). Core prepared this way can be preserved in non-insulated place for up to one hour, while in insulation up to a few hours. It is not necessary to gum the cores to join them since by the usual content they can ordinarily be joined. During pouring of the molten metal, water vapour is liberated from the frozen cores in small quantity. The cryogenic mixture does not cause the appearance of mechanical burn-on. When the frozen cores are handled manually, it is necessary to use hand gloves (Nwajagu, 1994).

2.24 Carbon Dioxide Process

Formerly this was used in Europe for hardening of moulds and core, made of green sand, but nowadays, it has been adopted in several countries because of rapid hardening of sand. It consists of thorough mixing of silica sand with 3.5 to 5% by weight of sodium silicate liquid base binder in a Muller. Sometimes coal-dust, pitch, graphite and wood flour are also added so as to improve the collapsibility. The mixture is then put into the core box. After packing, CO_2 is forced into the mould at a pressure of about 1.4 $Kgcm^{-2}$. The sodium silicate present in the mixture reacts with CO_2 and gives a hard substance called the silica gel.

2.25 Core Making by Hand

Cores are made manually by ramming closed or split core boxes. The split type of core boxes are used for the casting of intricate shapes. Small cores are made by hand filling of the core box with sand, usually on the core bench. The equipment required for such practices are just a core box and core plates. The box is filled with core sand and rammed. Core wires and grids are inserted into the core for strengthening followed by suitable venting arrangement. The core is stripped and transferred to the core plate for baking (Nwajagu, 1994).

2.26 Core Making by Machine

Machine core making process involves the use of machine to perform all the core making operations for fast production, efficiency and mass production. Core making machines in common use are squeeze machine, jolt machine, blowing machine, core shooters, wheel core machine and hot box machine (Nwajagu, 1994).

2.27 Core Baking

Generally, baking is carried out in ovens equipped with drawers, shelves or other holding devices. The heat in the oven is produced by burning oil or coke and by electric resistance. Core baking time depends upon the type and quantity of binders used, the amount of moisture used in sand and size of core while the core baking temperature depends on the core material used.

2.28 Core Dressing

Core dressing is the operation of applying a compound to the surface of a core, either in the green state or after baking, for the purpose of providing protection against the scouring action of flowing molten metal and to assist the formation of a smooth surface in a cored hole. The coating materials should have the ability to form an impervious layer on the core surface in order to avoid metal penetration and metal mould reaction. Some of the materials used for core dressing are silica flour, zircon flour, chamotte, graphite, black oil, coal dust and alumina powder (Jain, 2006).

2.29 Core Venting

Core venting is as important as grid reinforcement. Venting is for the purpose of allowing the gases and steam generated during casting to escape without undue accumulation of pressure on the casting. Cores are vented with the help of runners created in the process of ramming or with the use of venting wires. Venting channels can be made in different ways. For example, string could be inserted into the core which may be removed later on or may be burnt off during drying. Also cores are vented by filling them up with combustible materials such as cinder and coke. These combustible fillers can get burnt off during baking, thus creating channels for gases to escape.

2.30 Method of Supporting Cores in a Mould

Generally, core prints are provided in cores. These core prints are a sort of projections at the end of thecore and support the core in position in themould. Design should provide space for core prints to prevent sagging and resist the hydrostatic molten metal pressure. In some cores, small metal props (chaplets) are also used which are placed in the mould cavity to support the cores and these props fuse and become parts of the casting. For this reason, they should be clean, dry and selected from proper materials. For the cores that are used to create tiny holes or cavities, metal insert hinges are used to provide support to the cores. In this case, the use of chaplets should be avoided since fusion cannot take place in this case.

2.31 Properties Required of a Good Core

By virtue of their position and functions in the mould, cores are always surrounded by hot liquid metals and are subjected to very harsh conditions in comparison to the mould. As a result, cores must possess the following properties.

(a) Enough strength to withstand the severity of ferrostatic pressure without deformation. The strength of the core depends on grain size, shape and the distribution of sand grains, type and amount of clay or other binders and moisture content. Dry compressive strength of a core sand mixture increases as moisture is added until the sand becomes too wet to be workable (Jain, 2008). To find out the holding power of various bonding materials in green and dry sand moulds, strength test are performed. In determining the strength levels of a core, compression strength tests are most commonly performed, although tensile, shear and transverse tests are also sometimes performed (Jain, 2008).

(b) Little gas pores are desirable to impart adequate permeability. Permeability is defined as the ability of the rammed-in sand to allow the seepage of gas and steam through it. It is the quantity of gas, in cubic centimeters and under a pressure of $100Nm^{-2}$, which passes through one square centimeter cross sectional area of a standard test sample along the path of one centimeter in one minute.

(c) Little hygrosopy and good flowability.

2.32 Testing of Core Properties

Periodic tests are necessary to determine essential qualities of the foundry sand. The properties of the foundry sand depend upon shape, size, composition and distribution of the sand grain. The sand can be tested either by chemical or mechanical methods. The most important tests to be conducted for the foundry sand are grain fineness, flowability, permeability and strength. In addition to these, moisture content, clay content and hardness tests are also conducted (Jain, 2008).

2.33 Strength Tests

The strength test is performed on the horizontal hydraulic press. The specimen of cylindrical shape whose strength is to be determined is placed on the lugs and pressure is applied slowly by hand wheel until the specimen breaks. The reading of the needle on the manometer indicates the strength of the specimen. The manometers are graduated in four different scales each for compressive, shear, tensile and bending in Nm^{-2}. (Jain, 2008).

2.34 Permeability Test

Permeability test is carried out by means of permeability meter. Permeability meter consists of aluminium casting in the form of water tank and a base. A balanced tank floats inside the water tank. A specimen tube extends down to the specimen and opens into the air space. The sand specimen is placed at the base and is sealed with mercury. A predetermined amount of air is forced through under controlled conditions. The permeability reading is taken by noting the time in which 2000Cm^3 of air is passed through the specimen at constant pressure. Then, the permeability number K can be calculated using the formula:

Permeability (K) = 60vh/p.A.t (Jain, 2008)

Where v = volume of air = 2000cm^3,

h = height of the specimen in cm.

A = cross sectional area of specimen cm^2,

p = pressure in N/cm^2

t = time in minutes to allow passage of 2000cm^2 of air through the specimen.

If standard values were substituted, the formula becomes:

Permeability (K) = 3007.2/t (Jain, 2008).

2.35 Chemical Reaction During Baking

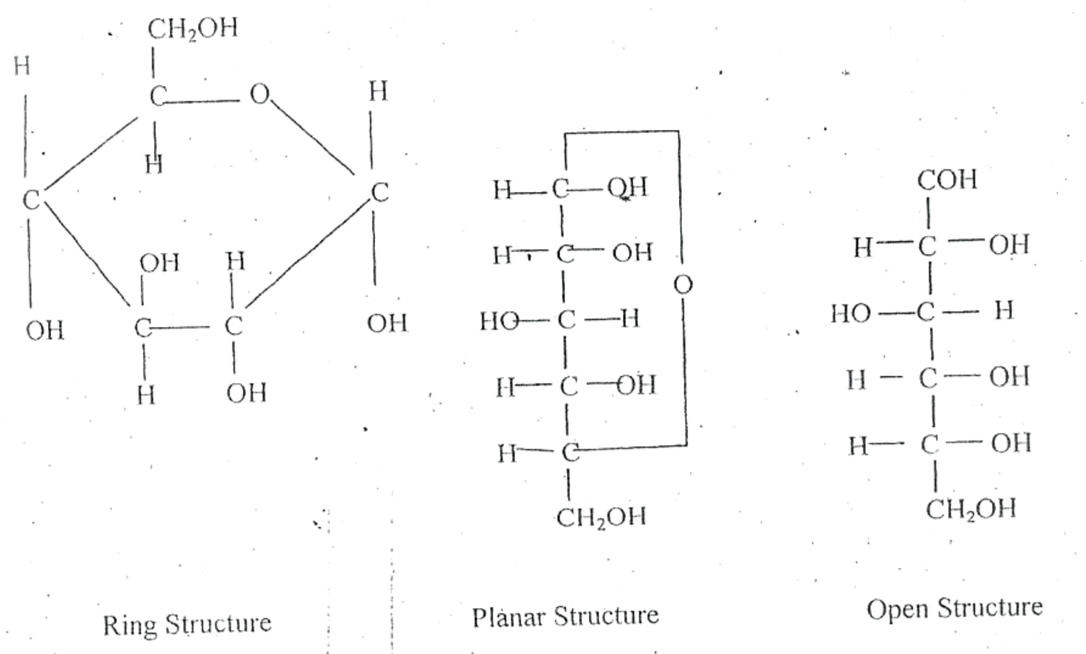
Most of the reactions that occur during core baking process are mostly between sand grains and the binders such as clay and starch. Clay takes the general structural form of minute plates in the approximate particle size range of 0.01 - 1μm and consists of fine silt. It impacts necessary bonding strength to the core sand so that core does not loose its shape. However it decreases permeability (Jain, 2008). Plasticity and bonds are developed by the addition of water (Davies, 1990).

It therefore means that the addition of clay to the core mixtures affects both the strength and permeability of the core. There are three forces that improve the bonding strength of the clay-sand mixture. These are electrostatic, surface tension and inter-particle friction. When clay particles are hydrated, water particles tend to hydrolyze. Clay particles preferentially absorb the hydroxyl ions due to unsatisfied valence bond at the surface of the clay crystal. Water particle becomes negatively charged. The surface tension surrounding the clay and clay-sand particles can then fill the capillary interstices of the clay particles and therefore increases the bonding strength of the core (Jain, 2008).

On drying, loss of absorbed water produces shrinkage of the lattice and further strengthening of the bond, so that clay binders are effective in both green and dried condition.

2.36 Structure of Starch and Bonding Characteristic

Starch belongs to the class of carbohydrates. It contains one or more double bonds per molecule. This enables it to absorb oxygen from air in order to become saturated and stable. The drying property of starch is therefore indicated by its ability to



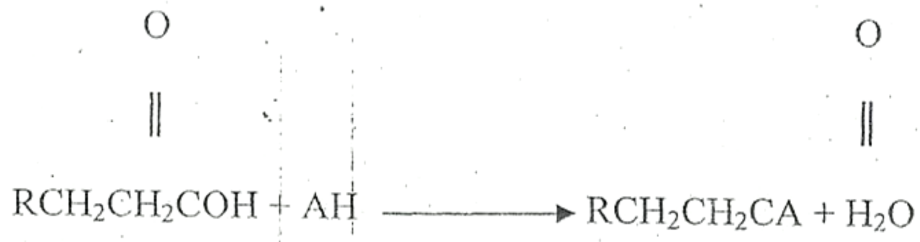
absorb oxygen.

Figure 2.1: Structural Forms of Starch

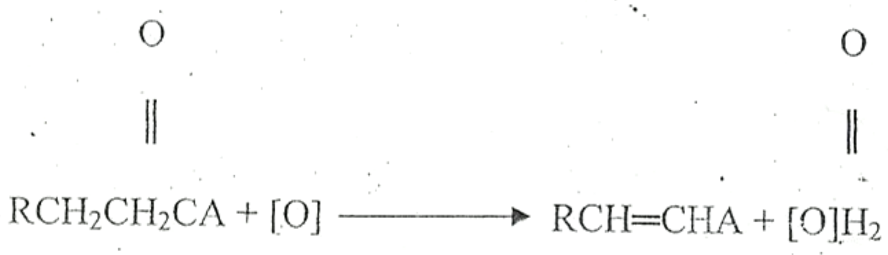
There are three structural forms exhibited by starch. These are ring, planar and open structures (Asuquo and Bobojama, 1991).

2.37 Chemical Reaction That Takes Place During Baking

There are five carbon atoms in the ring. Each carbon atom has four linkages in fulfillment of its tetravalency. One complete ring is joined to the next by what is known as an ether (-O-) bond at the carbon sites. The reaction group (OH)is designated as R. The chemical reaction that takes place is as follows;



The reaction continues thus:



Where A is a coenzyme .For this chemical reaction to take place sufficiently,the core must be heated to the temperature varying between150^{o}C and 200^{o}C . so that the starch absorbs about one fifth of its weight of oxygen and therefore, is gradually converted into a hard mass

2.38 Casting and Solidification Processes

Casting is a manufacturing process by which a liquid material (usually metal and polymers) is poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is known as a casting, which is ejected or broken out of the mold to complete the process. Casting materials are usually metals or various cold setting materials that cure after mixing two or more components together .Examples include epoxy, concrete, plaster or clay. A typical casting mold is shown in Figure 2.2. Casting is generally used for making intricate shapes (difficult or uneconomical to make by other methods).(Groover,2007)

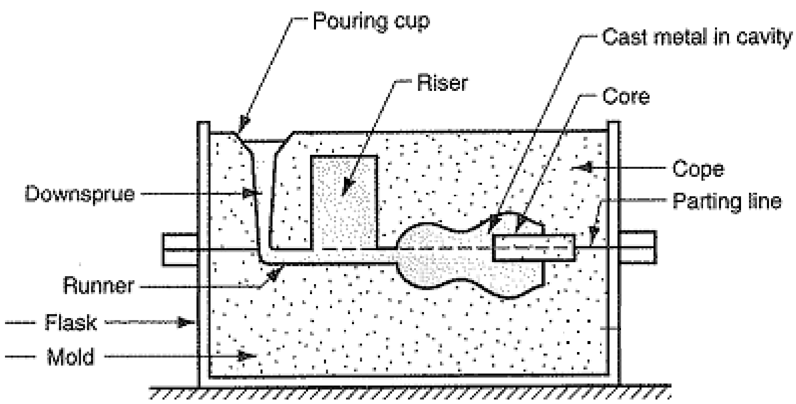


Figure 2.2. A typical casting mold.

In a casting process, the material is first heated to the liquid state and then poured into the cavity of the mold. As soon as the molten metal is in the mold, it begins to cool. When the temperature drops below the freezing point (melting point) of the material, solidification starts. Solidification involves a change of phase of the material and differs depending on whether the material is a pure element or an alloy. A pure metal solidifies at a constant temperature, which is its melting point (freezing point). For alloys, the solidification occurs over a temperature range depending upon the composition. A typical cooling curve for Ni-Cu system is given in Figure 2.2.(Groover,2007)

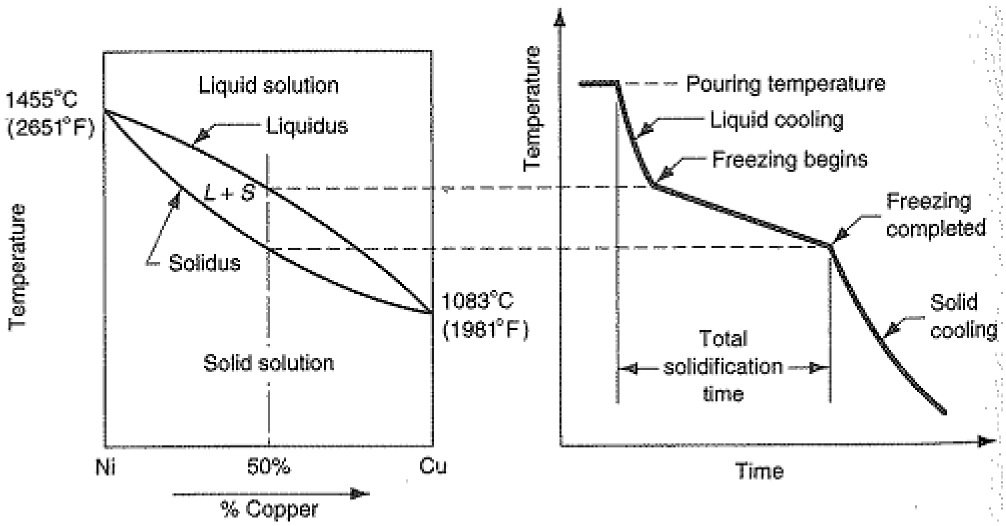


Figure 2.3.A typical cooling curve for Ni-Cu system.

As temperature drops, solidification begins at a temperature indicated by ***liquidus***and is completed when the ***solidus*** is reached.

2.39 Casting Defects

Due to various reasons the cast products may have defects, which may cause its scrapping. The defects may be minor, intermediate or major (Kumar, 2002).

The castings with minor defects can be economically and readily repaired. The castings with intermediate defects may result in high cost of repair but the casting may be usable. The casting having major defects, are scrapped.

Castings involve a number of process parameters, and accessories. In general any of the following factors may result to defective castings.

(i) Defective pattern design
(ii) Defective core making and moulding equipment
(iii) Improper core material
(iv) Improper mould material composition
(v) Improper placement of gating and risering
(vi) Non-optimal temperature of the molten metal
(vii) Improper handling of the equipment
(viii) Lack of experience of the foundry men

2.40 Various Defects, Their Causes and Remedies

1. **Blow holes.** Blow holes are cavities, normally round, with smooth walls. They remain inside the material and are not visible from outside.

If these cavities appear on the surface of the castings, they are called open holes (Kumar,2002) .

Possible causes

(a) Lower permeability due to hard ramming, excess moisture etc.
(b) Excess organic or carbonaceous material in the mouding or core sand. These may create excess gases on pouring of the metal.

(c) Excess dissolved gases in the molten metal. These gases may come out on solidification of the metal.
(d) Inadequate venting of the core.
(e) Wet, greasy, or rusty chaplets and chills. Excess gases may be formed causing blow holes.
(f) Inadequate venting of the moulds.

Remedies

(a) Controlling the permeability of the moulding material to an optimum value.
(b) Organic material in the mould and core sand should be in proper amount.
(c) Chills, chaplets should be properly cleaned.
(d) Core and mould should be properly vented.

2. Shrinkage. Shrinkage is a void or gap in or on the surface of the casting. The void on the surface as depressions or dishes is called surface shrinkage, and within the casting material, as internal shrinkage. **Possible causes**

(a) Improper location of gates and riser
(b) Inadequate runner gate and risers
(c) Poor design of the casting, such as abrupt change in section
(d) Inadequate or improper filleting of corners
(e) Improper pouring temperature.
(f) Failure of directional solidification.

Remedies

(a) Proper location and proper size of gate, risers and runners should be incorporated.

(b) Proper filleting should be provided, especially at the corners.

(c) Directional solidification should be ensured by providing chills, risers etc at right positions.

(d) Proper pouring temperature should be maintained.

3. Hot tears or hot cracks. Too much shrinkage may lead to cracks called hot cracks or tears which are external or internal ragged discontinuity in the metal casting resulting from hindered contraction occurring just after the metal has solidified.

Possible causes

(a) Poor design of the casting (abrupt changes in section)

(b) Improper and inadequate placement of chills, risers

(c) Poor collapsibility of core and mould materials, causing extra stress on certain portions of the castings

Remedies

(a) Proper sized gates runners and chills placed at proper positions will avoid undesirable temperature gradients, and will control hot tears.

(b) Core and mould materials used should have high collapsicility.

4. Cold cracks. Cold cracks are similar to hot tears except that the discontinuity is less ragged in this case. Moreover cold cracks occur below about 500^0F.

Possible causes

(a) Sudden chilling of the casting. This may be caused by

(i) Sudden removal of the casting from the mould

(ii) Spraying of water over hot casting

(iii) Severe handling of the casting before it has been completely relieved of the stresses.

Remedies

(a) Sudden chilling of the casting should be avoided

(b) Severe handling should be avoided specially before the casting is relieved of its stresses.

5. Misrun and cold shut. Due to certain shortcomings in the casting system sometimes the molten metal cannot fill the mould cavity completely and some portions (usually corners) remain unfilled. The resulting defect is called Misrun. Sometimes metal is poured from two opposite directions in the mould. If the two streams of metal approaching each other, make physical contact but do not fuse together, thus leaving a gap (however small it may be), the resulting defect is called cold shut.

Possible causes

(a) Low metal fluidity, due to low pouring temperature, and improper alloy analysis.

(b) Small gate and slow pouring rate

(c) Thin casting sections

(d) Low sprue height

(e) Improperly positioned gates and risers

Remedies

(a) Proper pouring temperature

(b) Proper pouring rate

(c) Proper size gates

(d) Proper positioning of gates and risers.

6. Run out and bust out. If the molten metal leaks out (or drains out) from the cavity during pouring and the casting remains incomplete, it is said that a run out has occurred.

Possible causes

(a) A pattern disproportionately too large for a flask

(b) Pattern placed very close to the flask edge

(c) Mismanagement of drag and cope

(d) Excessive pouring pressure

(e) Improper sealing of mould joints.

Remedies

(a) The pattern size should not be too large for the flask

(b) The patter should not be placed too near the flask edge

(c) The cope and drag should be properly clamped, and if needed, a weight may be placed over the assembly.

(d) Misalignment of cope with drag should be avoided.

(e) Mould joints should be properly sealed

(f) Excessive pouring pressure should be avoided.

7. Pour short. If the cavity is not filled completely due to insufficient metal it is called pour short.

Possible causes

(a) Insufficient metal in the ladle

(b) Interruption during operation

Remedies

(a) The ladle should have enough metal for a cavity

(b) The pouring operation should be completely without any interruptions.

8. Inclusions. Inclusions are unwanted non-metallic foreign materials such as slag, dirt, sand oxides, gas etc present in the casting.

Probable causes

(a) Breaking of core, gating etc at the time of metal pouring due to poor ramming of moulding sand, inferior core and mould sand, rough handling of the moulds, poor gating.

(b) Oxides are formed on the exposed surface of molten metal

(c) Slag is formed during melting.

Remedies

(a) Prevent the entry of oxides and slags, proper fluxing and skimming gate should be provided.

(b) Prevent entry of sand, mould should be of proper quality, ramming should be adequate and proper gating should be provided.

(c) Proper gating for minimization of turbulence of molten metal to reduce oxide formation and mould wall erosion should be made.

9. Porosity

Porosity is fine holes in the casting. These are so fine that they can be detected through X-ray technique only.

Probable causes

(a) Absorption of hydrogen by the metal. On solidification the gas is released. it escapes making pin holes in the casting. The common source of hydrogen pick up is moisture, present in the air, mould and furnace.

(b) Higher temperature of the metal and slower rate of solidification.

Remedies

(a) Moisture content of the mould should be minimized.

(b) Permeability of the mould should be high.

(c) Solidification rate of the casting should be increased by providing proper gating and risering system.

(d) Proper melting temperature and adequate amount of flux should be maintained.

10. Metal Penetration

Metal penetration results if the poured metal penetrates the interstices of the sand grains and causes a fused aggregate of metal and sand on the surface of the casting.

Probable causes

(a) Coarse moulding and core sands

(b) Soft ramming of the moulding sand

(c) High metal fluidity due to excessive metal temperature

Remedies

(a) Use of fine moulding and core sand

(b) Hard ramming

(c) Optimum metal temperature

11. Swell

Swell is unwanted enlargement of the casting. It may be localized or general enlargement due to the pressure of the liquid metal.

Probable causes

(a) Soft ramming of the mould

(b) Low strength of the mould

(c) Too high a sprue may also cause excessive pressure of the metal causing swell.

Remedies

(a) Hard ramming of the mould

(b) Proper size of sprue

(c) Moderate rate of metal pouring.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials Sourcing

All the materials required for this research were sourcedlocally. The silica sand was sourced from River Niger Beach at Onitsha (GPS: latitude 6^0 08’ 59.21”N and longitude 6^0 47’ 8.48”E), while the binding clay was sourced from Ukpor at Nnewi South Local Government Area (GPS: latitude 5.93136 and longitude 6.9227) both in Anambra State.The binding bentonite, alkali free dextrin and sodium hydroxide were procured from Ogbete main market Enugu. The Cassava starch was also sourced from Ugwogo Nike in Enugu East Local Government Area, Enugu State.

3.2 Equipment and Tools Used

The equipment and tools used were under the permission of some research organization such as Federal Institute of Industrial Research Oshodi (FIIRO) Lagos State, National Steel Council and National Defence Industry both in Kaduna State and Department of Metallurgical and Materials Engineering,Esut Enugu, Nigeria. These include:

1. X-ray fluorescence
2. Sieve shaker and sets of sieve
3. Electronic digital balance
4. Universal strength testing machine

5. Clay washer
6. Sand rammer
7. Kiln
8. Thermometer
9. Permeability meter
10. Diamond cutting machine
11. Jaw crushing machine
12. Disc miller and
13. vibrating cup miller
14. Heat treatment furnace

3.3 Experimental Methods

The sand sample was taken from three different sites, some distance away from River Niger bridge.

This study was experimental and consisted of the mechanical sieve analysis of the sand, chemical analysis of River Niger silica sand, bentonite and chemical and physical analysis of Ukpor clay, green compressive strength, dry compressive strength, green shear strength, permeability, refractoriness, moisture content of sand specimens and compactibility test of the sand specimen. The tests were all carried out according to American Foundry Society Standard (AFS) (1966) for foundry sands. The standard weight of sand mixture that gives A.F.S standard samples for tests is 150g.

3.4 Cassava Starch Preparation

Cassava tubers were peeled and properly washed. The washed tubers were pounded followed by grinding into pulp. Water was added to ease the extraction of starch. On the addition of water, it formed suspension which was left to stay for 2 hours before the water above was decanted. The starch residue was properly dried to white, odorless and tasteless powder.

3.5 Sand Preparation

The sand was collected from the site, washed to remove clay and other impurities. It was sieved using shaker on which meshes of different aperture were mounted. The clay was collected from the site and some quantities were sent for physical and chemical tests, while some were used for moulding. The tests were all carried out according to American Foundry Society (AFS) Standard (1966) for foundry sands. The standard weight of sand mixture that gives A.F.S. standard sample for tests is 150g.

3.6 Selection of Moulding Sand Mixtures

For this work, a large number of moulding sand mixtures, based on the proportion of the constituent of sand, clay, cassava starch,bentonite and water where prepared. The experiment was done in three batches. The first batch of the moulds was carried out using bentonite and sandbonded with water, second batch was carried out usingUkpor clay and sandbonded with water, while the third batch was done using cassava starch and sandbonded with water as shown in experimental design(see Tables 3.1a and 3.1b).

3.7 Determination of Grain Size Distribution

The stocks of sieve were arranged according to the sieve 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 1000g of the sand sample was put into the top of sieve stock and stocks were placed on a sieve shaker and then switched on, and allowed to vibrate for a period of thirty (30) minutes . The sieves were removed one after the other beginning with one on top. The quantity of sand remaining on each sieve was weighed. The weight was recorded accordingly for each sieve in the column corresponding to the sieve mesh serial number of 1.00mm, 0.71mm, 0.50mm, 0.18mm, 0.125mm, 0.09mm and 0.063mm. Each separate sieve weight was multiplied by the corresponding sieve mesh number. The sum total of the product was divided by the total sample aligned and this produced the fineness number of the sand as shown;

$$A.F.S\ gran\ fineness\ number = \frac{product}{Amount\ retained} \dots\dots\dots\dots\dots\dots\dots 3.1$$

3.8 Determination of Green Compression Strength

The green compression strength was carried out using universal sand strength testing machine (Model No: 6903). A prepared standard sample was positioned in the compression head already fixed into the machine. The sample was loaded gradually, while the magnetic rider moved along the measuring scale. As soon as the sample reached its maximum strength, the sample experienced failure and the magnetic rider remained in position of the ultimate strength (a value was noted), while the load was gradually released.

3.9 Determination of Dry Compression Strength

A prepared standard sample of 5cm diameter x 5cm height was dried in an oven at a temperature of 110°C for a period of 20minutes and then removed and allowed to cool in the air to ambient temperature. After cooling, the sample was fixed into the universal sand-testing machine with the compression head in place. The compressive load was applied and the samples failed at the ultimate compressive strength of the sample. The point at which the failure occurred was recorded as DCS

3.10 Determination of Dry Shear Strength

The prepared standard sample of 5cm diameter x 5cm height was dried in an oven at a temperature of 110°C for 20 minutes and then removed from the oven to cool in air to ambient temperature. The same universal testing machine was used for dry compression strength. In this case, the shear head was replaced for the compression head. The shear strength was recorded at the point of failure of the standard test sample.

3.11 Determination of Green Shear Strength

The green shear strength (GSS) is the measure of the shear strength of the prepared sample, when shear load is applied in its green state. The machine used for the GCS was also used for the determination of green shear strength (GSS), except that the compression head was replaced with shear head in the machine. The green shear strength was recorded at the point of failure of the sample loaded

3.12 Determination of Permeability

The permeability test was carried out on the standard sample specimen of 5cm diameter x 5cm height. The specimen, while still in the tube, was mounted on the permeability meter. Air at a constant pressure was applied to the standard sample specimen, immediately after producing the sample and the drop in pressure was measured using a pressure gauge, which is calibrated directly in permeability numbers.

3.13 Refractoriness:

The sand for the refractory test was mixed with the desired quantities of binders and water. The mixture was moulded into cone shape and then dried in oven at 110^0C. This was followed by sintering the cone shaped sample in the furnace to a temperature of 1000^0C. The standard pyrometric cones of known softening temperature and the prepared sample were arranged in the furnace to test for the refractoriness. The cones were heated gradually until softening of the cones was observed. The softening point of the pyrometric cones which corresponded with the time of the softening of the test sample was recorded. The temperature at which this occurred was recorded as the refractoriness. After this, the fusion point was also observed and noted.

3.14 Chemical Analysis

The chemical composition of the samples (River Niger sand, bentonite and Ukpor clay) was determined using X-ray florescence (XRF) spectroscopy technique at National Defence Industry, Kaduna. The samples were dried in an oven at 60^0C for 30mins. After which, the dried sample was then ground into powder sample of particle size 100mesh (0.15micron), recommended for XRF analysis. The equipment was allowed to run for 5 hours with the recommended voltage and current of 45volts and 40A respectively, to enable the standards and other mechanical parts responsible for analysis to stabilize and initialized for XRF test.

3.15 X-Ray Diffraction

Bulk Analysis

The phases present in the River Niger beach sand and Ukpor clay deposit were determined using X-ray diffraction (XRD) at National Steel Council, Kaduna. It was performed with a Schimadzu 6000 model diffractomer using CuK$\propto$ radiation and a graphite manochromater (λ=1.5418A^0). The samples were ground into powder of particle size 0.15micron recommended for XRD analysis. The X-ray pattern was allowed to run between 0^0 to 120^0 theta Bragg angle with recommended voltage and current level of 40V and 30A respectively.

3.16 AFS Clay Content:- The total clay content in sand was determined by washing 50g of the moulding sand using 500cm^3 of water and 25cm^3 of standard sodium hydroxide (NaOH) in a jar. Several washing was done to fully remove the clay. The remaining sand was then dried and weighed to determine the amount of clay removed from the original sample.

3.17 Standard Specification: The following tests were performed using AFS specification as follows:

- Grain fineness No: AFS 11-6-00-S
- Compactibility: AFS 2220-00-S
- Moisture determination: AFS 2218-00-S
- Compressive strength/dry/green strength: AFS 5202-00-S
- Permeability: AFS 5224-00-S
- Sieve analysis: AFS 1105-00-S

3.18 Performance Evaluations: This work would be successfully completed with a practical evaluation of the effectiveness and suitability of the moulds that were produced. To achieve this, Ukpor clay and bentonite moulds were produced for casting Mercedes Benz upperarm using Al-10% Cu alloy. To cast the upperarm, clay bonded and bentonite bonded mixtures were used to produce the mould. 5924.5g of pure aluminium and 665.59g of copper wire which had been cut into manageable sizes were charged into the heat treatment furnace. Tapping and pouring into the moulds were done after appropriate slag removal. Moulding, melting and casting processes were carried out in the foundry shop of Metallurgical and Materials Engineering Department, Enugu State University of Science and Technology, Enugu, Enugu State.

After the molten metal had solidified, the moulds were broken to bring out the cast products. The riser, the ingate and other unwanted parts, were removed to obtain good finished product.

3.19 Calculation of Charge

The calculation of charge consists of estimated mass proportion of the various materials which were charged into the furnace in order to produce alloy with desired or specified chemical composition. The charge was calculated based on the weight of the work at hand. During the charging, the quantity of each component to be charged was increased in order to compensate for any irretrievable loss, that is the melting loss due to burning-out and oxide formation.

3.20 Tensile Properties Determination.

The specimens were produced with Al-10% Cu alloy. The specimen dimensions (diameter and guage length) were measured and recorded for the calculation of engineering stress and engineering strain, using a universal tensile testing machine at the Department of Metallurgical and Materials Engineering, Enugu State University of Science and Technology, Enugu.

For good reproducibility of the result, the guage length was selected sixteen times the rod diameter. Thus with rod diameter equal to 6mm, the guage length was selected as 96mm.

3.21 Design of Experiment using Response Surface Methodology

In the conventional method, one variable changes when all other parameters are at a specified value. Response surface method was used to evaluate the effect of several factors and their interaction on the system response. It is a combination of mathematical and statistical methods.RSM contains three major steps in the data analysis and modelling which include:

1) Design of experiments;
2) Response surface modeling; and
3) Optimization

In the experimental design, the software used for the analysis was the trial version of the stat-ease, incorporation design expert software 10.0. Central composite circumscribed (CCC) design was chosen to analyse the samples. CCC designs provided high quality predictions over the entire design space because it generated new extremes for all factors outside the design bracket. The high and low values were selected, while the software generated the alpha high and alpha low values. These points are called the star points of the design.

The three factor study generated a 20 runs per each requirement using the fractional factorial CCD and the corresponding experimental tables are shown on tables 3a and 3b for bentonite and Ukpor clay bonded with River Niger beach sand.

Table 3a Central composite design table for Ukpor clay bonded with River Niger sand in terms of actual process factors

Std	Run	Factor 1 A: Sand %	Factor 2 B: ukpo Clay %	Factor 3 C: Water %
6	1	97	1	2
5	2	95	2	3
15	3	94	3	3
10	4	98	1	1
2	5	96	2	2
8	6	96	3	1
13	7	95	4	1
4	8	93	4	3
16	9	94	3	3
17	10	94	3	3
20	11	94	3	3
7	12	92	4	4
14	13	94	1	5
11	14	95	1	4
9	15	91	4	5
1	16	93	3	4
12	17	94	5	1
3	18	94	4	2
19	19	94	3	3
18	20	94	3	3

Table 3b Central composite design table for bentonite bonded with River Niger sand in terms of actual process

Std	Run	Factor 1 A sand %	Factor 2 B: Bentonite	Factor C: Water %
11	1	95	1	4
9	2	91	5	4
12	3	94	5	1
2	4	96	2	2
6	5	97	1	2
7	6	92	4	4
10	7	98	1	1
13	8	95	4	1
5	9	95	2	3
1	10	93	3	4
3	11	94	4	2
4	12	93	4	3
8	13	96	3	1
14	14	94	1	5
15	15	94	3	3
16	16	94	3	3
17	17	94	3	3
18	18	94	3	3
19	19	94	3	3
20	20	94	3	3

CHAPTER FOUR

RESULTS AND DISCUSSION

The results of the tests conducted are presented in Tables 4.1a – 4.24d and Figures 4.1-4.143.

4.1 Sand Grain Fineness Number: The sieve analysis result as shown in Tables 4.16a, 4.16b and Figures 4.1 and 4.2, shows that the grain fineness number fell within the acceptable range. According to the American Foundryman's Society (AFS) standard (1963) 40 to 330 average fineness is suitable for foundry application. According to McLaws(1971), 70-86 AFS grain fineness number is basically suitable for medium grey iron casting (Table4.21b). The River Niger Onitsha beach sand has an average fineness number of 82.

The grain fineness number is a useful parameter that represents the sieve number through which all the sand grains would pass if they were of the same sizes. The grain fineness number though is a useful parameter but the choice of sand for moulding should be based on particle size distribution. The size distribution of the sand affects the quality of casting.

Coarse grain sands allow metal penetration into moulds and thus giving poor surface finish to the casting (Brown, 1994). Rundman (2000) agreed also that the properties of moulding sand depend strongly upon the size distribution of the sand that is used, whether it is silica, olivine or other aggregates.

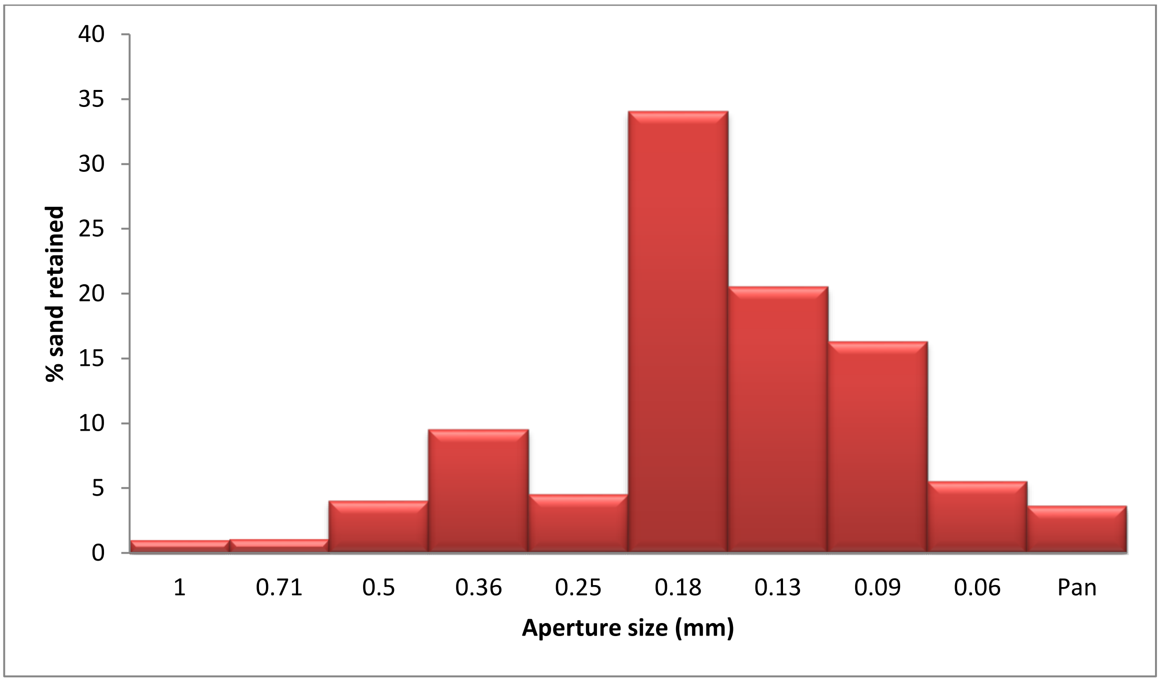


Fig. 4.1 – Percentages of sand retained on each aperture size.

Figure 4.1 presents a summary of the mechanical sieve analysis of the River Niger Onitsha beach sand. The sieve numbers and the weight percentages retained are shown in the horizontal and vertical axis. From the Figure 4.1, it was shown that the sieve was

distributed in all the screens with about 70.85(%)percent concentration of the sand grains retained by the three adjacent sieves of 0.18mm, 0.125mm and 0.09mm

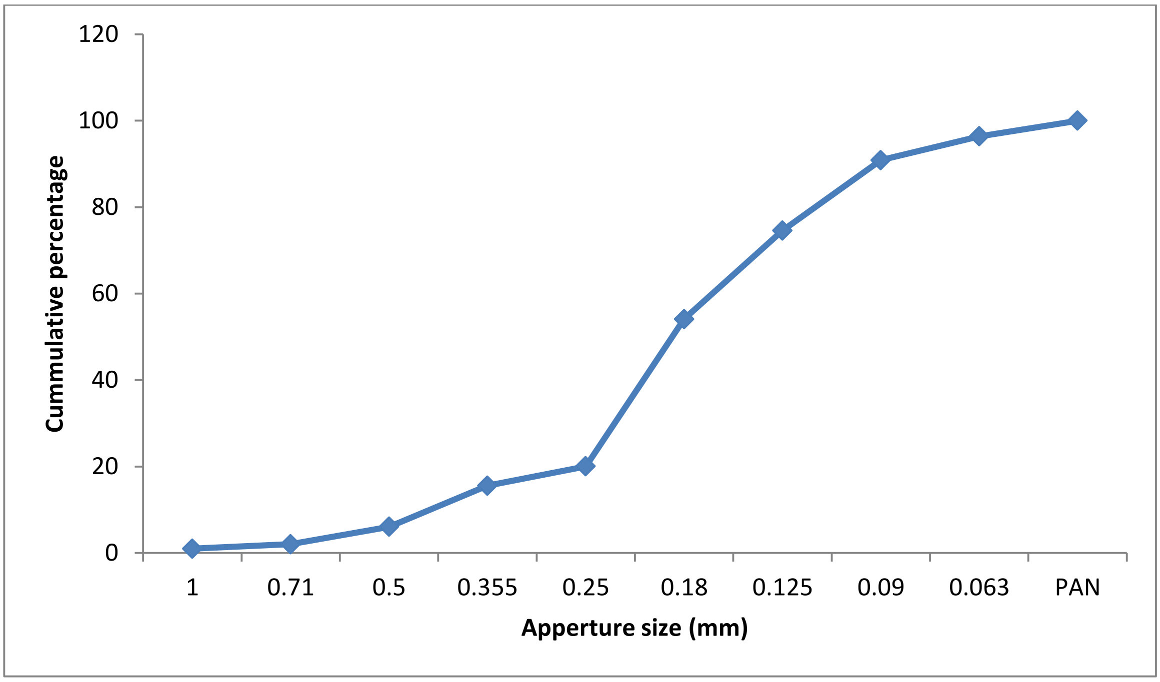


Fig. 4.2 Cumulative percentages retained on each aperture size

The degree of uniformity of the sand is described by the coefficient of uniformity, which is calculated from the formula;

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.18}{0.5} = 0.36$$

Where D_{60} = sieve number corresponding to the 60 percent intercept on the cumulative curve,

D_{10} = sieve number corresponding to the 10 percent intercept on the cumulative curve

Thus, from Figure 4.2, it was shown that the degree of uniformity of the sand is 0.36, and as the sand becomes less uniform the value of C, increases proportionately.

4.2 Chemical Analysis of River Niger Onitsha Beach Sand, Ukpor Clay and Bentonite

The chemical analysis shown in Table 4.17a and Figure 4.3 showed that the River Niger sand contains 94.49% SiO_2, 1.30% k_2O and 1.675% Fe_2O_3 as the major components. The silica content of 94.49% compares well with the acceptable values of between 80% and 97% recommended for moulding (Jain, 2008), but cannot be used for ferrous castings, because according to Mclaws (1976), ideal sand for ferrous castings should contain silica in the region of 98% - 99%. It can also be seen from Table4.3, that the percentage of SiO_2 content for Chelford,Warri and Ughelli River sand sample are very close to that of River Niger Onitsha sand sample.Silica being the predominant component in the River Niger Onitsha beach sand is of good advantage, since high percentages of silica in sand according to Richard et al (1983) usually enhance its refractory and thermal stability. Also, it is noted that the presence of iron oxide, potassium oxide and some other minor oxides can cause objectionable lowering of the fusion point in sand. The fusion point of the sand as experimentally determined was 1390^0C, which is quit low and could be as a result of the combined effects of these impurities of River sand. It was a measure of refractoriness and thermal stability that dictates the alloy the sand will be suitable for casting. This implies that River Niger sand mainly will be suitable for casting metals, and alloys with melting point lower than 1390^0C.

Ukpor clay has 70.3% silica, 22.1% Al_2O_3, 2.113% Fe_2O_3 and 0.126% CaO as the principal constituents. This is shown clearly in Table 4.17c and Figure 4.4. These values are adequate for moulding.

Bentonite on the other hand had Al_2O_3 (24.60%), S_1O_2 (64.1%), Fe_2O_3 (6.94%), CaO (1.39%), as the major constituents. The minor constituents comprised of CaO (1.39%), SO_3 (0.704%) K_2O (0.449%) etc.

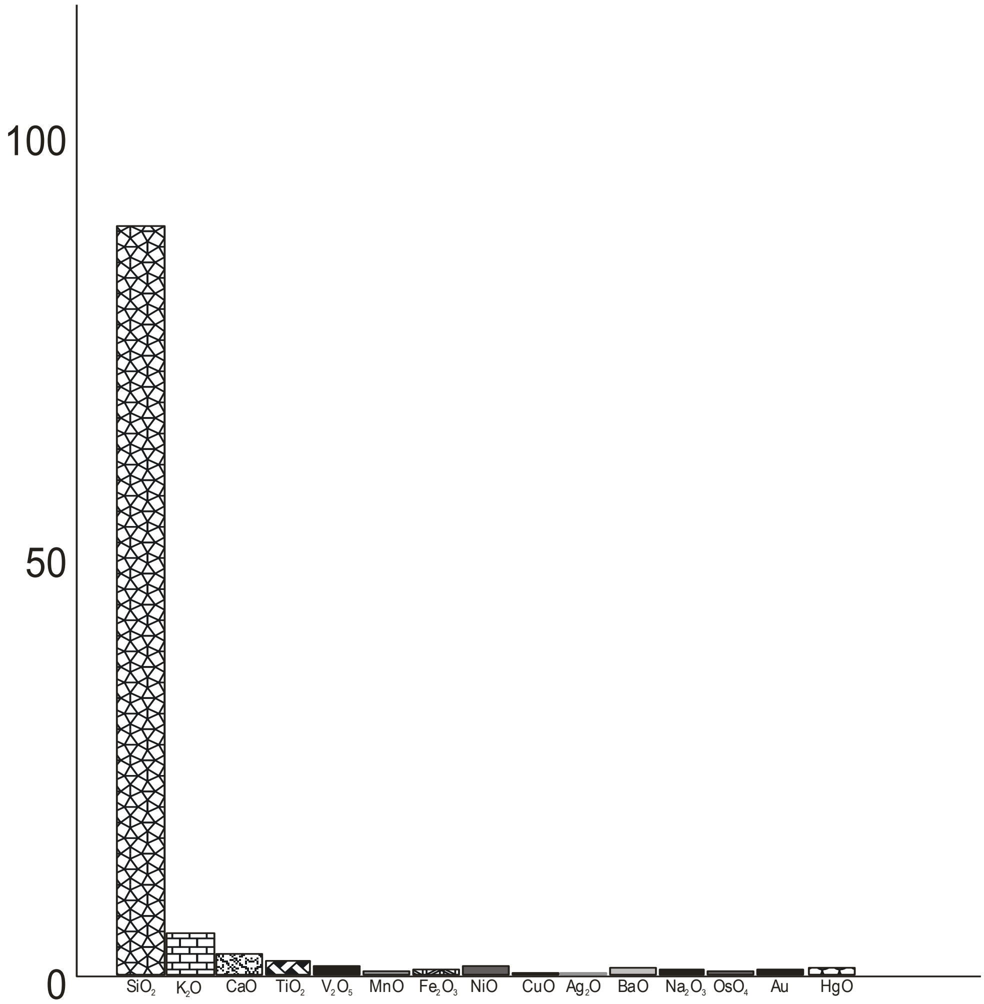


Fig. 4.3 Chemical compositions of the River Niger beach sand

Figure 4.3 illustrates the result of the chemical composition of the River Niger beach sand. From the Figure 4.3, it was observed that silica was the predominant component in the sand, which is desirable since high percentage of silica in sand, usually enhance its refractoriness. This is followed by Fe_2O_3, K_2O, Ag_2O, CaO and other oxides such as V_2O_5, MnO, NiO etc which were present in minor quantities.

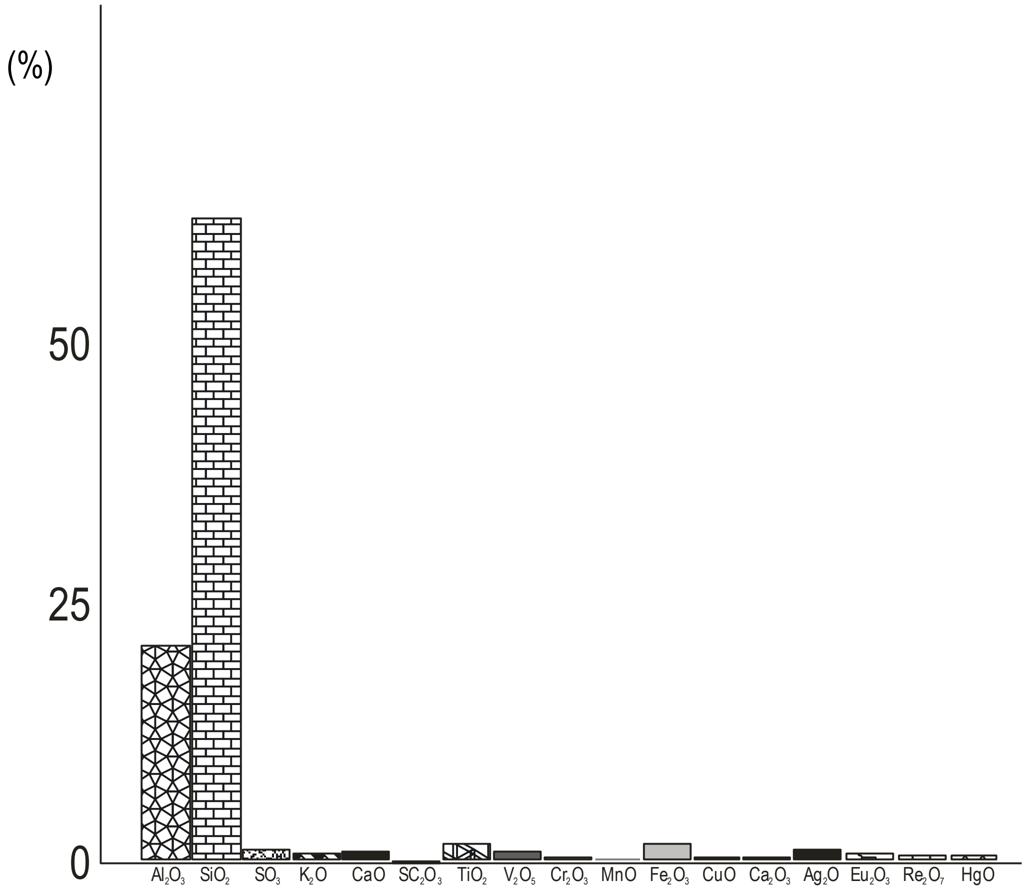


Fig. 4.4 Chemical composition of the Ukpor clay deposit

Figure 4.4 shows the result of the chemical composition of Ukpor clay deposit. The clay has silica (70.3%) and Al_2O_2(22.1%) as its predominant oxides, followed by TiO_2, Fe_2O_3, Ag_2O and other oxides such as Cr_2O_3, K_2O, CuO etc are present in minor quantities.

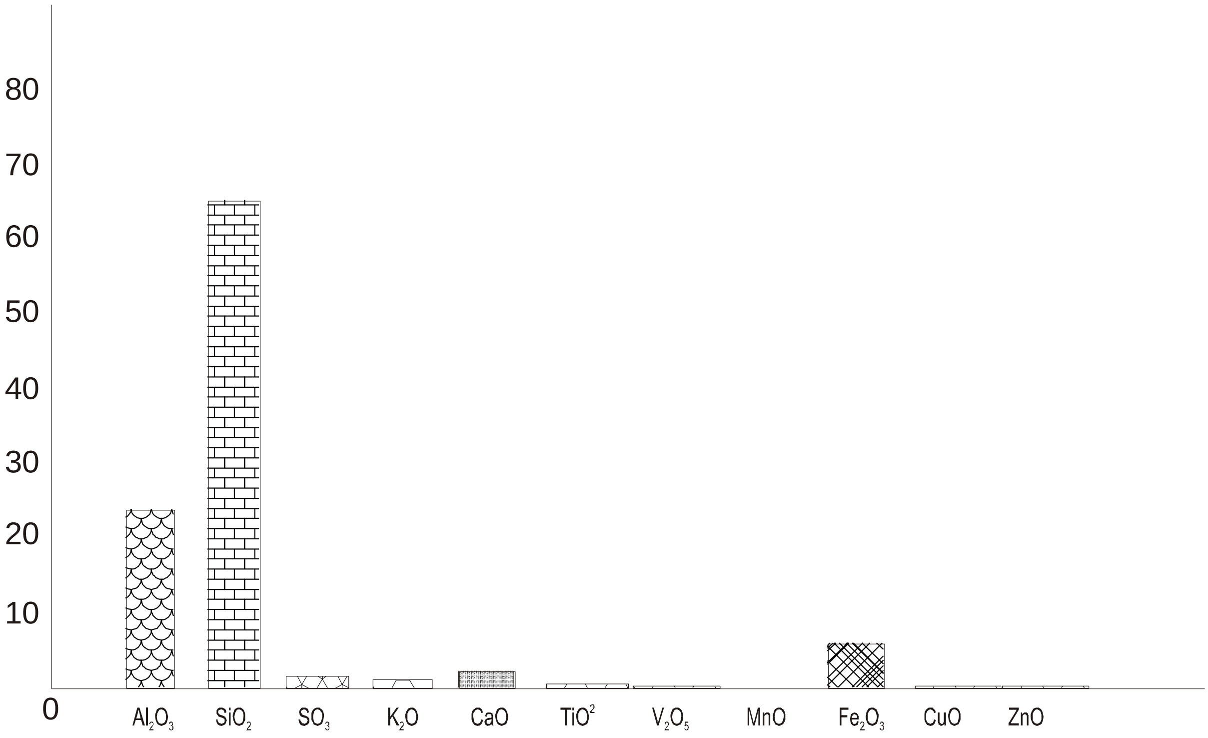


Fig. 4.5 Chemical composition of bentonite

Figure 4.5 shows the chemical composition of the bentonite used in the study. It comprised of silica (64.10%) and alumina (24.60%), as its major constituent oxides, followed by Fe_2O_3 (6.94%), CaO (1.39%), SO_3 (0.704%), K_2O (0.449%) and other oxides such as TiO_2 (0.198%), V_2O_5 (0.015%), MnO (0.003%), CuO (0.01%) ZnO (0.005%),Ga_2O_3 (0.015%) and WO_3 (0.06%) etc. as minor oxides.

4.3 Fusion Point of the River Niger Sand

The fusion point of the pure silica sample is1390^{0}C, this is a measure of the refractoriness and gives important information about the thermal resistance. It showed that the sand is mainly suitable for non-ferrous metals with melting point lower than 1390^{0}C. The fusion points when mixed with 5% bentonite and 5% Ukpor clay each with a constant 5% water were 1464^{0}C and 1480^{0}C respectively (Table 4.23a).

4.4 X-Ray Diffraction Results

The X-ray diffraction spectrum results of River Niger Onitsha beach sand indicated the presence of quartz, feldspare, antigorite,muscovite and albite as the predominant minerals and also hopeite and orthoclasetc as minor minerals. They were closely observed on the individual strongest peaks using manual matching and Card File Data. The three major peaks found in the River Niger beach sand as expressed on the diffractogram, were at the following 2Theta Braggs angles of 24.0248deg, 18.2689deg and 47.4841deg with their various intensity ratios of 100,28 and 10. Their corresponding diffraction peaks were at 3.7011.7A^o, 4.85223A^o and 1.91321A^o respectively as shown in Figure 4.5 and Table 4.18a.

Similar composition has been reported by Alcides et. al (1997) on the characterization of a Brazilian smeltite by solid state NMR and X-Ray Diffraction techniques.

Further more, the x-ray diffraction spectrum results of Ukpor clay deposit showed anhydrodite, truscottite, paragonite and rebekite as the predominate minerals and also gibbsite and heamatite, as the minor minerals, as shown in Figure 4.6 and Table 4.18b in the appendix.

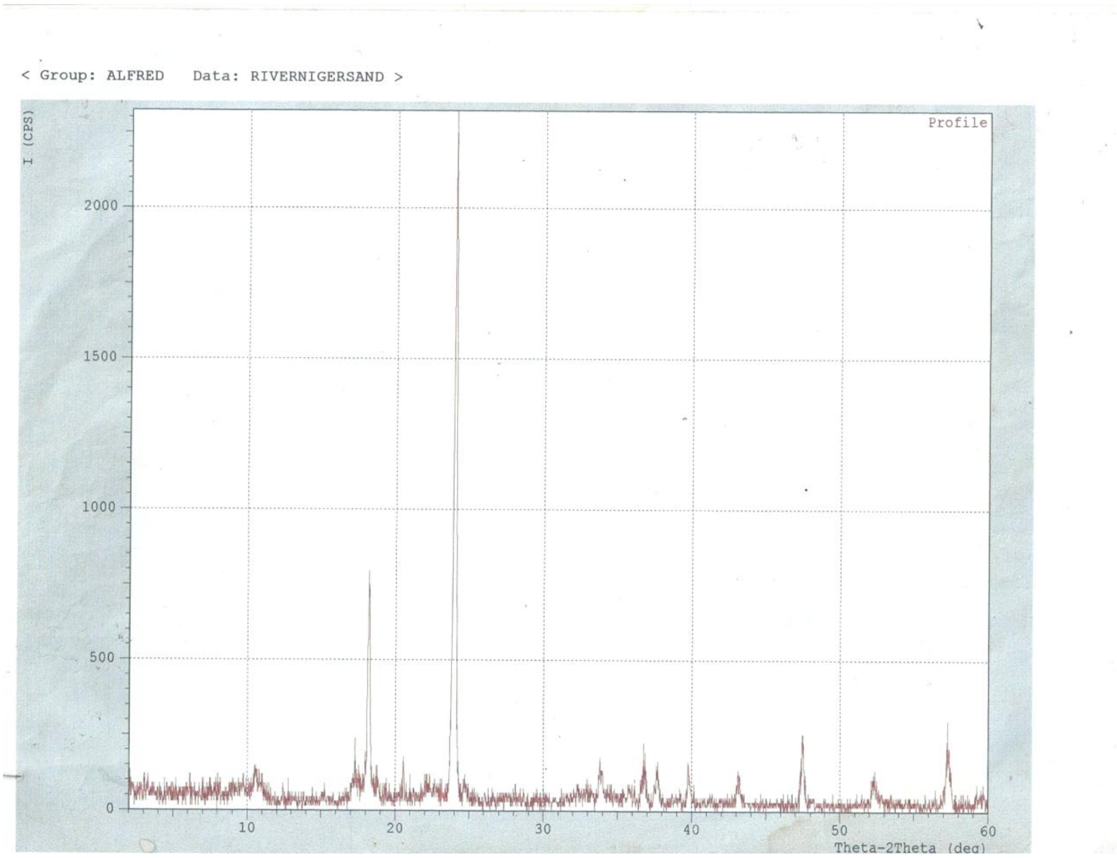


Fig 4.6 X-Ray diffraction spectrum of River Niger beach sand

Figure 4.6 shows the x-ray diffraction spectrum of River Niger Onitsha beach sand. From the Figure, it was observed that the three strongest peaks found in the River Niger sand were at 2Theta Braggs angle of 24.0248 deg, 18.2689 deg and 47.4844 deg with their various intensity ratio of 100, 28 and 10 respectively.

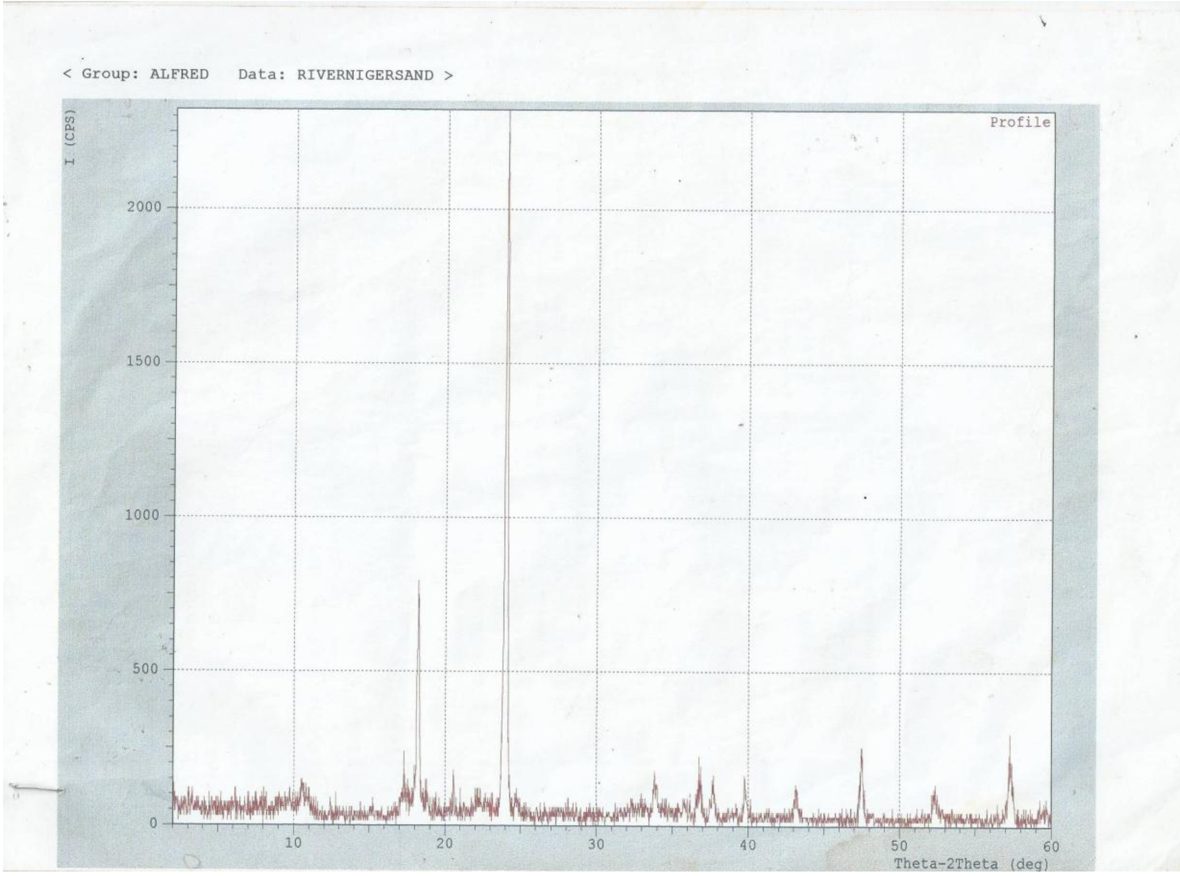


Fig 4.7 X-Ray diffraction spectrum of Ukpor clay sample

Figure 4.7 illustrates the x-ray diffraction spectrum of Ukpor clay deposit. It was revealed that the three strongest peaks found in the Ukpor clay deposit were at 2θ Bragg's angle of 24.1227deg, 18.3535deg, 57.4312deg and their corresponding intensity ratio of 100, 31 and 10. This is shown in Table 4.18b in the appendix.

4.5 Comparison of Foundry Properties Results of River Niger Onitsha Beach Sand Using 2% and 3% Bentonite Content with Varying Percentages of Water

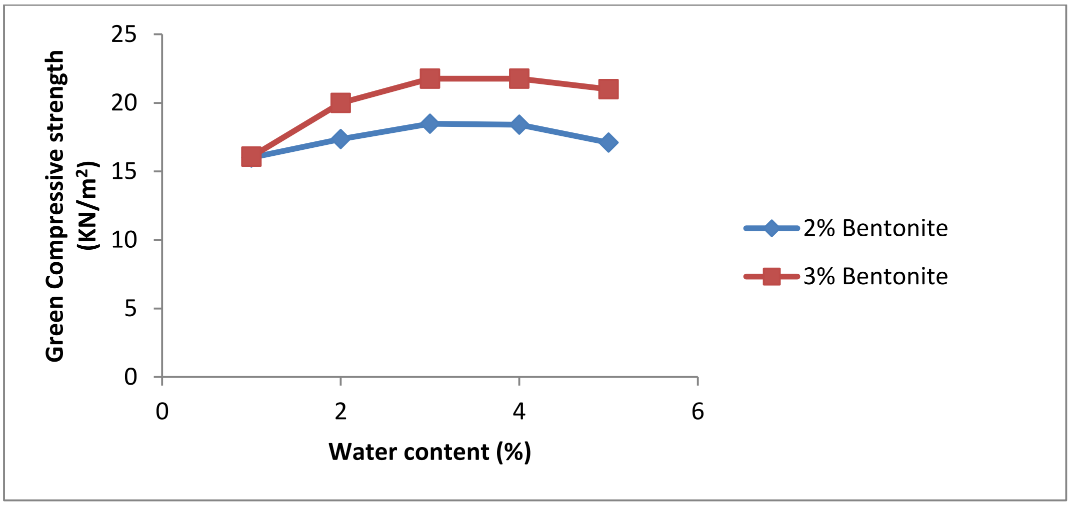


Fig 4.8: Effect of water content on the green compressive strength at 2%, 3%, bentonite content

The values of green compressive strength increased with increase in percentage water content upto a certain maximum point after which, it decreased as shown in Figure 4.8. Green compressive strength increased steadily from 16.0KN/m^2 at 1% water content, reaching a maximum value of 18.48KN/m^2 at 3% water content after which decreased to 17.10 at 5% water content addition for 2% bentonite content. The maximum value of green compressive strength of 21.76KN/m^{2}was obtained at percentage water content of 4%. Thereafter, it decreased to 21.00KN/m^2 at 5% water content addition for 3% bentonite sample.

The result agreed with work doneg by different researchers on green sand (Chakraborty 1982, Heine 1967).

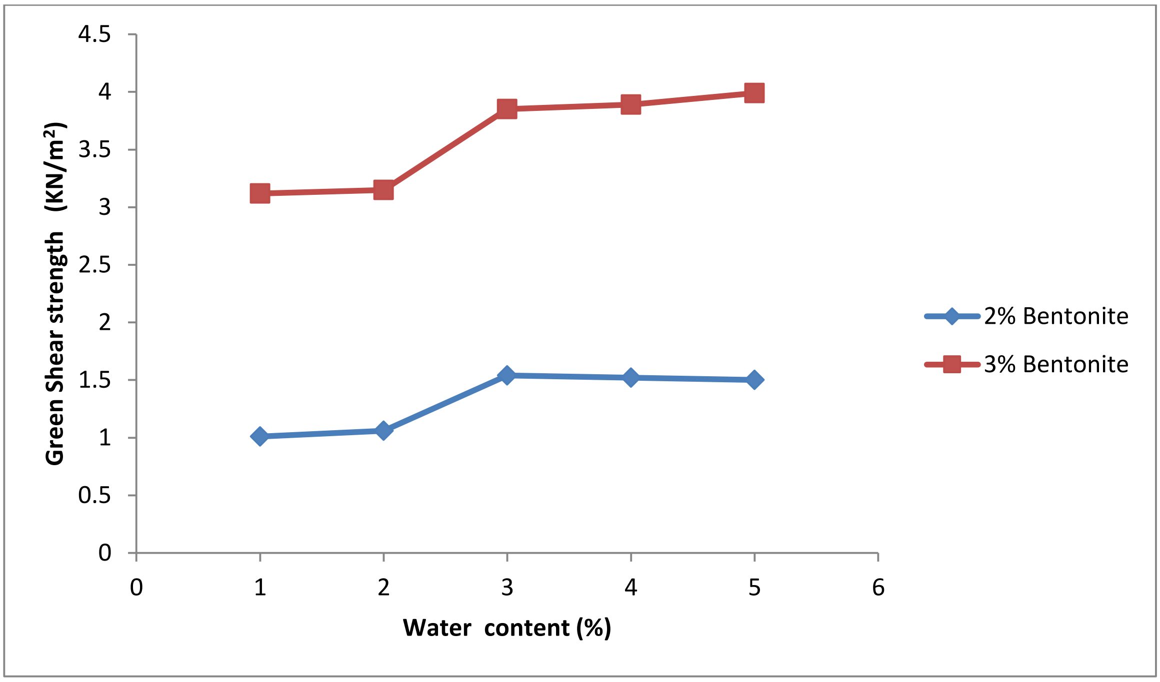


Fig 4.9: Effect of percentage water content on green shear strength at 2%, 3% bentonite content.

Figure 4.9 shows the variation of water content with the values of green compressive strength for both 2% and 3% bentonite. It was observed that when mixed with 1% water content, the dry shear strengths were 1.0KN/m^2 and 3.12KN/m^2 respectively for 2% bentonite and 3% bentonite. These values increased to 1.50KN/m^2 and 3.99KN/m^2 at 5% water addition respectively for 2% and 3% bentonite samples

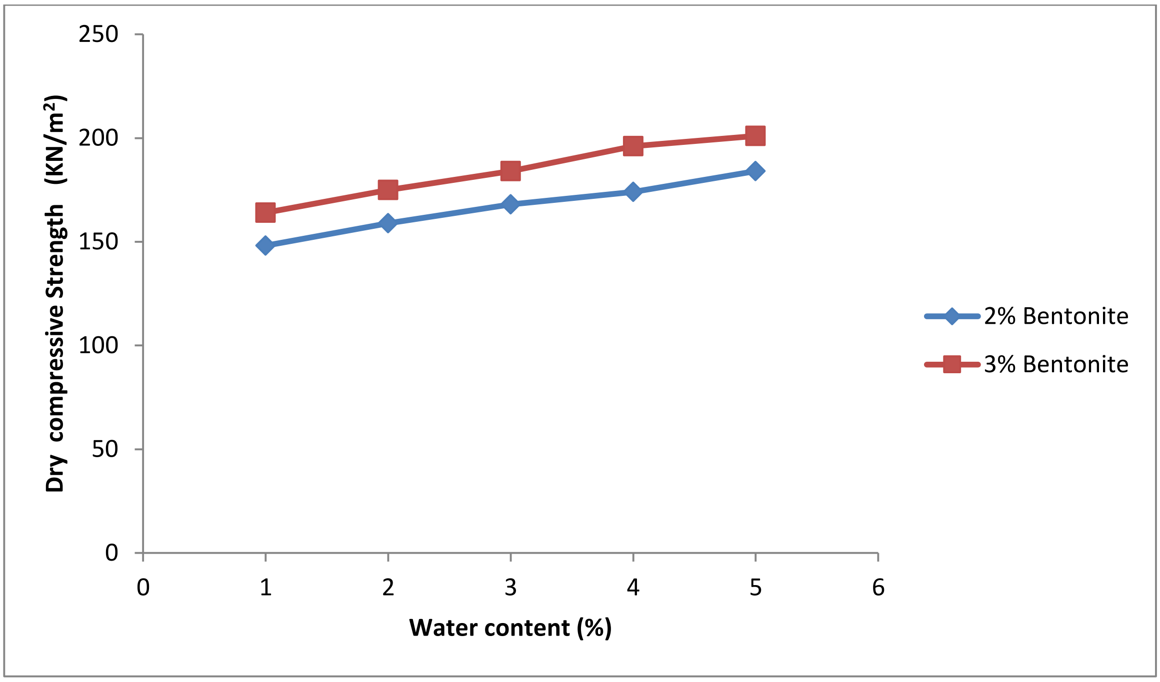


Fig. 4.10: Effects of dry compressive strength on varying percentages of water content at constant 2%, 3% bentonite content.

The variation of water content with the values of dry compressive strength of the moulding sand obtained using constant 2% and 3% bentonite content is shown in Figure 4.10. It was observed that the dry compressive strength increased with increase in water content for both binders with 3% bentonite sample having higher values at all levels as shown in Figure 4.10. When mixed with 1% water the dry compressive strength were 148.20 KN/m^2 and 164.08 KN/m^2 respectively for 2% bentonite and 3% bentonite samples. These values increased to 184.00KN/m^2 and 201.00KN/m^2 at 5% water content addition respectively for 2% bentonite and 3% bentonite content. The dry compressive strength of 2% bentonite and 3% bentonite content are 184.00KN/m^2 and 201.00KN/m^{2}at the maximum point of 5% water content, and these corresponded with 4.10% and 4.00% moisture content (Tables 4.19b and 4.19c). This trend is seen in the literature (Heine, 1967 and Ihom 2006). It should be noted that although the green compressive strength were reduced after 3.50% and 3.20% moisture content for 2% and 3% moisture content respectively, the dry compressive strength kept increasing as the water content increased. It therefore means that if higher dry compressive strength is required with the natural sand, then higher moisture contents of above 3.50% and 3.20% will be needed.

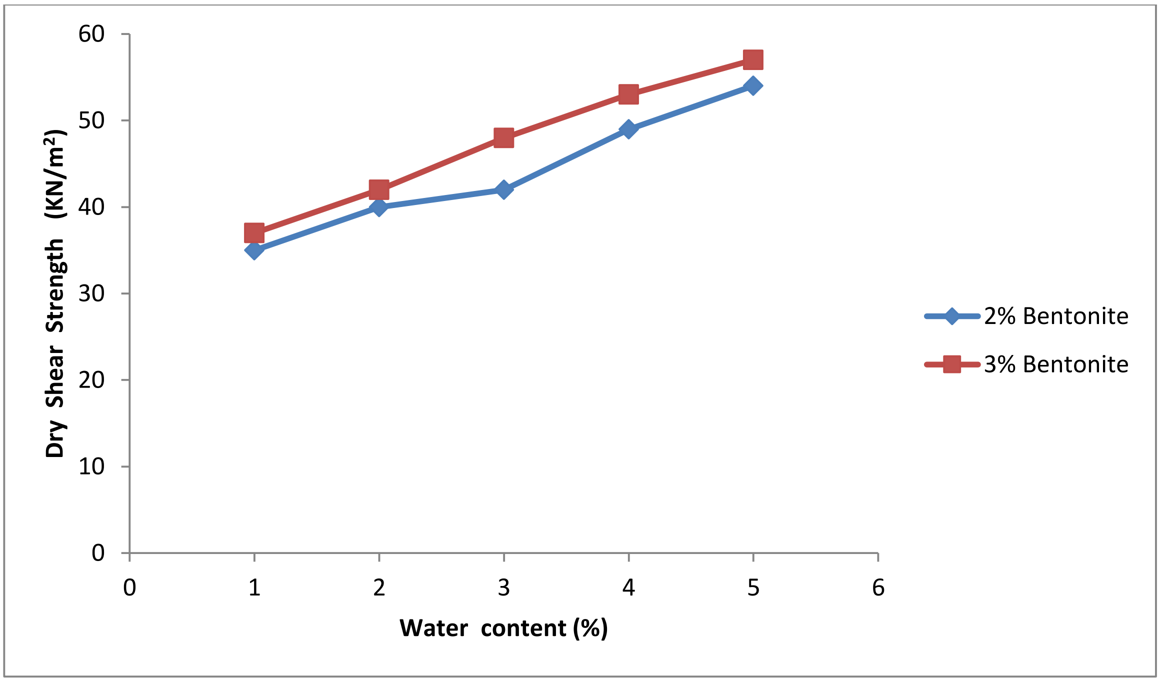


Fig 4.11: Effect of water content on dry shear strength at 2%, 3% bentonite content.

The variation of dry shear strength with water content is presented in Figure 4.11. From the Figure, 3% bentonite sample recorded higher values of 57.00KN/m^2 at 5% water content compared to 54.00KN/m^2 recorded for 2% bentonite sample at the same 5% water content. The 3% bentonite sample showed a higher value of dry shear strength than the 2% bentonite sample.

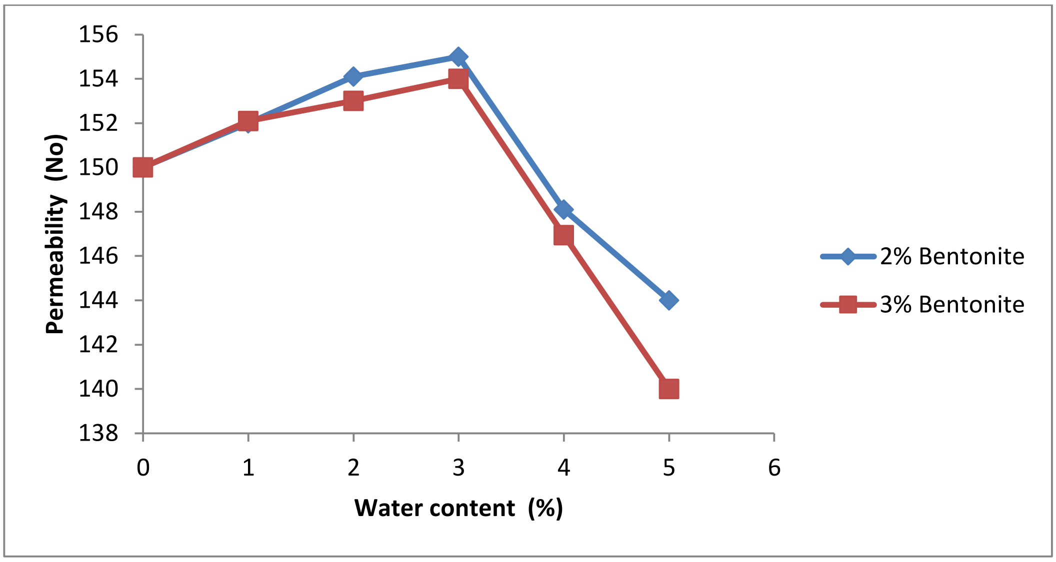


Fig. 4.12: Effect of Permeability on added water content at 2%, 3% bentonite content.

Figure 4.12 shows the effect of varying percentages of water content at 2%, 3% bentonite sample on the permeability of the moulded River Niger Onitsha beach sand. From the Figure, it was observed that the water content introduced increased as the permeability of the River Niger Onitsha silica sand increased, upto a certain maximum value and after which decreased. For 3% bentonite sample, the permeability values increased from 150.00 (No) at 0% water content to 154.00 (No) at 3% water content, after which decreased from 154.00 (No) at 3% water content to 140.00 (No) at 5% water content addition. For 2% bentonite sample, the permeability values increased from 150.00 (No) at 0% water content to 155.00 (No) at 3% water content addition, after which decreased from 155.00 (No) at 3% water content to 140.00 (No) at 5% water content addition. The 2% bentonite sample showed a higher value of permeability (No), than the 3% bentonite sample by 4.00 (No).

This trend is seen in some of the work reviewed by Roumidman, (2009) and Chakraborty (1982). According to Rundman, the permeability increases in a nearly linear manner due to the swelling action of the clay particles, thereby pushing the sand particles further apart and making more room for air passages.

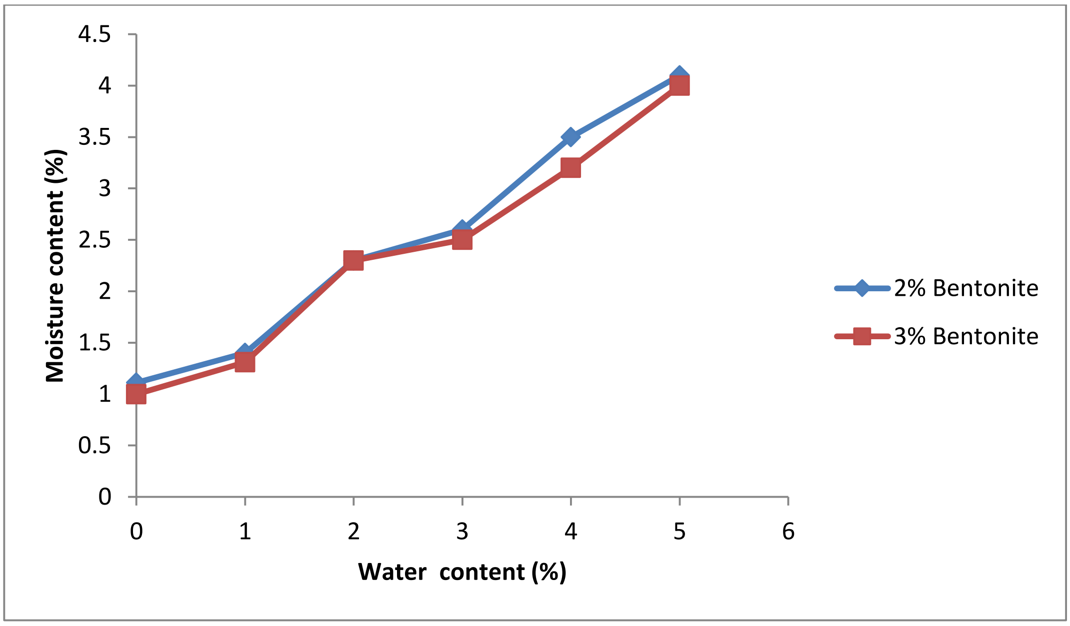


Fig 4.13: Effect of water content on moisture content at 2%, 3% bentonite sample

Figure 4.13 illustrates the effect of moisture content on the varying percentages of water content addition and constant 2%, 3% bentonite contents. It was revealed that the percentage moisture content increased with increase in water content addition. For 2% and 3% bentonite samples with 2% bentonite sample having higher value of moisture content at 5% water content addition as shown in the Figure 4.13. When blended with 5% water content, the moisture content were 4.10% and 4.0 respectively for 2% and 3% bentonite samples. This is consistent with the observations by Ahem and Nuhu (2008) stating that the initial water added to a sand mix is absorbed by the binder till saturation. After water saturation of the sand mix is attained, any more added water is held up as free water thereby accounting for the continuous increase in moisture content observed in the Figure 4.13.

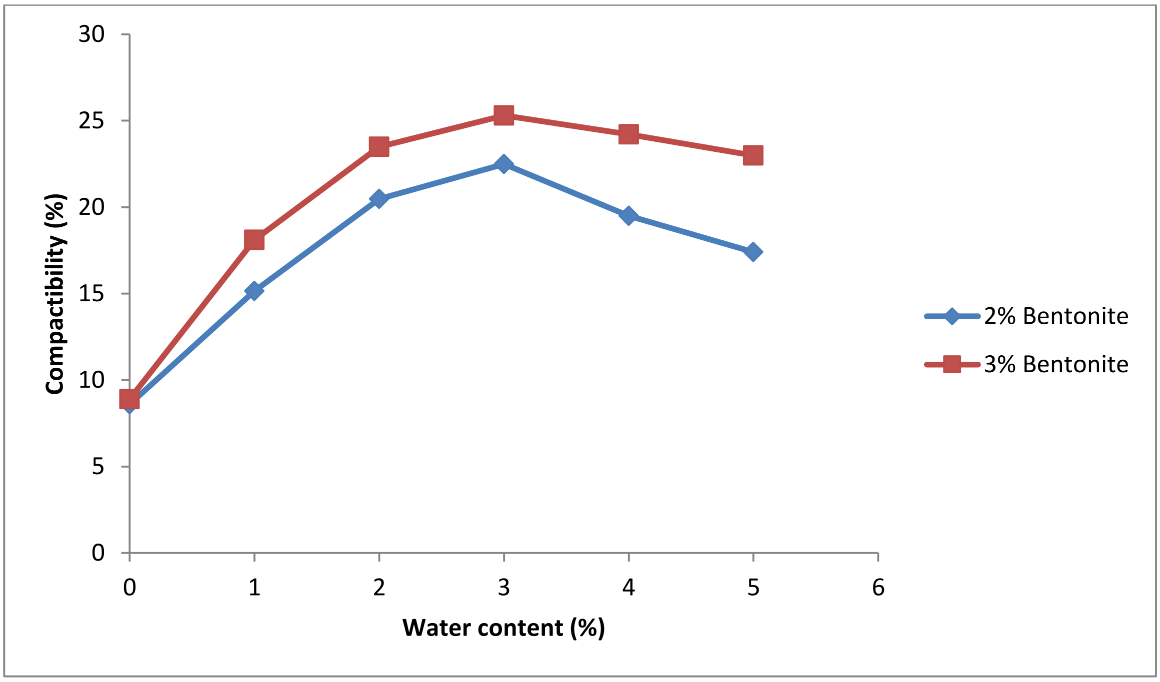


Fig. 4.14 Effect of compactibility on added water content at 2%, 3% bentonite content.

From the Figure 4.14, it was revealed that the compactibility values increased as the percentage water content introduced increased upto a certain maximum value after which, the compactibility values decreased. For 2% bentonite sample, the compactibility values increased from 8.60% at 0% water content to 22.50% at 3% water content addition, after which decreased from 22.50% at 3% water content to 17.40% at 5% water content. For 3% bentonite sample, the compactibility values increased from 8.90% at 0% water content to 24.21 at 4% water content. Thereafter, it decreased from 24.21% at 4% water content to 23.0% at 5% water content addition.

4.6 Comparison of Foundry Properties Result of River Niger Onitsha Beach Sand using 4% and 5% Bentonite Content and Varying Percentages of Water

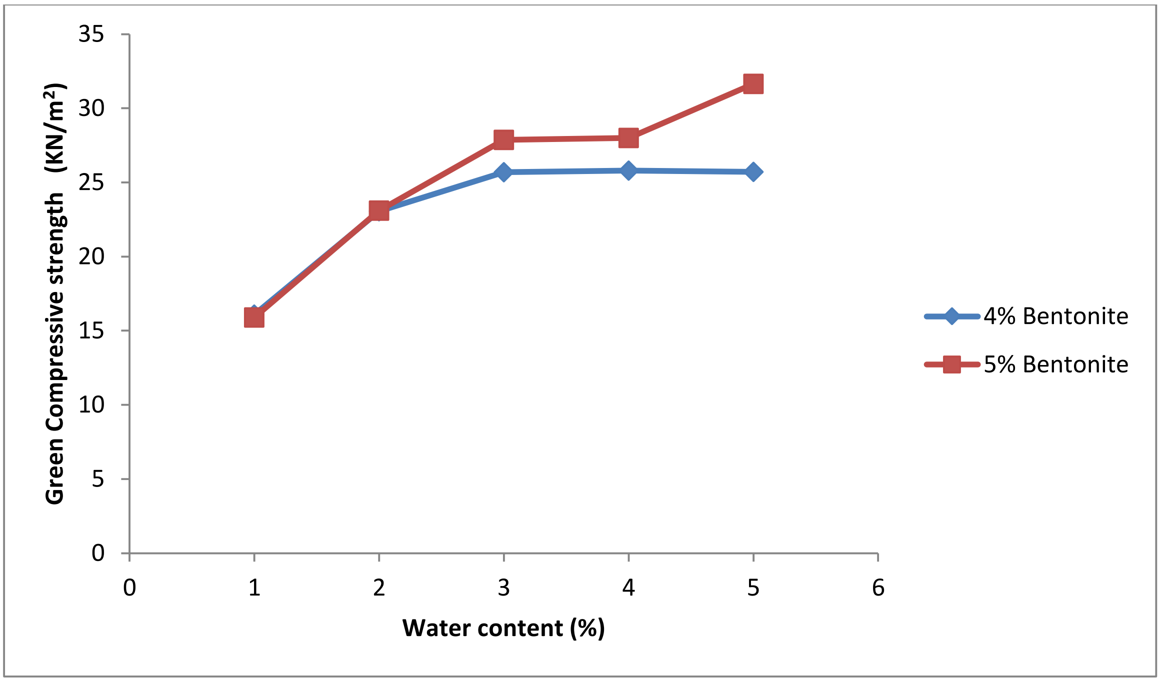


Fig. 4.15 Effect of green compressive strength on varying percentages of water content at 4%, 5% bentonite content.

It was observed from the Figure 4.15 that the green compressive strength increased upto a certain maximum value and then decreased as the water content introduced increased. For 4% bentonite sample, the green compressive strength increased from 16.08KN/m^2 at 1% water content to 25.80KN/m^2 at 4% water content, after which decreased to 25.72KN/m^2 at 5% water content. For 5% bentonite sample, the green compressive strength increased from 15.90KN/m^2 at 1% water content to 31.65KN/m^2 at 5% water content addition.

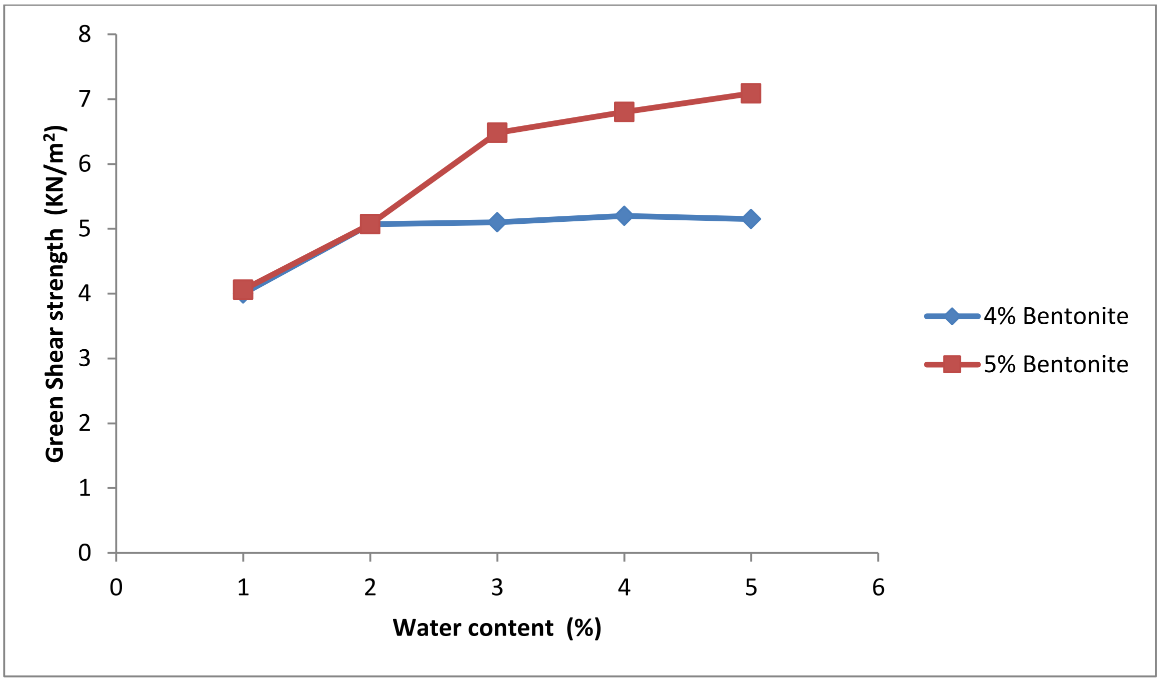


Fig. 4.16 Effect of green shear strength on water content at 4%, 5% bentonite samples.

It was observed that green shear strength increased as the percentage water content introduced increased upto a certain maximum point, after which decreased. For 4% bentonite sample, the green compressive strength increased from 4.00KN/m^2 at 1% water content, upto a certain maximum value of 5.20KN/m^2 at 4% water content, after which decreased from 5.20KN/m^2 at 4% water to 5.15KN/m^2 at 5% water content. For 5% bentonite content, the green compressive strength increased from 4.06KN/m^2 at 1% water content addition to 7.09KN/m^2 at 5% water content addition. The 5% bentonite sample showed a higher value of green shear strength than 4% bentonite sample by 1.94KN/m^2.

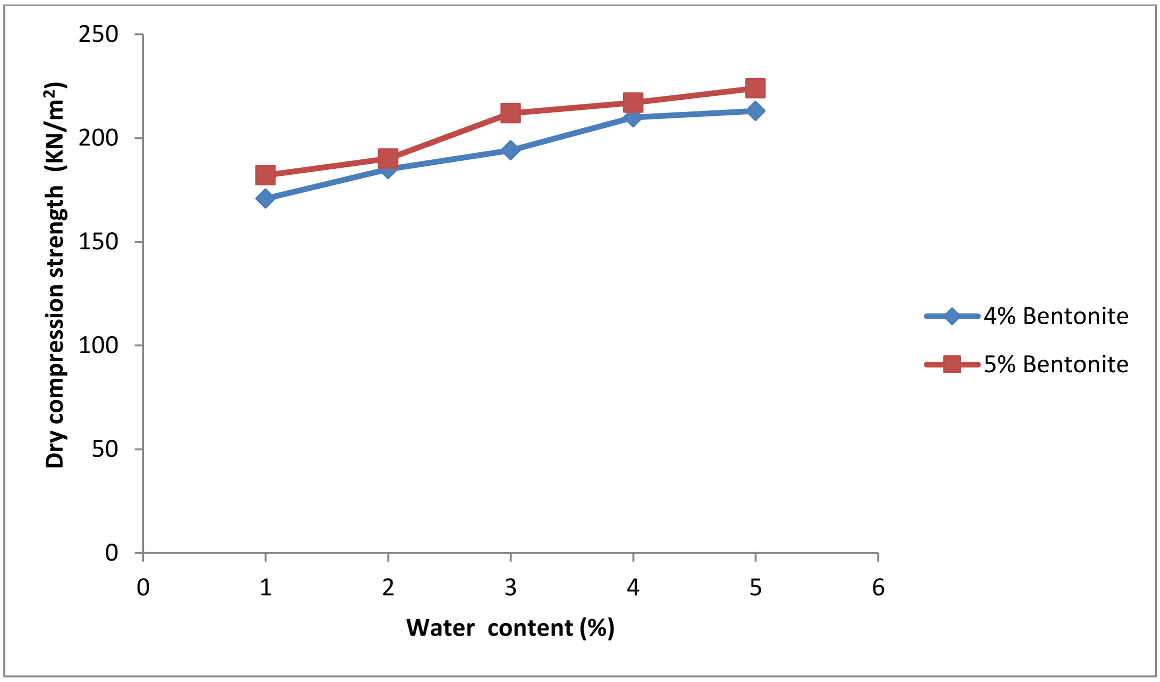


Fig 4.17 Effect of dry compressive strength on varying percentage of water content at 4%, 5% bentonite.

It was observed from the Figure 4.17, that the dry compressive strength increased as the water content introduced increased. For 4% bentonite content, the dry compressive strength increased from 170.75KN/m^2 at 1% water content to 213.00 KN/m^2 at 5% water content. For 5% bentonite content, the dry compressive strength increased from 182.00KN/m^2 at 1% water content to 224.00KN/m^2 at 5% water content addition. This increase indicated that the sand can absorb more moisture. This also indicated that with 4% - 5% bentonite sample and 3%-5% water content, the sand in dry condition can withstand the pressure intensity of 200KN/m^2 of the molten metal during the period of solidification in the mould once the moulding water is at the maximum condition. The values obtained using 4% and 5% bentonite samples were in agreement with the American Foundrymen Society Standard (AFS) (1966), shown in Table 4.21a in the appendix.

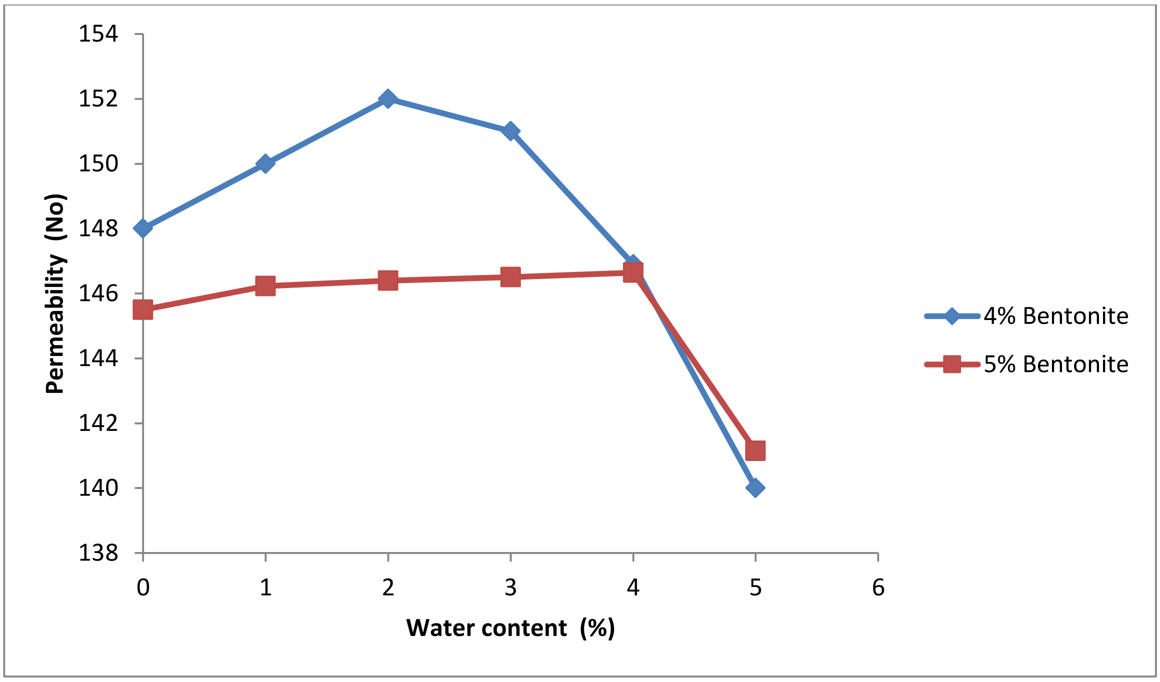


Fig 4.18 Effect of permeability on water content at 4%, 5% bentonite content

From the Figure 4.18, it was observed that the permeability values increased upto a certain maximum value, after which increased as the water content introduced increased. For 4% bentonite sample, the permeability values increased from 148.00 (No) at 0% water content to 152.00 (No) at 2% water content, after which decreased from 152.00 (No) at 2% water content to 140.00 (No) at 5% water content. For 5% bentonite sample, the permeability values increased from 145.50 (No) at 0% water content to 146.64 (No) at 4% water content, after which decreased from 146.64 (No) at 4% water content to 141.15 (No) at 5% water content.

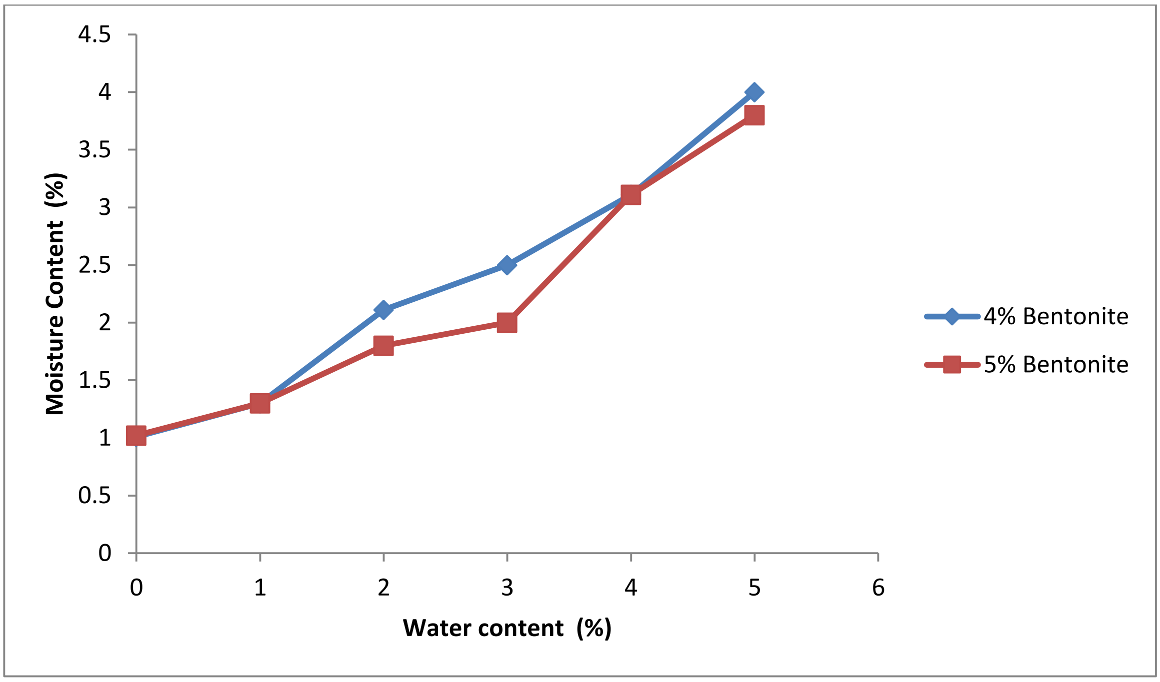


Fig 4.19 Effect of moisture content on added water content at 4%, 5% bentonite content.

Figure 4.19 represents the effect of varying percentages of water content and constant 4%, 5% bentonite samples on the moisture content of the moulded River Niger Onitsha beach sand. It was observed that as the added water content introduced increased, the moisture content also increased. For 4% bentonite sample, the moisture content increased from 1.01% at 0% water content to 4.0% at 5% water content addition. For 5% bentonite sample, the moisture content increased from 1.02% at 0% water content to 3.80% at 5% water content. The 4% bentonite sample showed a higher value of moisture content, than 5% bentonite sample by 0.2%.

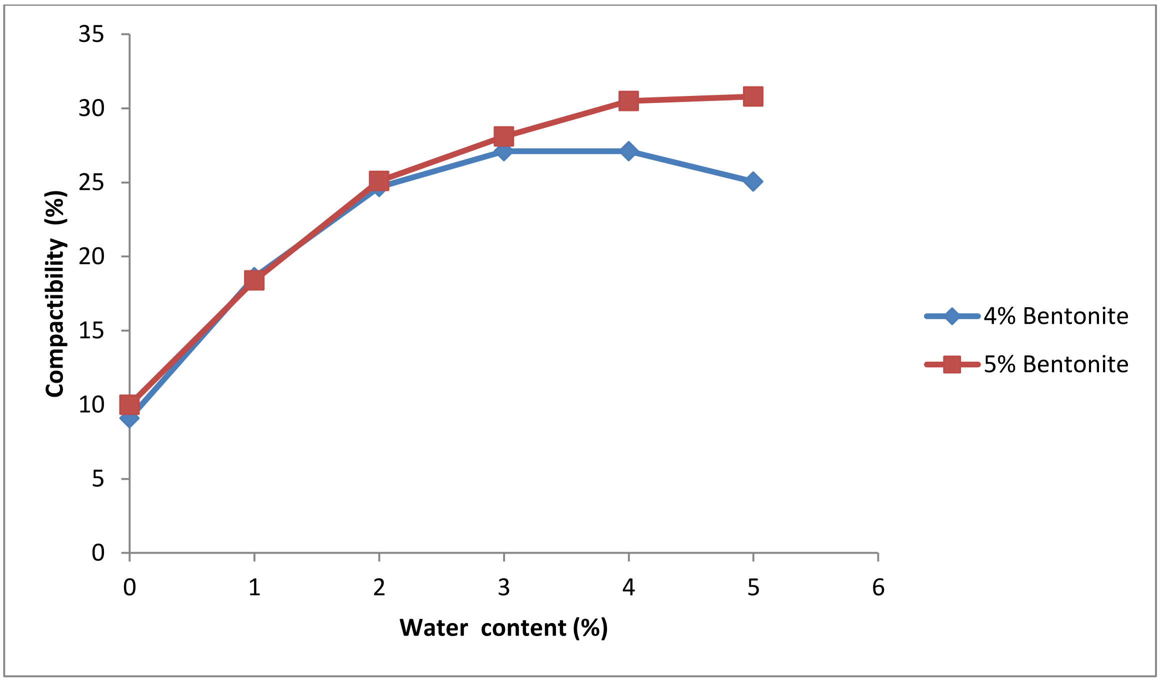


Fig 4.20 Effect of compactibility on water content at 4%, 5% bentonite content

The variation of water content with the values of the compactibility obtained using 4% and 5% bentonite sample is shown in the Figure 4.20. The compactibility values increased as the percentage water content introduced increased. For 4% bentonite sample, the compactibility values increased from 9.10% at 0% water content to 27.10% at 4% water content addition, after which decreased to 25.05% at 5% water content. For 5% bentonite sample, the compactibility values increased from 10% at 0% water content to 30.80% at 5% water content addition.

4.7 Comparison of Foundry Properties Results of River Niger Onitsha Beach Sand Using 2% and 3% Ukpor Clay Content and Varying Percentages of Water

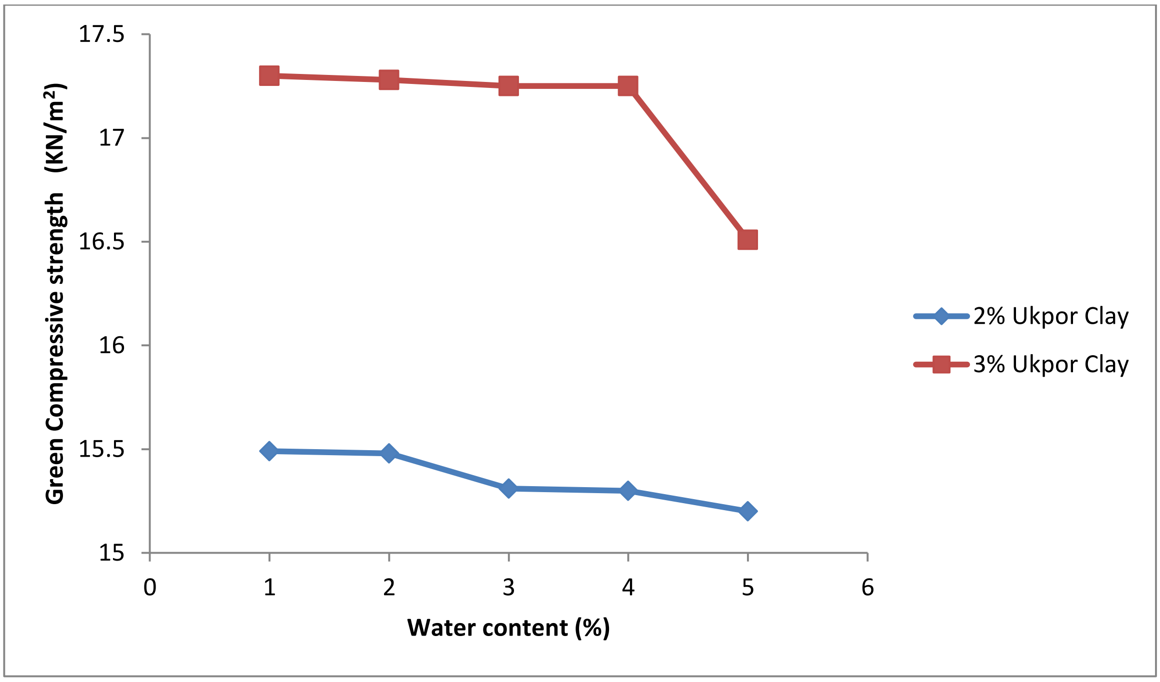


Fig. 4.21 Effect of green compressive strength on water content at 2%, 3% Ukpor clay content.

Figure 4.21 shows the results of green compressive strength of River Niger Onitsha beach sand with varying percentages of water content. It was observed that the green compressive strength decreased as the percentage water content introduced increased for both samples. For 2% Ukpor clay sample, the green compressive strength decreased from 15.49KN/m^2 at 1% water content introduced to 15.20KN/m^2 at 5% water content. For 3% Ukpor clay content, the green compressive strength decreased from 17.30KN/m^2 at 1% water content to 16.51KN/m^2 at 5% water content addition.

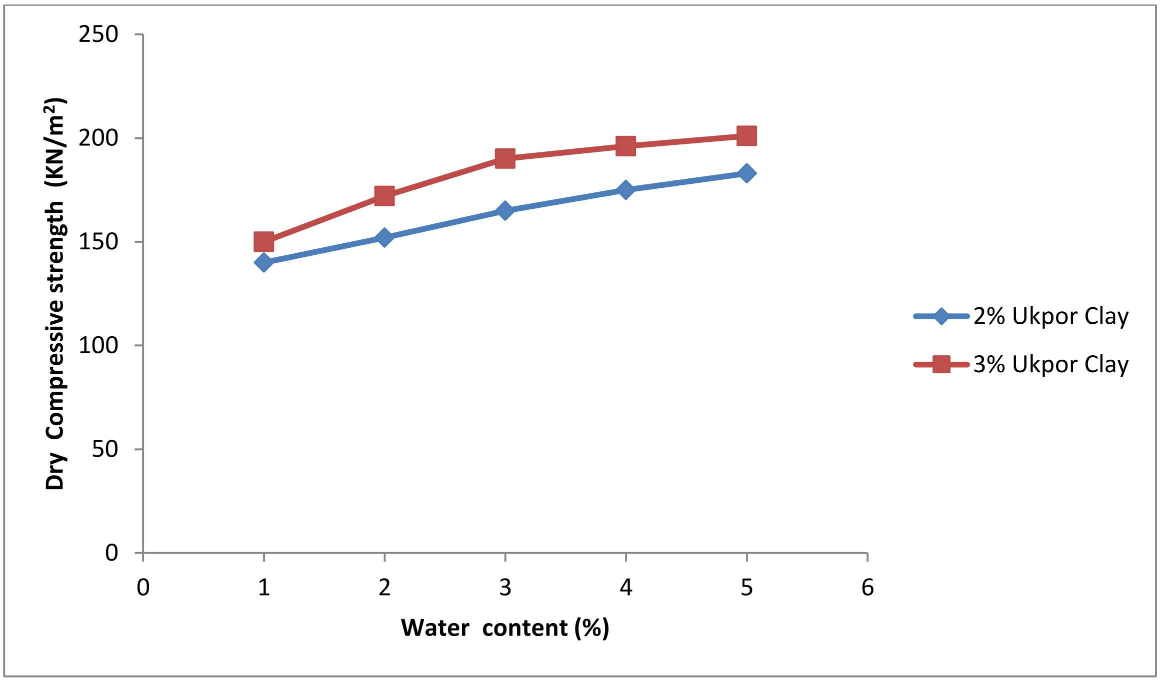


Fig. 4.22 Effect of dry compressive strength on water content at 2%, 3% Ukpor clay content

Figure 4.22 shows the variation of water content with the values of dry compressive strength. It was observed that the dry compressive strength of River Niger Onitsha beach sand increased with increase in percentage water content addition. For 2% Ukpor clay sample, the dry compressive strength increased from 140.00KN/m^2 at 1% water content to 183.00KN/m^2 at 5% water content. For 3% Ukpor clay content, the dry compressive strength increased from 150.00KN/m^2 at 1% water content to 201.00KN/m^2 at 5% water content addition.

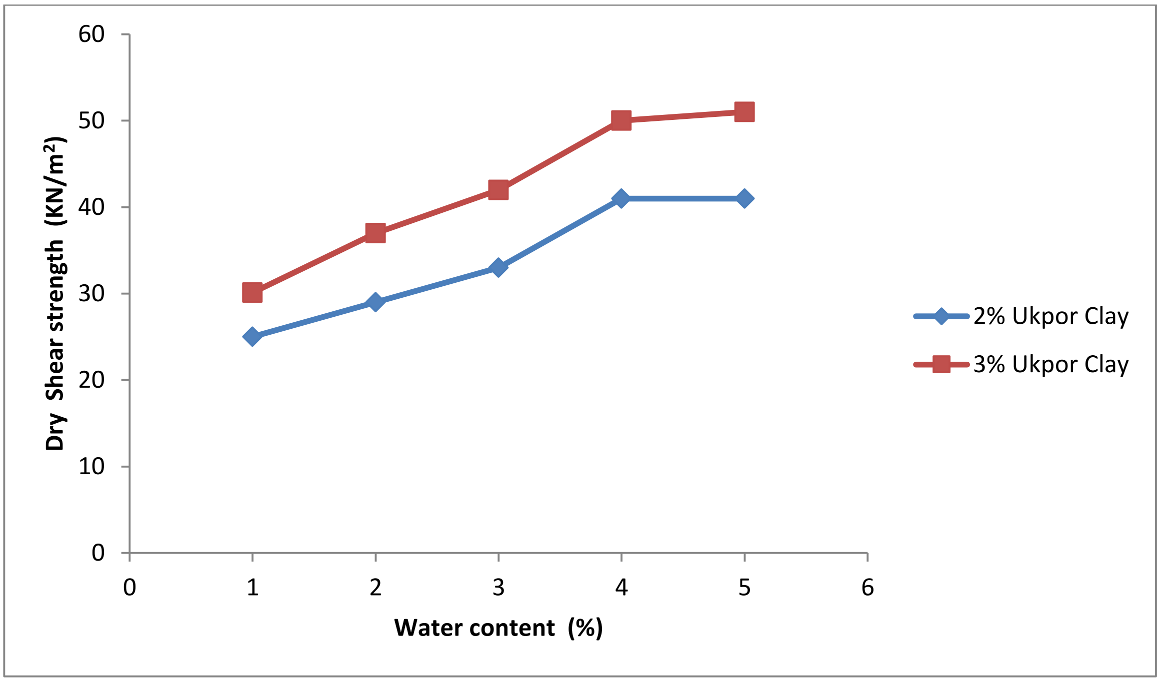


Fig. 4.23 Effect of dry shear strength on water content at 2%, 3% Ukpor clay sample.

From the Figure 4.23, it was observed that the dry shear strength increased as the percentage water content introduced increased. For 2% Ukpor clay sample, the dry shear strength increased from 25.00KN/m^2 at 1% water content to 41.00KN/m^2 at 5% water content. For 3% Ukpor clay content, the dry shear increased from 30.10KN/m^2 at 1% water content to 51.00KN/m^2 at 5% water content addition.

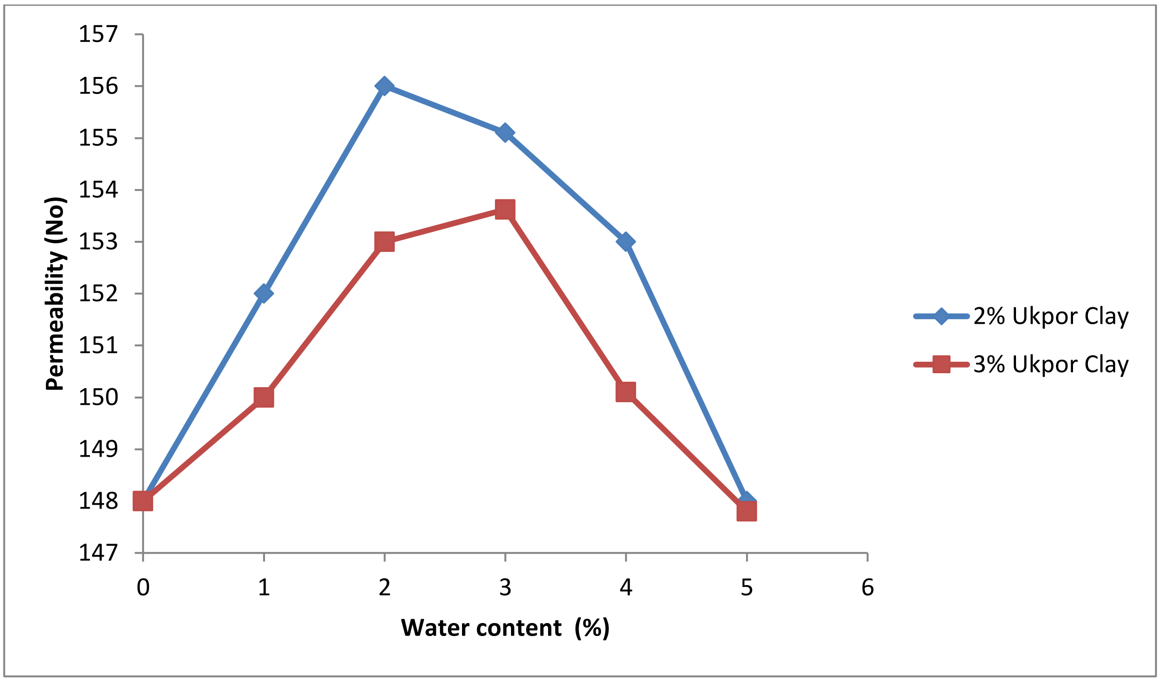


Fig 4.24 Effect of permeability on water content at 2%, 3% Ukpor clay sample.

It was observed from the Figure 4.24, that the permeability values increased as the percentage water content introduced increased, upto a certain maximum level, after which decreased. For 2% Ukpor clay content, the permeability values increased from 148.00KN/m^2 at 0% water content to 156.00KN/m^2 at 2% water content, after which decreased from 156.00KN/m^2 at 2% water content to 148.00KN/m^2 at 5% water content. For 3% Ukpor clay sample, the permeability values increased from 148.00 (No) at 0% water content to 153.62 (No) at 3% water content addition, after which decreased from 153.62 (No) at 3% water content to 147.80 (No) at 5% water content addition.

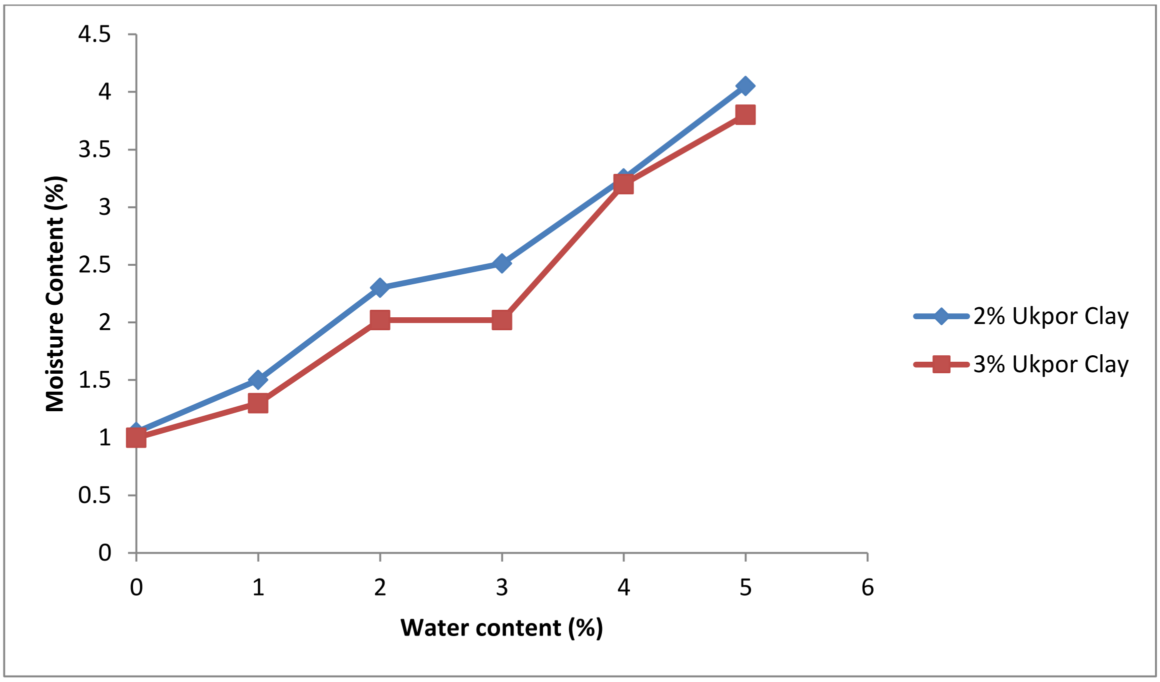


Fig. 4.25 Effect of moisture content on water content at 2%, 3% Ukpor clay saimple.

Figure 4.25 illustrates the variation of percentage water content introduced on moisture content of River Niger Onitsha beach sand. It was observed that the increase in the percentage water content addition corresponded to the increase in the moisture content of the moulded sand for both samples as shown in the Figure 4.25. The 2% Ukpor clay sample recorded higher value of 4.05 at 5% water content addition compared to 3.80% recorded for 3% Ukpor clay sample at the same 5% water content. The 2% Ukpor clay sample showed a higher value in moisture content than the 3% Ukpor clay sample by 0.25%

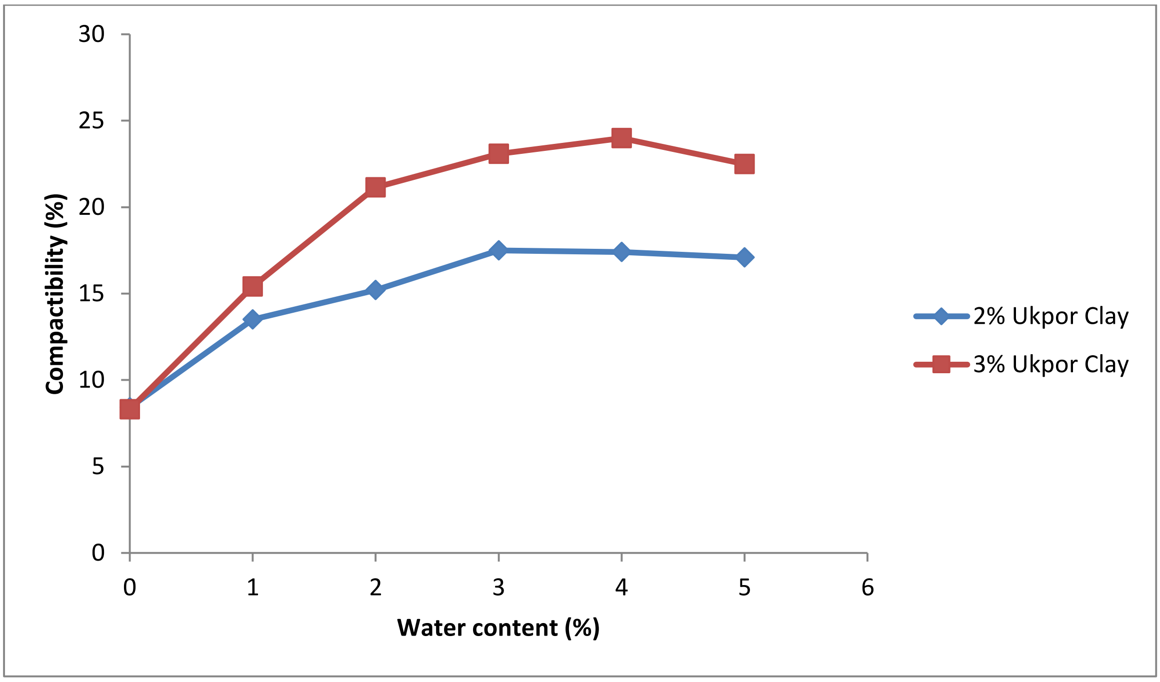


Fig. 4.26 Effect of compactibility on water content at 2%, 3% Ukpor clay sample

Figure 4.26 shows the results of compacbility test with varying percentages of water content for both binders, with 3% Ukpor clay sample having higher values at all level. From the Figure 4.26, it was observed that the compactibility of River Niger Onitsha beach sand increased as the percentage water content introduced increased. For 2% Ukpor clay sample, the compactibility values increased from 8.41% at 0% water content to 17.50% at 3% water content, after which decreased from 17.50% at 3% water content to 17.10% at 5% water content introduced. For 3% Ukpor clay sample, the compactibility increased from 8.30% at 0% water content to 24.00% at 4% water content, after which decreased from 24.00% at 4.0% water content to 22.50% at 5.0% water content.

4.8 Comparison of Foundry Properties Results of River Niger Onitsha Beach Sand Using 4% and 5% Ukpor Clay Content and Varying Percentages of Water

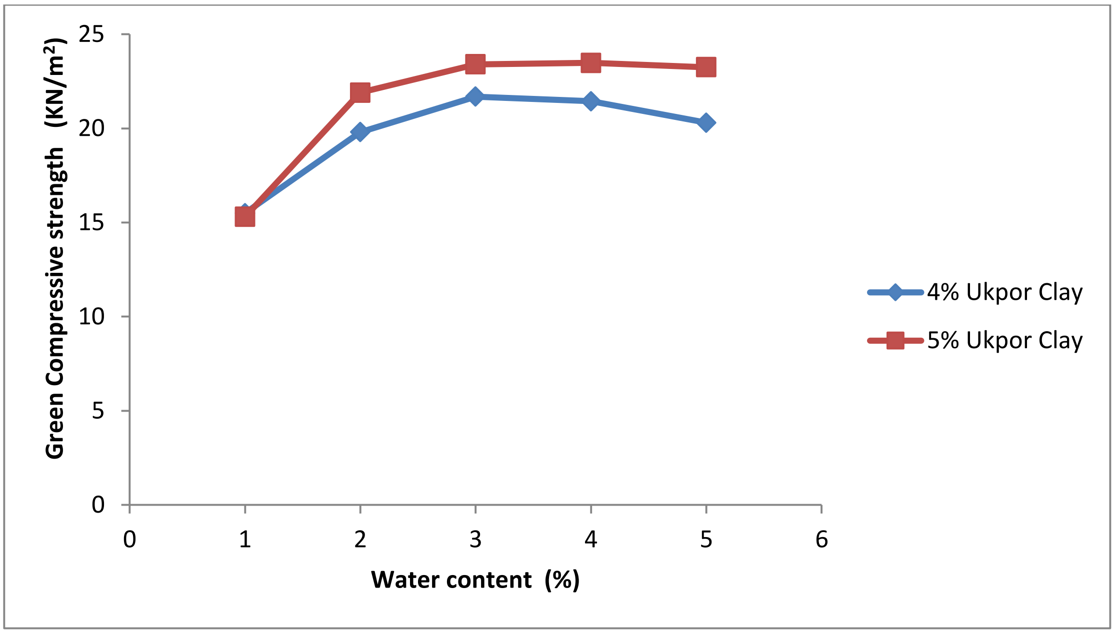


Fig. 4.27 Effect of green compressive strength on water content at 4%, 5% Ukpor clay sample.

Figure 4.27 shows the variation of water content with the values of green compressive strength. It was observed that the green compressive strength increased with increase in percentage water content addition upto a certain maximum value, after which decreased. The green compressive strength increased from 15.50% at 1% water content to 21.69KN/m^2 at 3% water content, after which decreased from 21.69KN/m^2 at 3% water content to 20.30KN/m^2 at 5% water content addition, for 4% Ukpor clay sample. The maximum value of green compressive strength of 23.48KN/m^2 was obtained at the percentage water content of 4%, for 5% Ukpor clay sample. Further increase in the percentage water content addition above 3% and 4% would leads to reduction in the green compressive strength for 4% and 5% Ukpor clay samples respectively. Decline in green compressive strength with increase in water content suggests the presence of excess moisture in the sand mould.

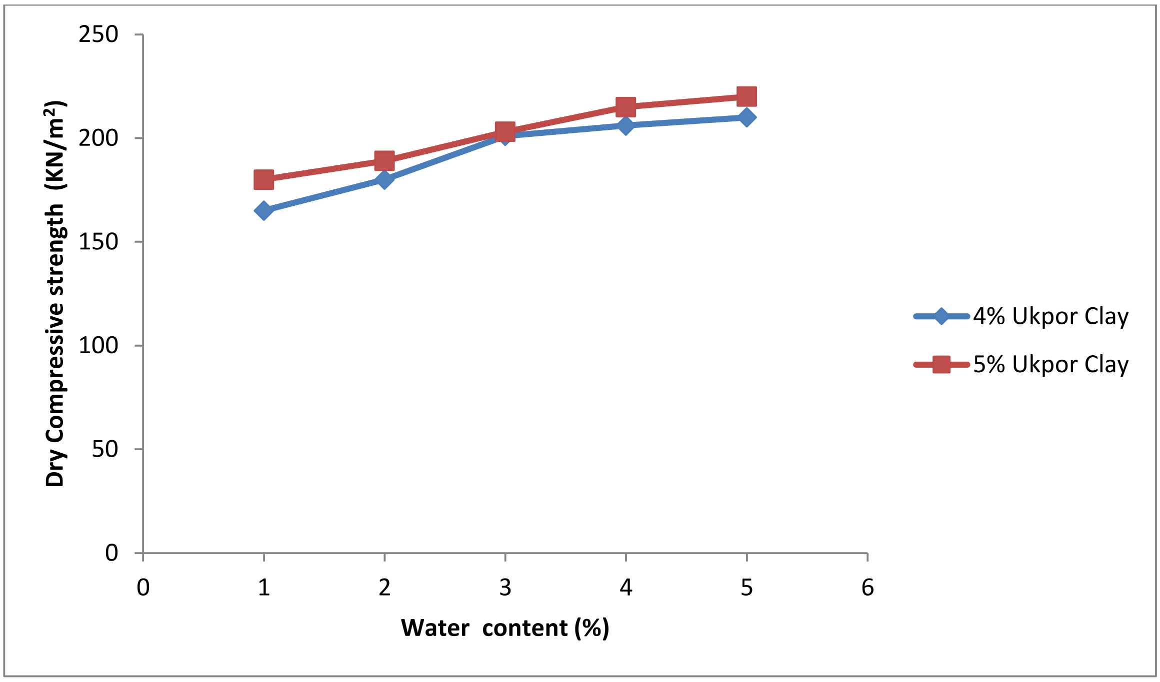


Fig. 4.28 Effect of dry compressive strength on water content at 4%, 5% Ukpor clay sample.

Figure 4.28 represents the effect of varying percentages of water content at constant 4%, 5% Ukpor clay sample, on the dry compressive strength of the moulded River Niger sand deposits. It was observed that as the added water content introduced increased, the dry compressive strength increased. For 5% Ukpor clay sample, the dry compressive strength increased from 165.00KN/m^2 at 1% water content to 210.00KN/m^2 at 5% water content. For 5% Ukpor clay content, the dry compressive strength increased from 150.00KN/m^2 at 1%

water content to 220KN/m^2 at 5% water content introduced. The 5% Ukpor clay sample, showed a higher value of dry compressive strength than 4% Ukpor clay sample by 10.00KN/m^2.

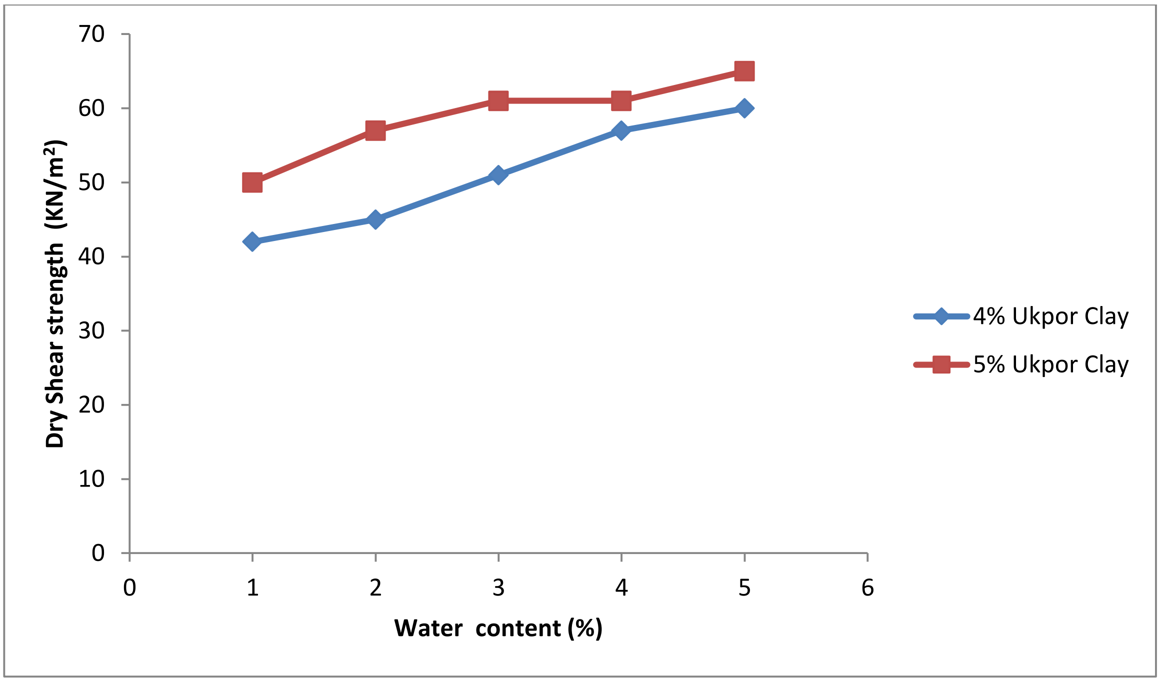


Fig 4.29 Effect of dry shear strength on water content at 4%, 5% Ukpor clay content.

Figure 4.29 illustrates the effect of dry shear strength on varying percentages of water content at constant 4%, 5% Ukpor clay sample. It was observed that for 4% and 5% Ukpor clay sample, the dry shear strength increased as the water content introduced increased. For 4% Ukpor clay sample, the dry shear strength increased from 42.00KN/m^2 at 1% water content to 60.00KN/m^2 at 5% water content. For 5% Ukpor clay sample, the dry shear strength increased from 50.00KN/m^2

at 1% water content to 65KN/m² at 5% water content introduced.

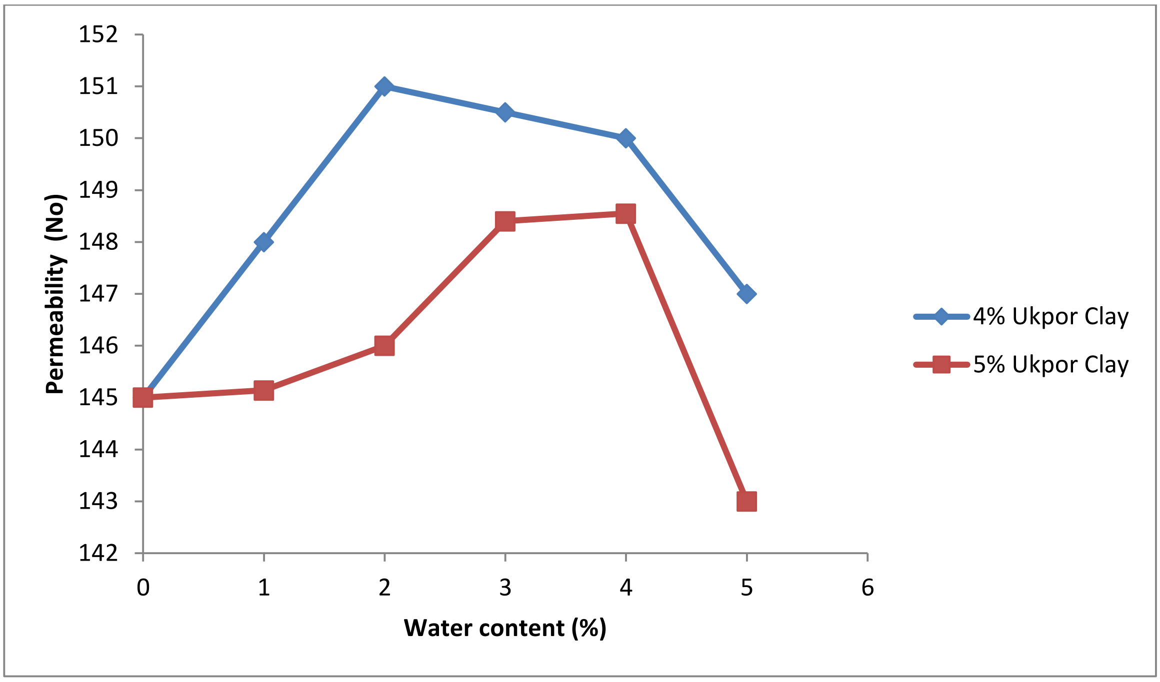


Fig. 4.30 Effect of permeability on water content at 4%, 5% Ukpor clay content.

From the Figure 4.30, it was observed that the permeability increased as the percentage water content introduced increased, upto a certain maximum level, thereafter decreased. For 4% Ukpor clay sample, the permeability increased from 145.00 (No) at 0% water content, to 151.00 (No) at 2% water content, after which decreased from 151.00 (No) at 2% water content to 147.00 (No) at 5% water content, for 5% Ukpor clay sample. For 5% Ukpor clay sample, the permeability values increased from 145.00 (No) at 0% water content, to 148.55 (No) at 4% water content addition, after which decreased from 148.55 (No) at 4% water content to 143.00 (No) at 5% water content addition,

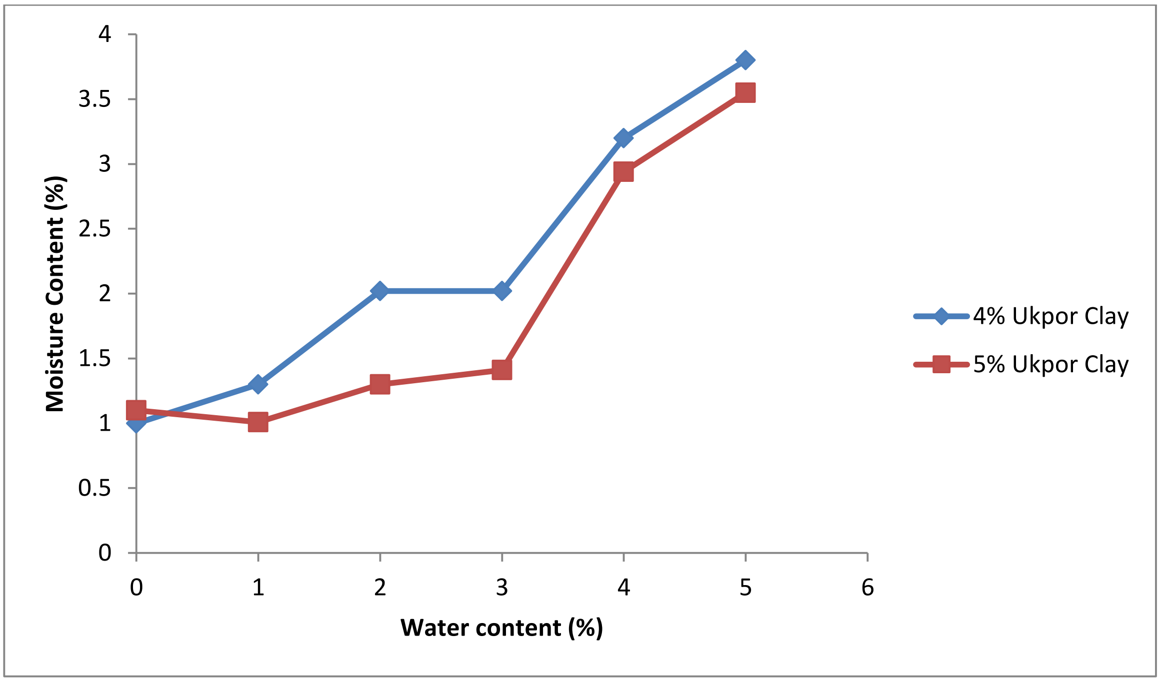


Fig. 4.31 Effect of moisture content on water content at 4%, 5% Ukpor clay sample.

From the Figure 4.31, it was observed that the moisture content increased as the percentages of water content introduced increased. For 4% Ukpor clay sample, the moisture content increased from 1.00% at 0% water content to 3.80% at 5% water content introduced. For 5% Ukpor clay sample, the moisture content increased from 1.10% at 0% water content to 3.55% at 5% water content introduced. This is consistent with the observations of Ahem and Nuhu (2008), stating that the initial water, introduced to a sand mix is absorbed by the binder till saturation. After water saturation of the sand mix is obtained, any more added water is held up as free water thereby accounting for the continuous increase in moisture content observed in the Figure 4.31.

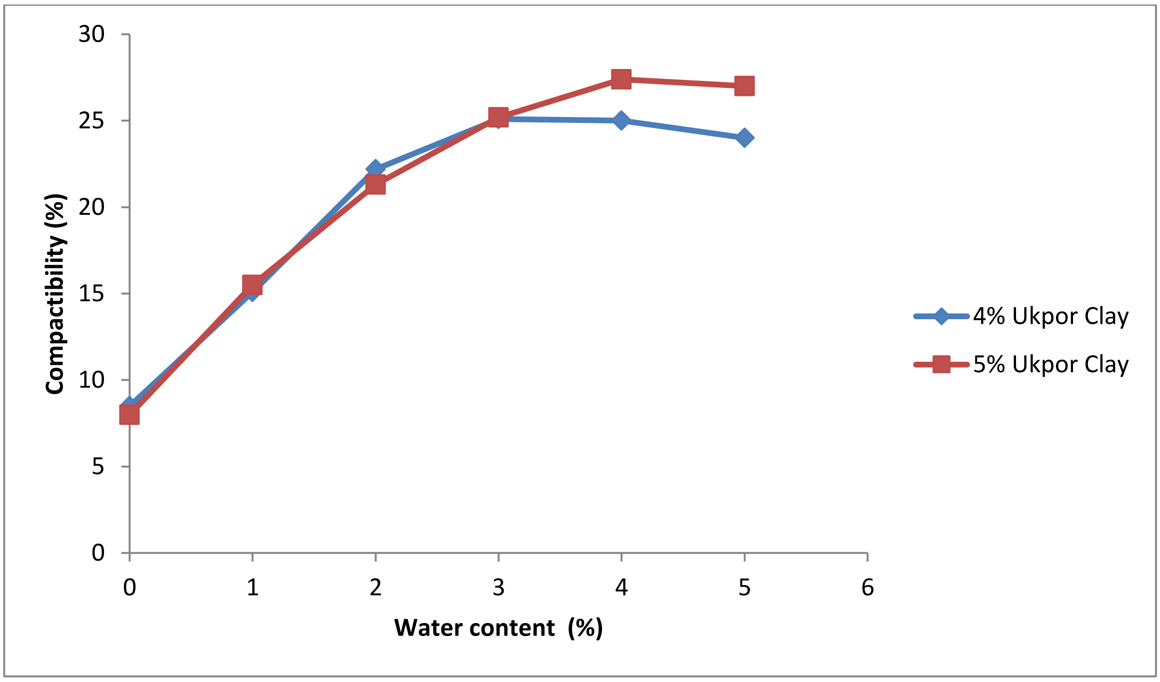


Fig 4.32 Effect of compactibility on water content at 4%, 5% Ukpor clay sample

Figure 4.32 shows the effect of compactibility values on varying percentages of water content at constant 4%, 5% Ukpor clay sample. It was observed that the compactibility values increased as the percentage water content introduced increased, upto a certain maximum level, after which decreased. For 4% Ukpor clay sample, the compactibility increased from 8.50% at 0% water content to 25.10% at 3% water content, after which decreased from 25.10% at 3% water content to 24.01% at 5% water content. For 5% Ukpor clay sample, the compactibility increased from 8.00% at 0% water content to 27.40 at 4% water content introduced. Thereafter, decreased from 27.40 at 4% water content to 27.00% at 5% water content addition.

4.9 Comparison of Foundry Properties Result of River Niger Onitsha Beach Sand Using 2% and 3% Water Content and Varying Percentages of Bentonite Content

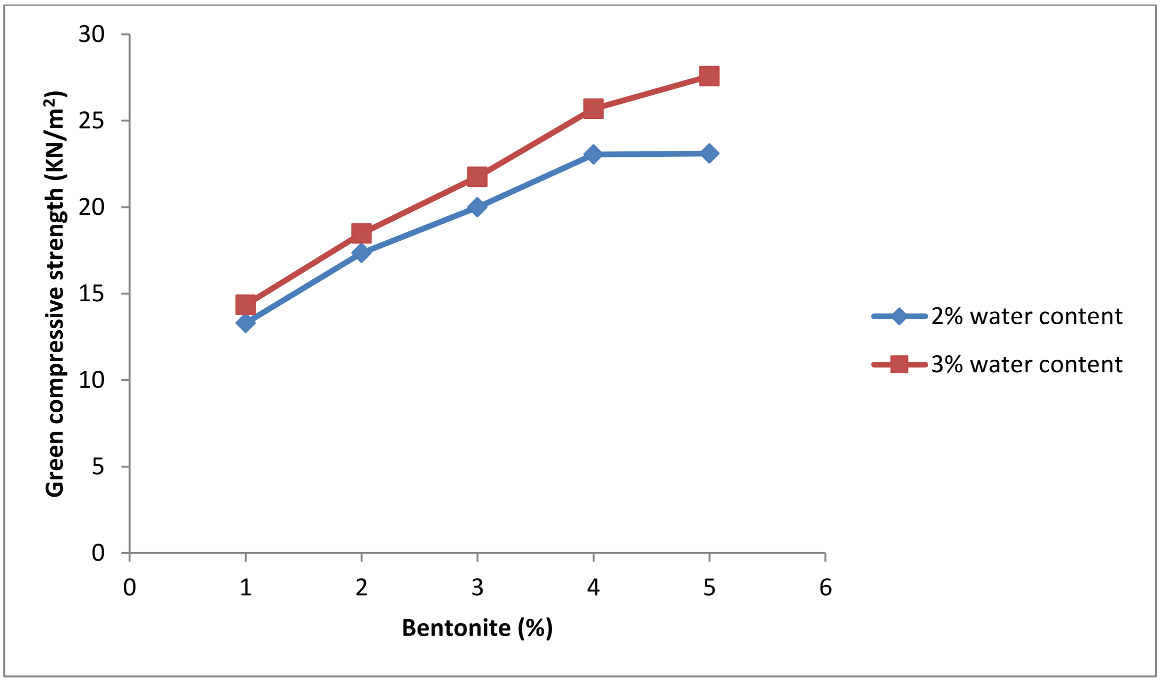


Fig 4.33 Effect of green compressive strength on bentonite content at 2%, 3% water content.

Figure 4.33 illustrates the effect of green compressive strength on varying percentages of bentonite content at 2%, 3% water content. It was observed that the green compressive strength increased as the bentonite content introduced increased.For 2% water content, the green compressive strength increased from 13. 30 KN/ m^2 at 1% bentonite content to 23.10KN/ m^2 at 5% bentonite content. For 3% water content, the green compressive strength increased from 14.35KN/m^2 at 1% bentonite content to 27.58KN/m^2 at 5% bentonite content.

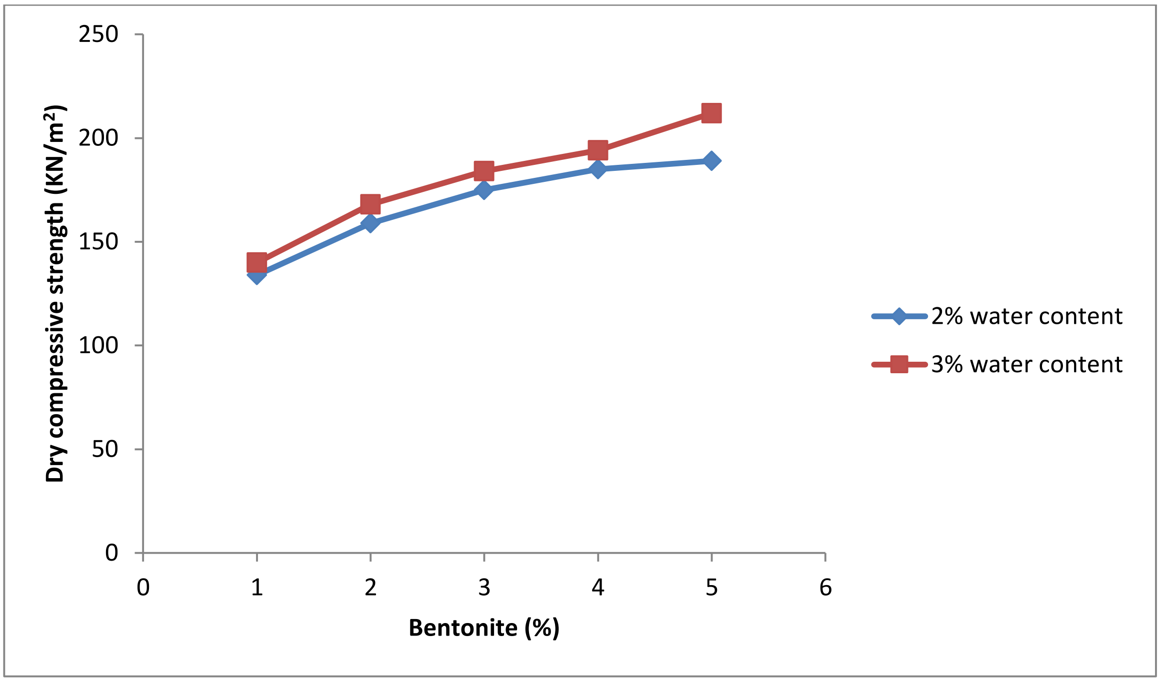


Fig 4.34 The effect of dry compressive strength on bentonite at 2%, 3% water content.

From the Figure 4.34, it was revealed that the dry compressive strength of the River Niger beach sand increased as the bentonite content introduced increased. For both water content, with 3% water sample having a greater value of 23KN/m^2. When mixed with 5% (bentonite), the dry strength values of 189KN/m^2 and 212KN/m^2 were recorded for 2% and 3% water samples, respectively.

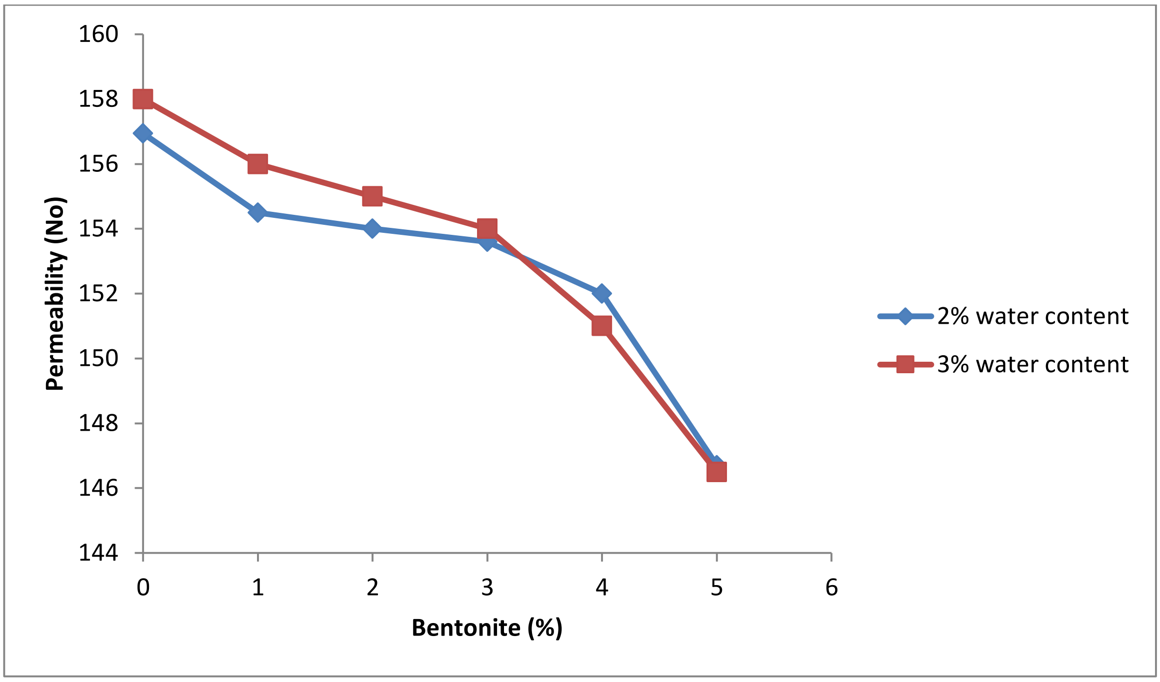


Fig 4.35 Effect of Permeability on bentonite content at 2%, 3% water content.

It was observed that the permeability of the beach sand decreased as the bentonite content introduced increased. For 2% water content sample, the permeability values decreased from 156.94 (No) at 0% water content to 146.70 at 5% bentonite content. For 3% water content, the permeability values decreased from 158.00 (No) at 0% bentonite content to 146.50 No at 5% bentonite content addition.

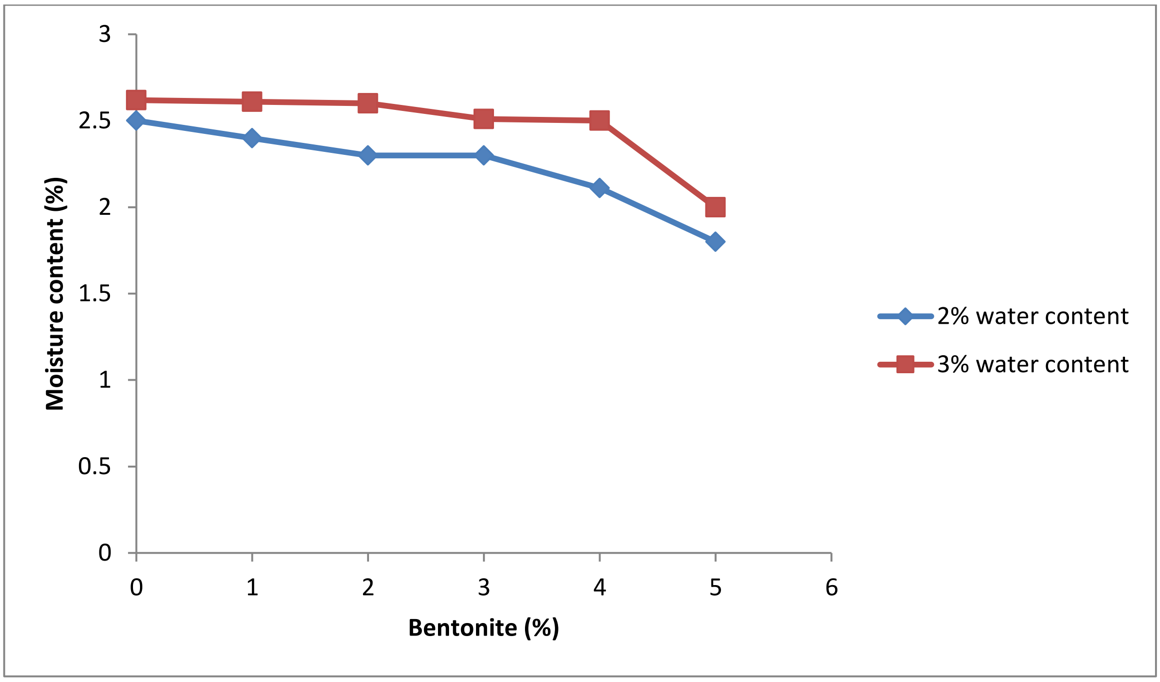


Fig 4.36 Effect of moisture content on bentonite content at 2%, 3% water content.

From the Figure 4.36, it was revealed that the moisture content of the River beach decreased as the bentonite introduced increased. For 2% water content, the moisture content decreased from 2.50% at 0% bentonite content to 1.80% at 5% bentonite content: For 3% water content, the moisture content decreased from 2.62% at 0% bentonite content to 2.0% at 5% bentonite content addition.

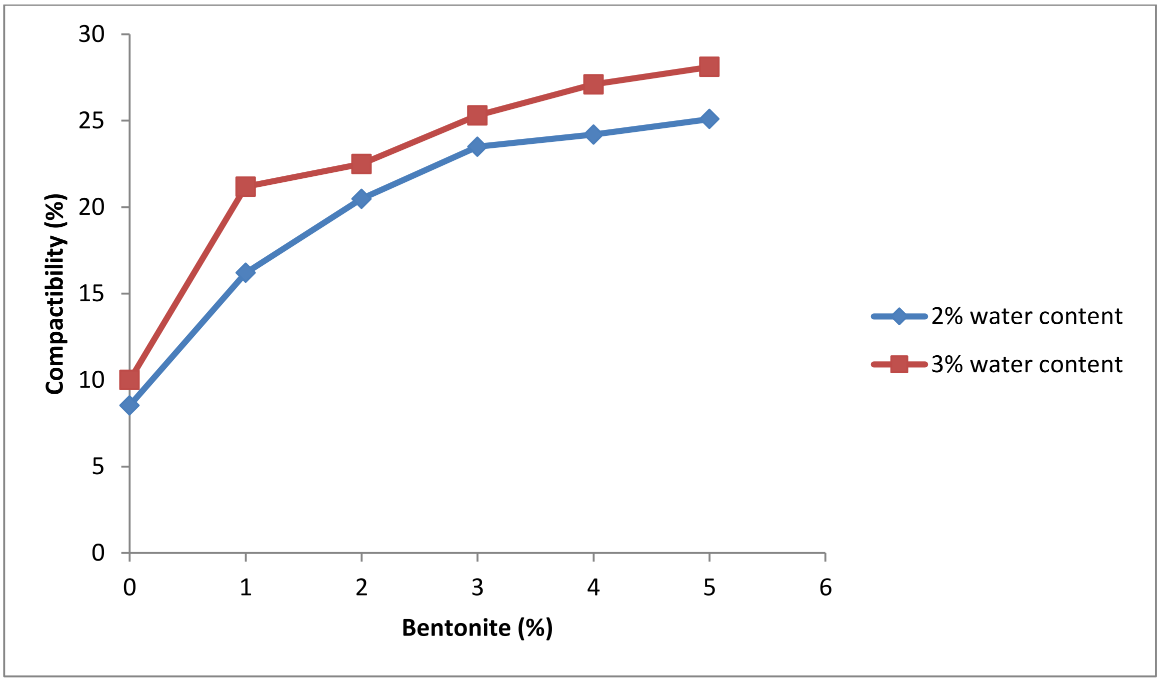


Fig 4.37 Effect of compactibility on bentonite content at 2%, 3% water content.

Figure 4.37 shows the effect of compactibility values on varying percentages of added bentonite content. It was observed that the compactibility of the River Niger beach sand increased as the additive introduced increased, for both 2% and 3% water content samples. When blended with 5% bentonite content, the compactibility values of 25.10% and 28.11% were recorded for 2% water content and 3% water content samples respectively

4.10 Comparison of Foundry Properties Result of River Niger Onitsha Beach Sand Using 4% and 5% Water Content and Varying Percentages of Bentonite Content

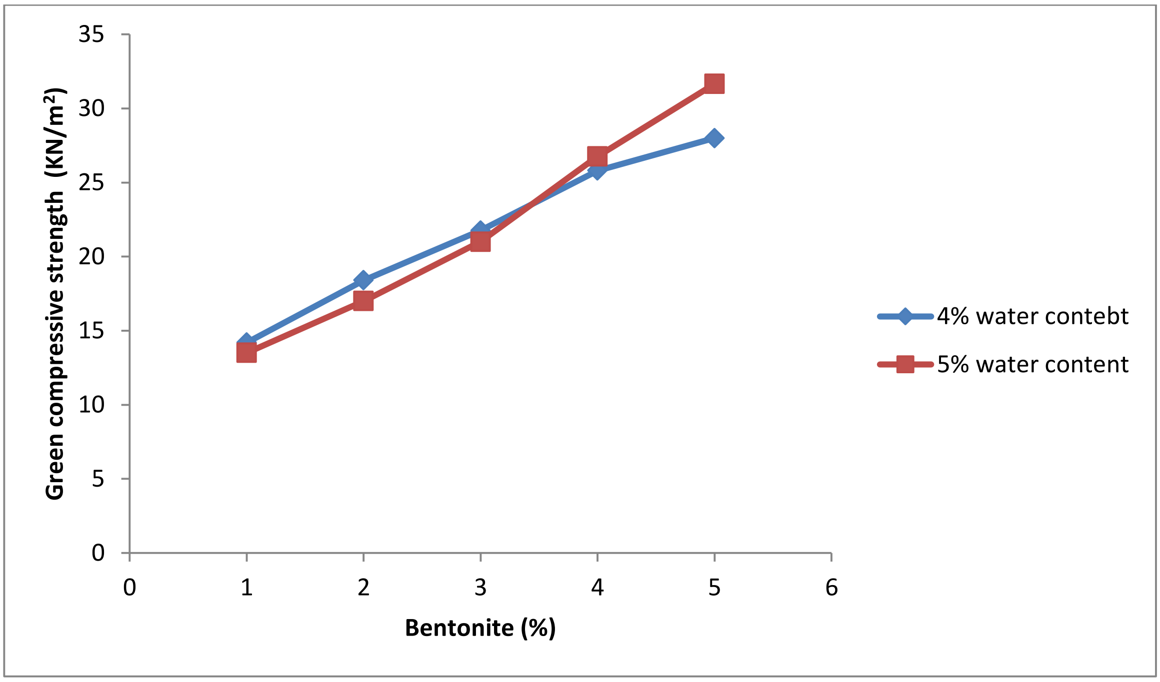


Fig 4.38Effect of green compressive strength on added bentonite at 4%, 5% water content.

From the Figure 4.38, it was observed that the green compressive strength increased as the additives introduced increased: For 4% water content, the green strength increased from 14.20KN/ m^2 at 1% bentonite content to 28.00KN/m^2 at 5% bentonite content. For 5% bentonite sample, the green compressive strength increased from 13.50KN/m^2 at 1% bentonite content to 31. 65KN/m^2 at 5% bentonite content addition.

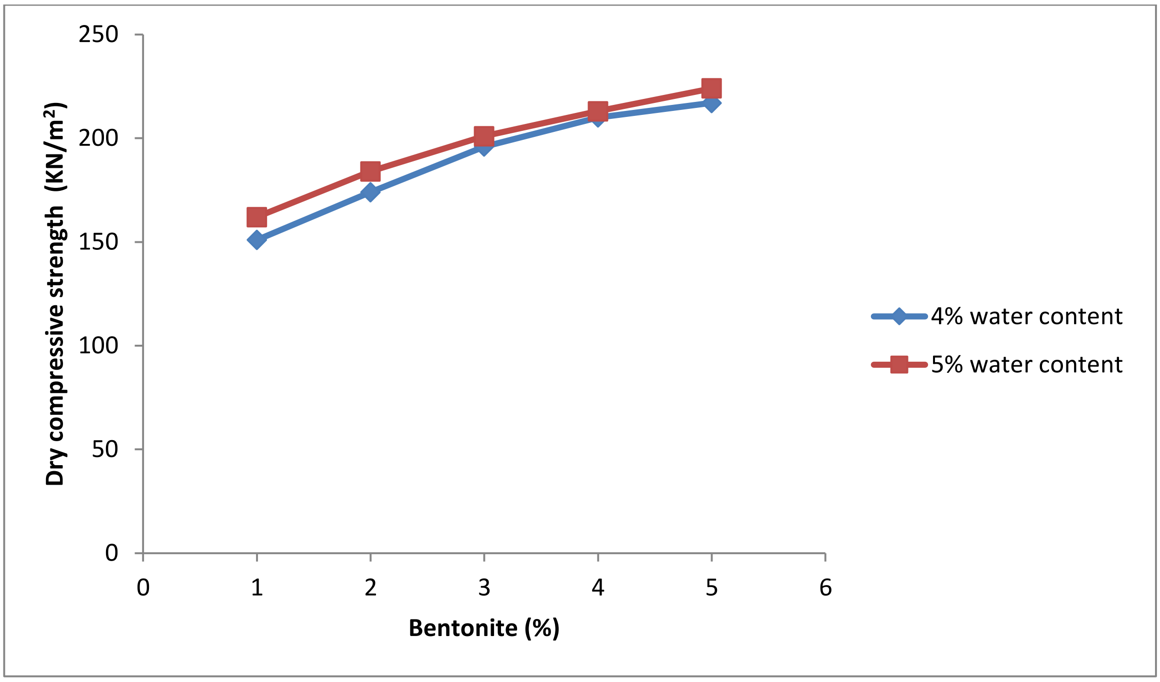


Fig 4.39 Effect of green compressive strength on added bentonite and 4%, 5% water content.

Figure 4.39 Illustrates the effect of dry compressive strength on varying percentages of bentonite at 4%, 5% water content. It was observed that the dry compressive strength increased as the added bentonite introduced increased, for both 4% and 5% water content sample. For 4%, 5% water content sample, when mixed with 1% of bentonite content, the dry compressive strength were 151.00KN/m^2 and 162.00KN/m^2 respectively for 4% and 5% water contents. When mixed with 5% bentonite content, the dry compressive strength were 217.00KN/m^2 and 224.00KN /m^2 respectively for 4% and 5% water content.

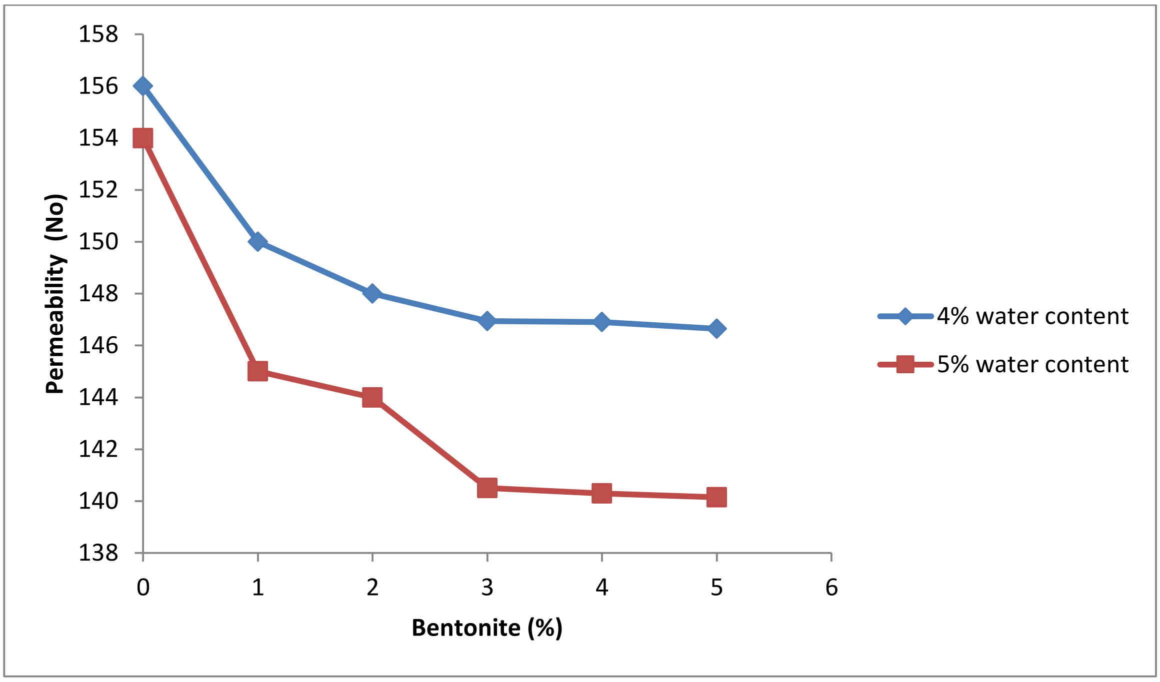


Fig 4.40 Effect of permeability on bentonite content at 4%, 5% water content.

Figure 4.40 Shows the effect of permeability on varying percentages of added bentonite at 4% , 5% water content. It was observed that the permeability of the River beach sand decreased as the bentonite content introduced increased. For 4% water content sample, the permeability values decreased from 156.00 (No) at 0% bentonite content to 146.64(No) at 5% bentonite content. For 5% water content sample, the permeability decreased from 154.00(No) at 0% bentonite content to 140.15(No) at 5% bentonite content.

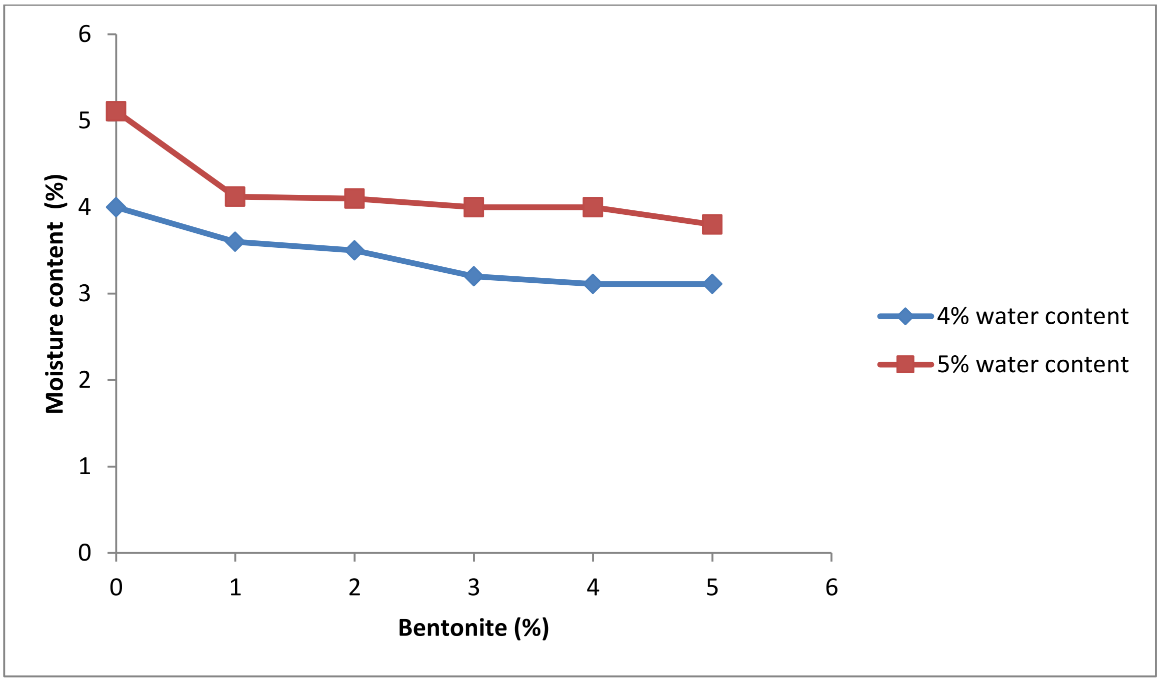


Fig 4.41 Effect of moisture content on bentonite at constant 4%, 5% water content.

Figure 4.41 Illustrates the effect of moisture content on varying percentages of added bentonite content. It was observed that the moisture content of the River beach sand decreased as the added bentonite introduced increased. For 4% water content sample, the moisture content decreased from 4.0% at 0% bentonite content to 3.11% at 5% bentonite content. For 5% water content sample, the moisture content decreased from 5.11 at 0% bentonite to 3.80% at 5% bentonite content.

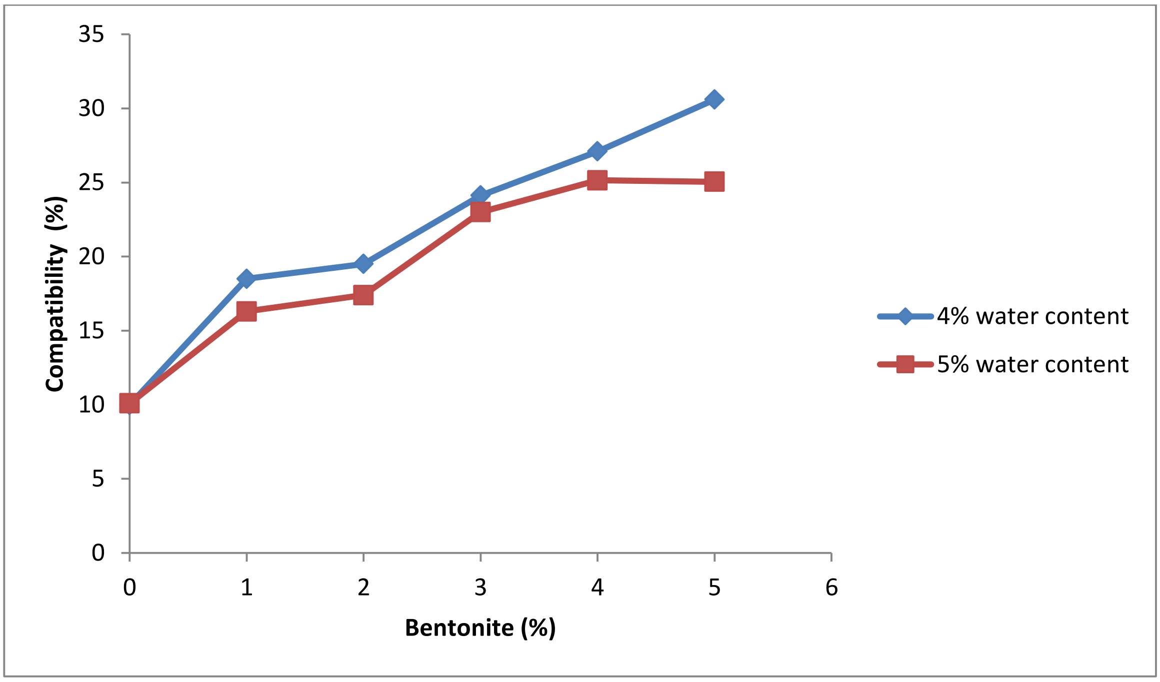


Fig 4.41 Effect of compactibility on bentonite at constant 4%, 5% water content.

Figure 4.42 shows the effect of compactibility values on varying percentages of added bentonite content at 4%, 5% water content. It was observed that the compactibility of the River Niger beach sand increased as the additives introduced increased, for both 4% and 5% water content samples. When blended with 5% bentonite content, the compactibility values of 30.60% and 25.05% were recorded for 4% and 5% water content samples respectively.

4.11 Comparison of Foundry Properties Result of River Niger Onitsha Beach Sand Using 2% and 3% Water Content and Varying Percentages of Ukpor Clay Content.

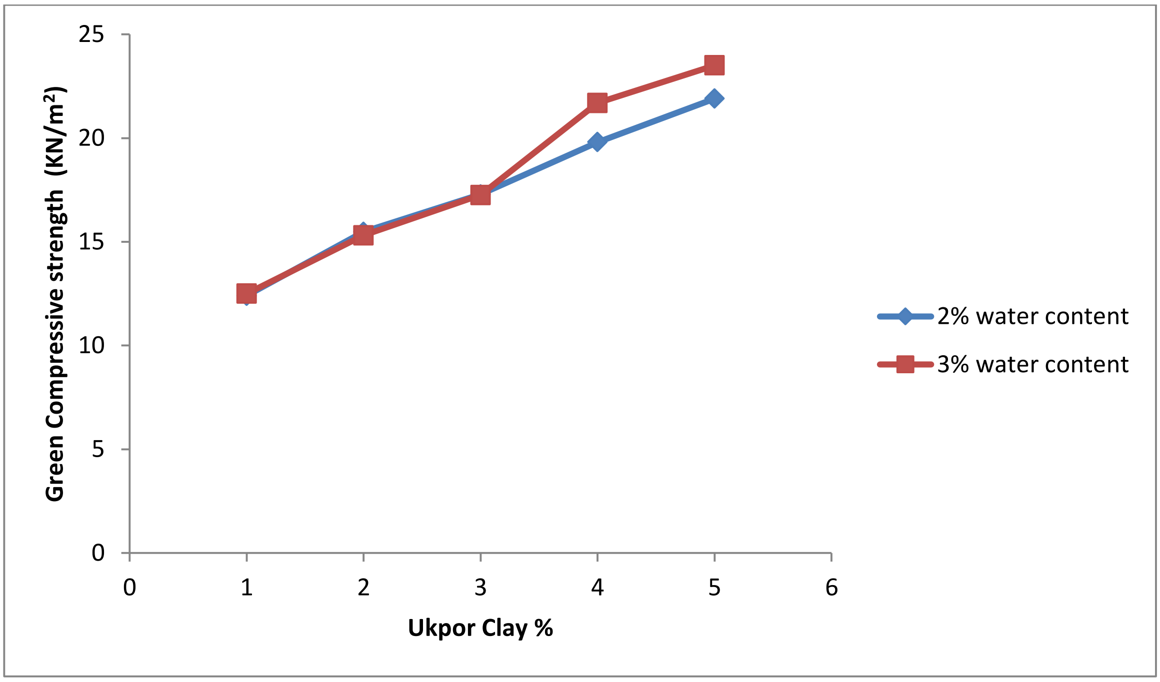


Fig 4.43 Effect of green compressive strength on bentonite content at 4%, 5% water content.

From the Figure 4.43, it was observed that the green compressive strength increased as the additives introduced increased. For 2% water content, the green strength increased from 12.40KN/ m^2 at 5% Ukpor clay content to 21.90KN/m^2 at 5% Ukpor clay content. For 3% Ukpor clay sample, the green compressive strength increased from 12.50KN/m^2 at 1% Ukpor clay content to 23.50KN/m^2 at 5% Ukpor clay content

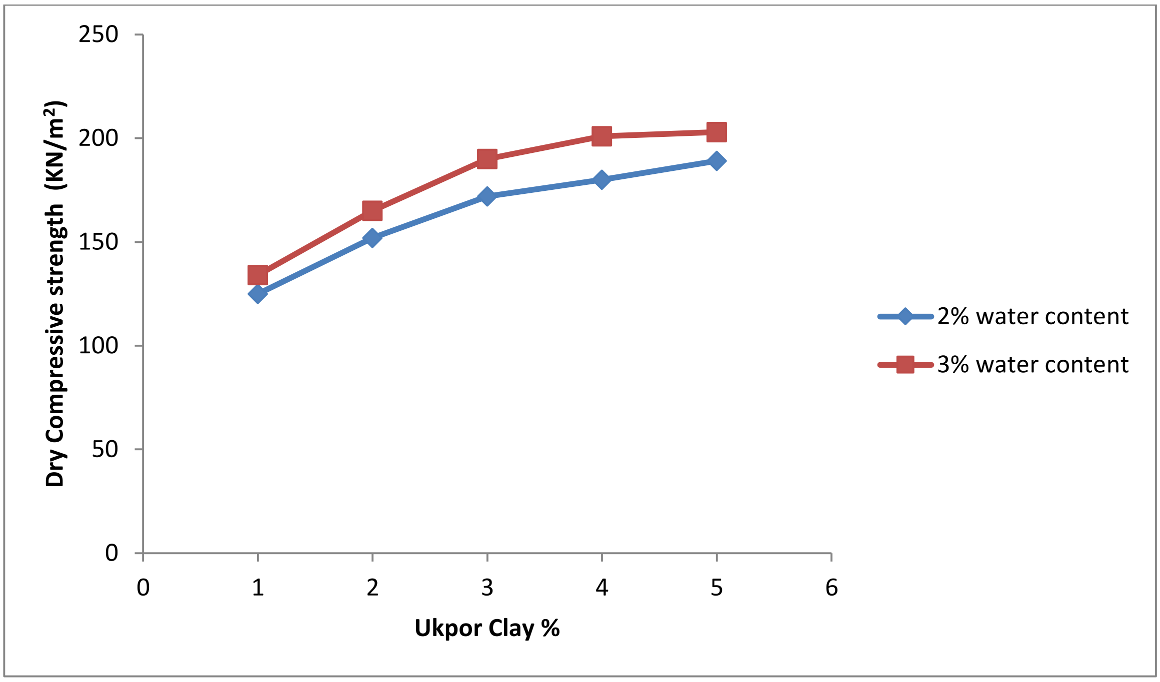


Fig 4.44 Effect of dry compressive strength on Ukpor clay at 2%, 3% water content sample.

Figure 4.44 represents the effect of varying percentages of Ukpor clay content at constant 2%, 3% water content samples on the dry compressive strength of the moulded River Niger sand deposits. It was observed that as the added clay content introduced increased, the dry compressive strength also increased. For 2% water content sample, the dry compressive strength increased from 135.00KN/m^2 at 1% Ukpor clay content to 189.00KN/m^2 at 5% Ukpor clay content. For 3% water content, the dry compressive strength increased from 134.00KN/m^2 at 1% clay content to 203KN/m^2 at 5% Ukpor clay content introduced. The 3% water content sample showed a higher value of dry compressive strength than 2% water content sample by 14.00KN/m^2.

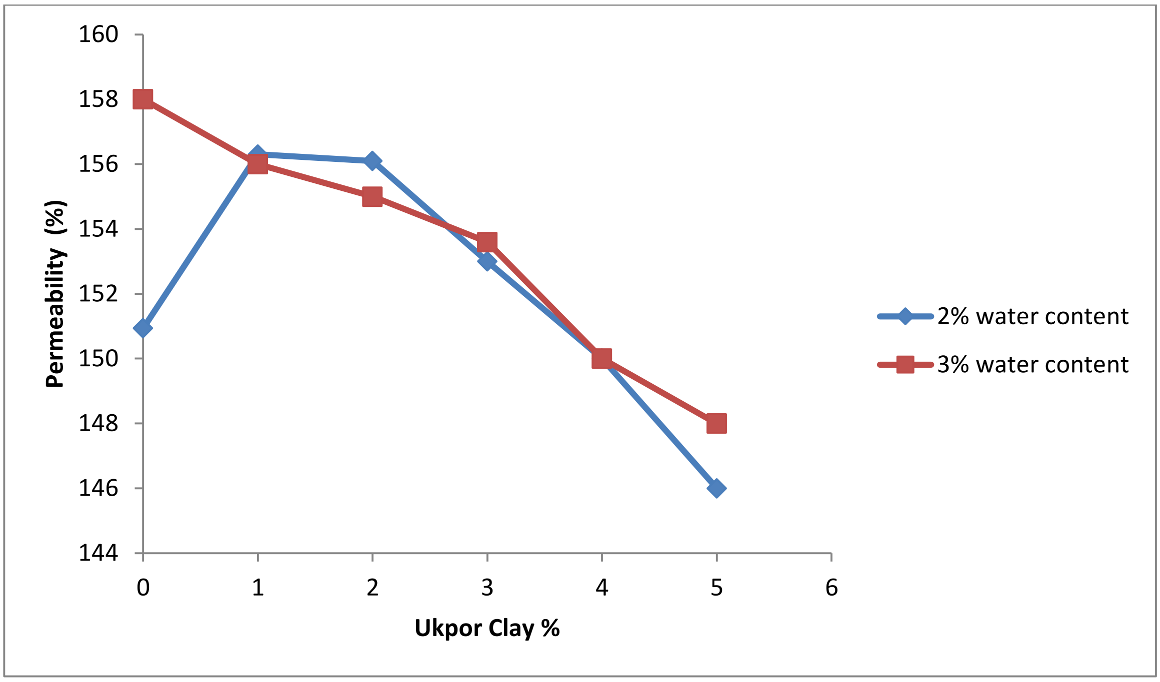


Fig 4.45 Effect of permeability on Ukpor clay content at 2%, 3% water content.

Figure 4.45 Shows the effect of permeability on varying percentages of added Ukpor clay at 2%, 3% water content. It was observed that the permeability of the River beach decreased as the Ukpor clay content introduced increased, for both 2% and 3% water content. For 2% water content, the permeability values decreased from 150.94No at 0% Ukpor clay content to 146.00(No) at 5% clay content. For 3% water content, the permeability decreased from 158.00(No) at 0% clay content to 148.00(No) at 5% clay content.

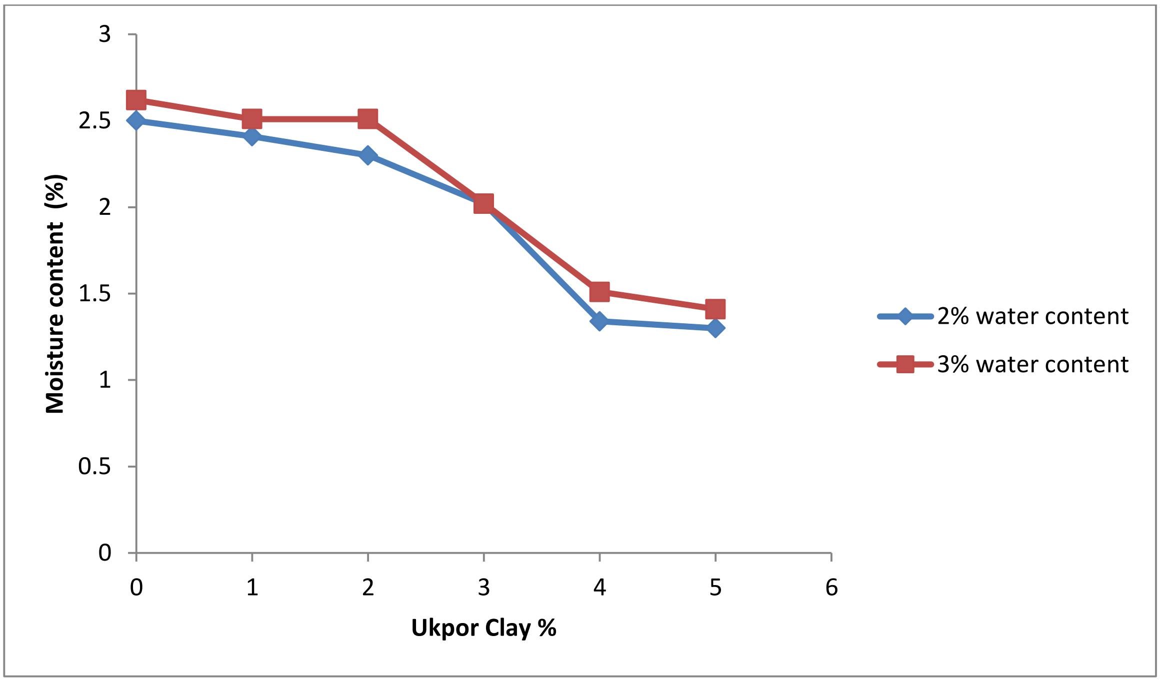


Fig 4.46 Effect of moisture content on Ukpor clay at constant 2%, 3% water content.

Figure 4.46 Illustrates the effect of moisture content on varying percentages of added Ukpor clay at 2%, 3%, water content. It was observed that the moisture content of the beach sand decreased as the added Ukpor clay content introduced increased. For 2% water content sample, the moisture content decreased from 2.50% at 0% Ukpor clay content to 1.30% at 5% Ukpor clay content. For 3% water content sample, the moisture content decreased from 2.62% at 0% clay content to 1.41% at 5% Ukpor clay content.

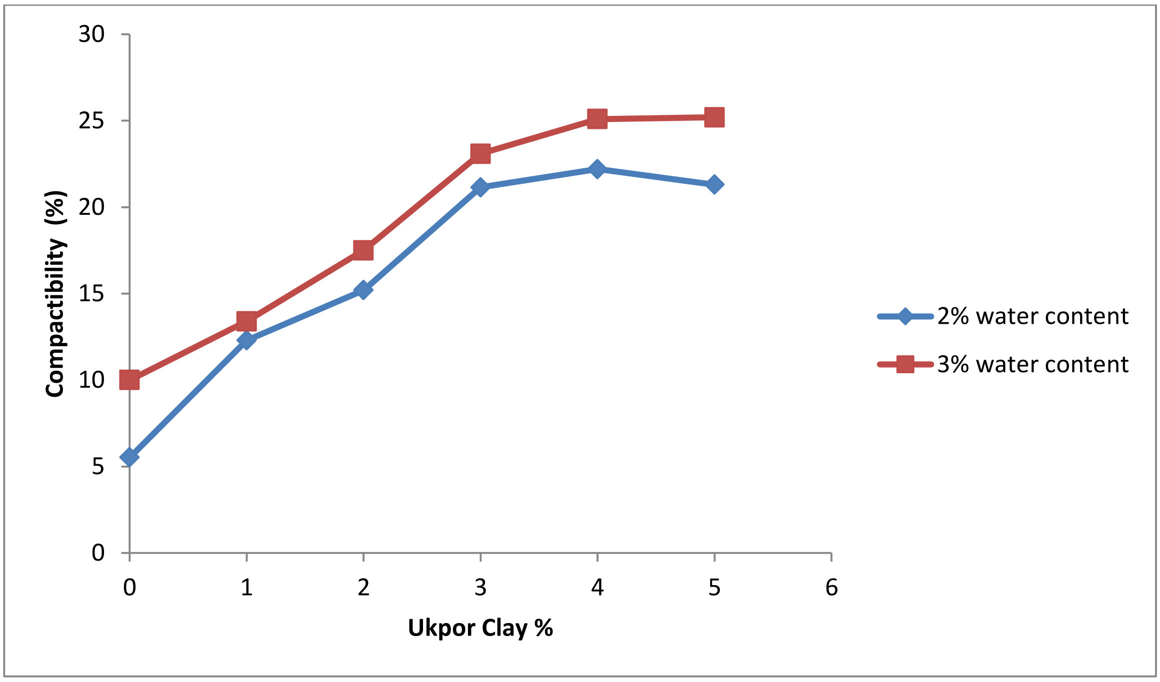


Fig 4.47 Effect of compactibility on Ukpor clay content at 2%, 3% water content.

Figure 4.47 shows the effect of compactibility values on varying percentages of added Ukpor clay content at 2%, 3% water content. It was observed that the compactibility of the River Niger beach sand increased as the Ukpor clay introduced increased for both 2% and 3% water content samples. When blended with 5% Ukpor clay content, the compactibility values of 21.30% and 25.20% were recorded for 2% water content and 3% water content samples respectively

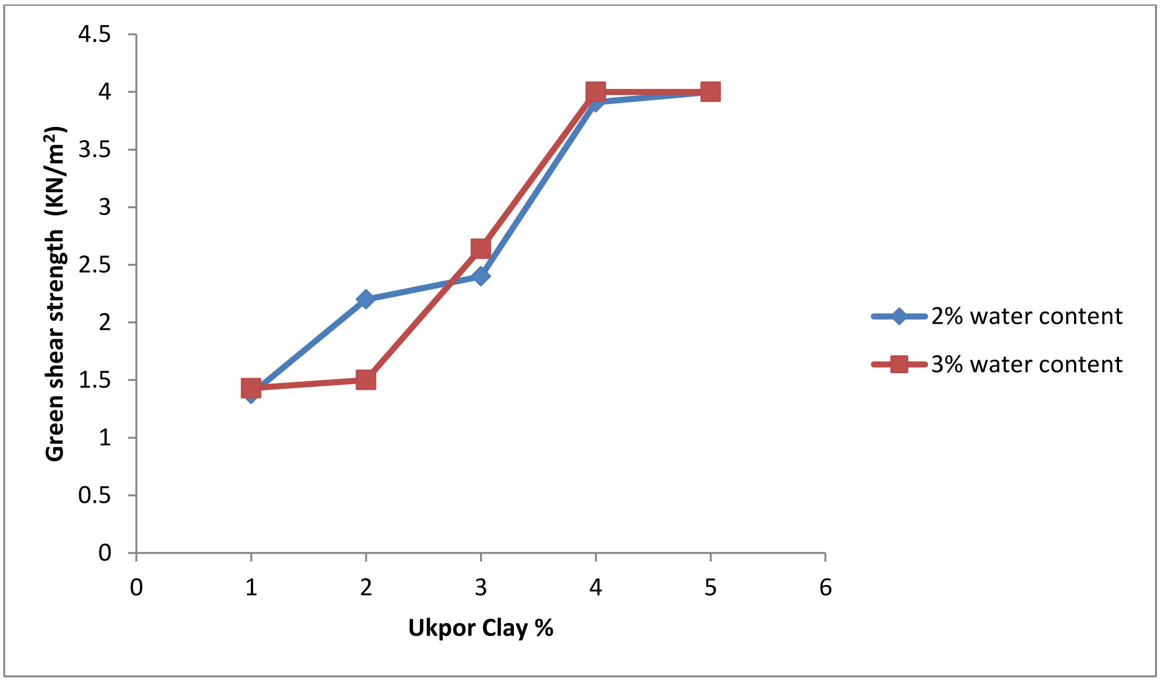


Fig 4.48 Effect of green shear strength on Ukpor clay at 2%, 3% water content.

From the Figure 4.48, it was observed that the green shear strength increased as the additives introduced increased. For 2% water content, the green shear strength increased from 1.38KN/m^2 at 1% clay content to 4.00 at 5% Ukpor clay content. For 3% clay sample, the green shear strength increased from 1.43KN/m^2 at 1% clay content to 4.00KN/m^2 at 5% Ukpor clay content

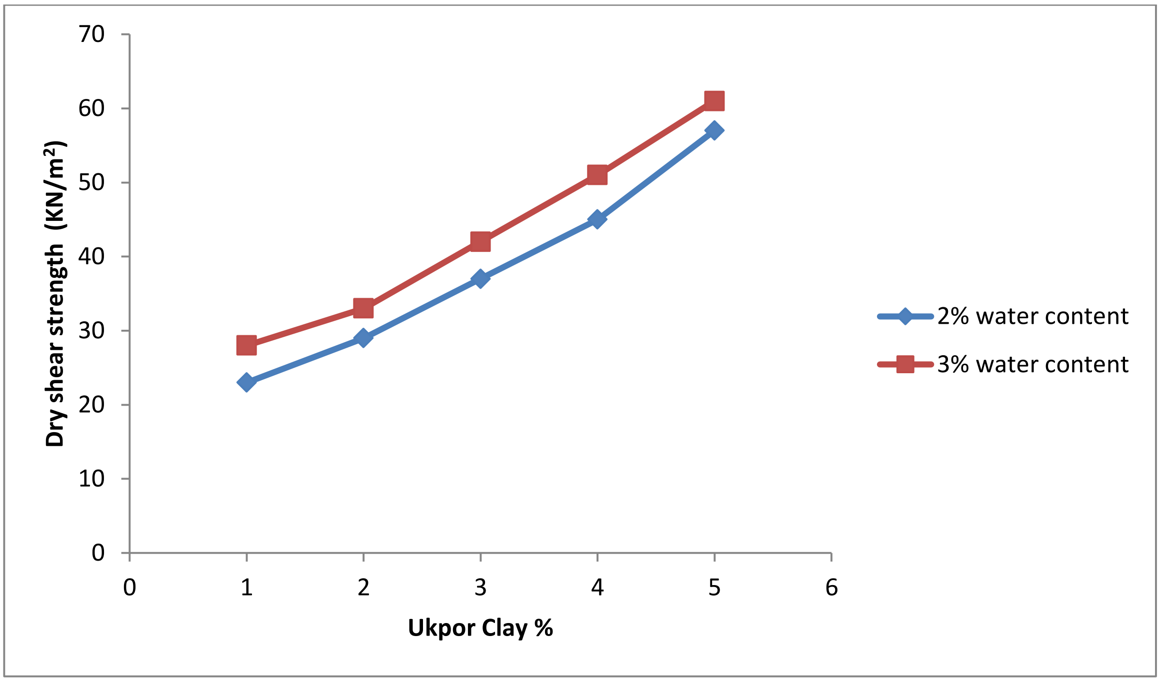


Fig 4.49 Effect of dry shear strength on added water content at 4%, 5% Ukpor clay content.

Figure 4.49 illustrates the effect of dry shear strength on varying percentages of Ukpor clay at constant 2%, 3% water content. It was observed that for 2% and 3% water content samples, the dry shear strength increased as the Ukpor clay content introduced increased. For 2% water content, the dry shear strength increased from 23.00KN/m^2 at 1% clay content to 52.00KN/m^2 at 5% clay content addition. For 3% water content sample, the dry shear strength increased from 28.00KN/m^2 at 1% water content to 61.00KN/m^2 at 5% clay content addition introduced.

4.12 Comparison of Foundry Properties Result of River Niger Onitsha Beach Sand Using 4% and 5% Water Content and Varying Percentages of Ukpor Clay

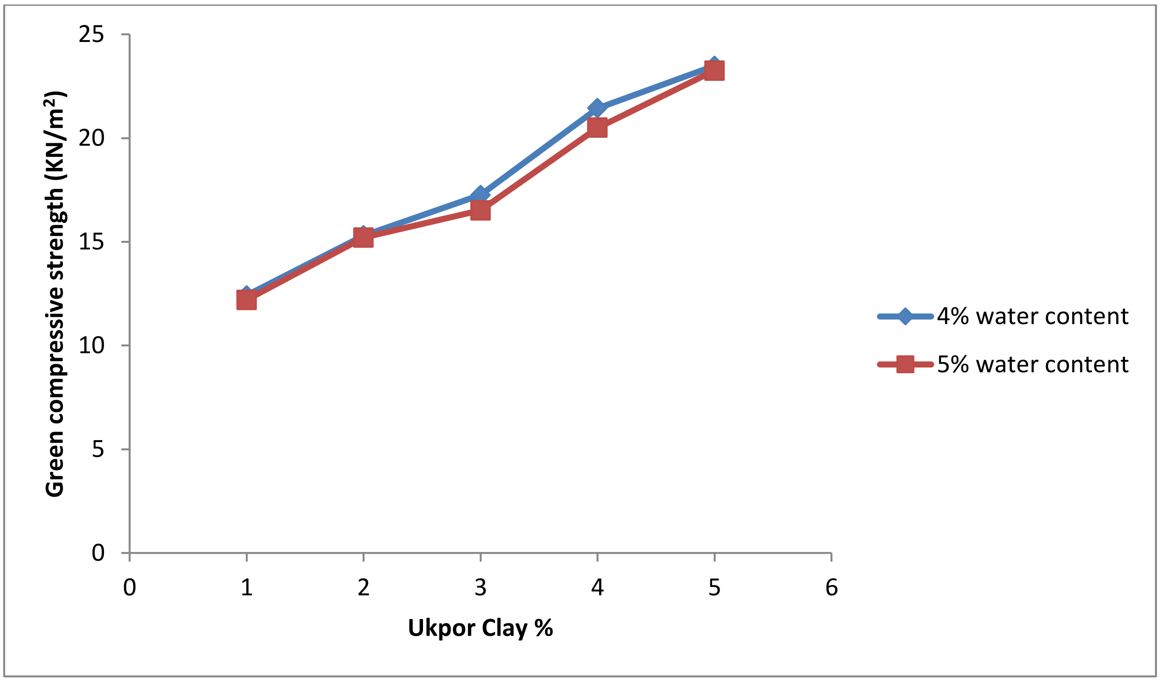


Fig 4.50 Effect of green compressive strength on Ukpor clay content at 4%, 5% water content.

From the Figure 4.50, it was observed that the green compressive strength increased as the additives introduced increased. For 4% water content, the green strength increased from 12.41KN/ m^2 at 1% clay content to 23.48KN/m^2 at 5% Ukpor clay content. For 5% water content sample, the green compressive strength increased from 12.20KN/m^2 at 1% clay content to 23. 25KN/m^2 at 5% clay content

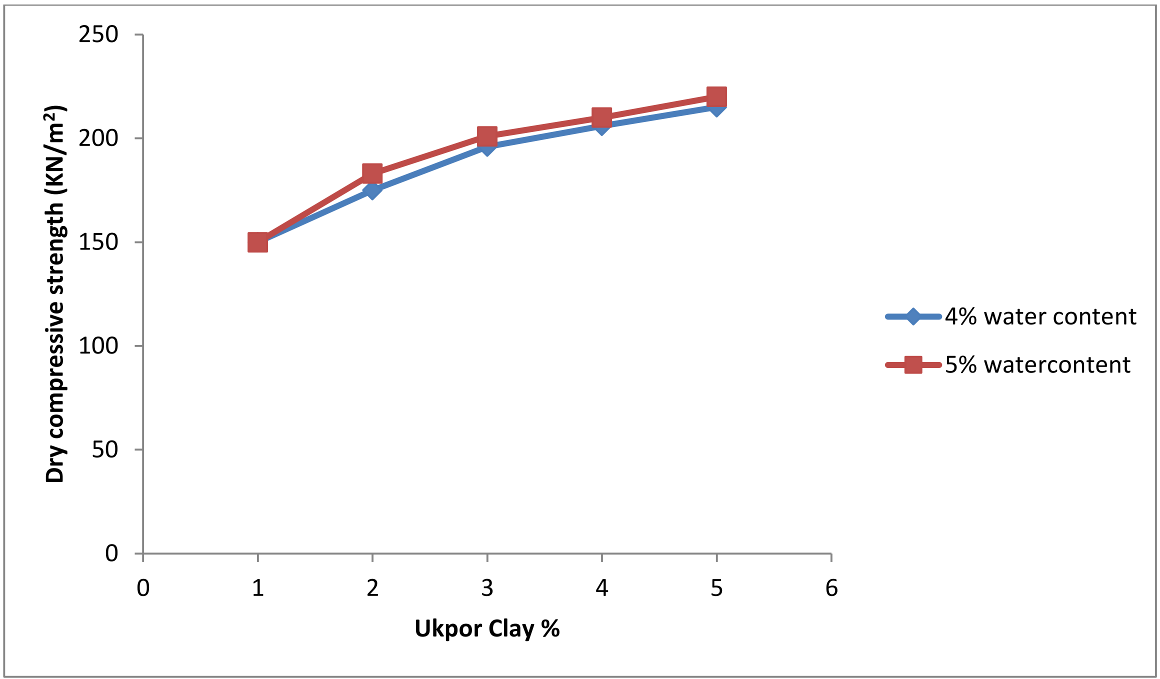


Fig 4.51 Effect of dry compressive strength on Ukpor clay content at 4%, 5% water content.

Fig. 4.51 represents the effect of varying percentages of clay at constant 4%, 5% water content, on the dry compressive strength of the moulded River Niger sand deposits. It was observed that as the added water content introduced increased, the dry compressive strength also increased. For 4% water content, the dry compressive strength increased from 150.00KN/m^2 at 1% clay content to 215.00KN/m^2 at 5% clay content. For 5% water content, the dry compressive strength increased from 150.00KN/m^2 at 1% water content to 220KN/m^2 at 5% water content introduced. The 5% water content sample showed a higher value of dry compressive strength than 4% Ukpor clay sample by 5.0KN/m^2.

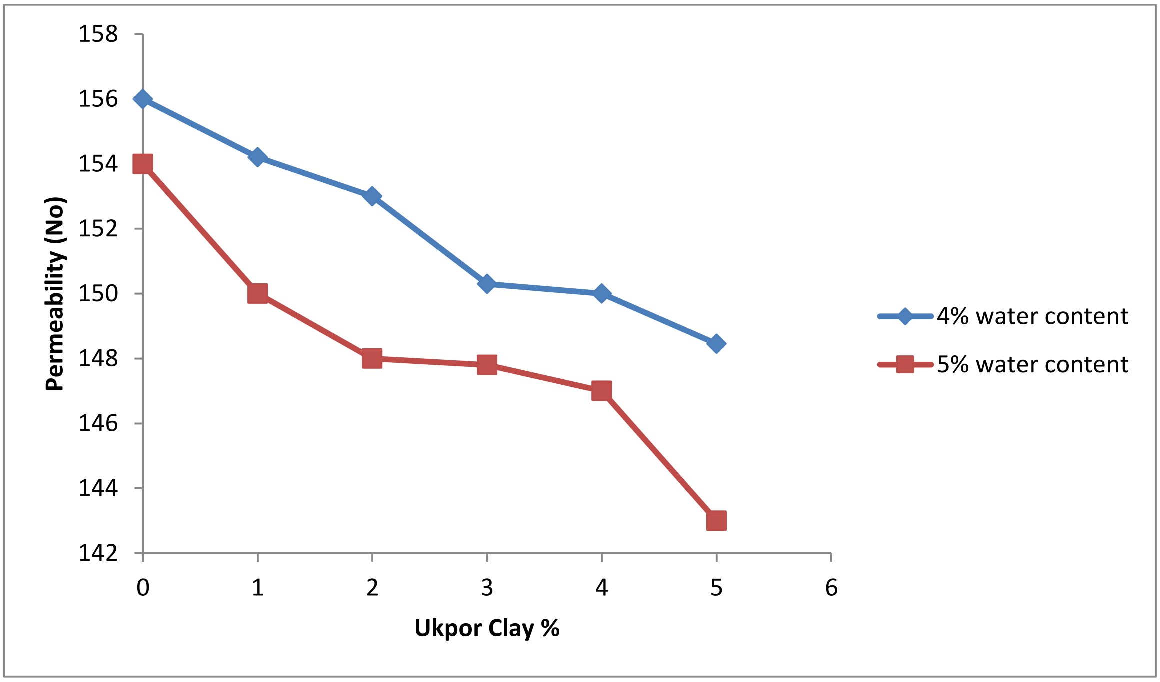


Fig 4.52 Effect of permeability on Ukpor clay content at 4% and 5% water content.

Fig 4.52 Shows the effect of permeability on varying percentages of added clay content at 4%, 5% water content. It was observed that the permeability of the River beach sand decreased as the clay content introduced increased, for both 4% and 5% water contents. For 4% water content, the permeability values decreased from 156.00No at 0% clay content to 148.45(No) at 5% clay content. For 5% water content, the permeability decreased from 154.00(No) at 0% clay content to 142.00(No) at 5% clay content.

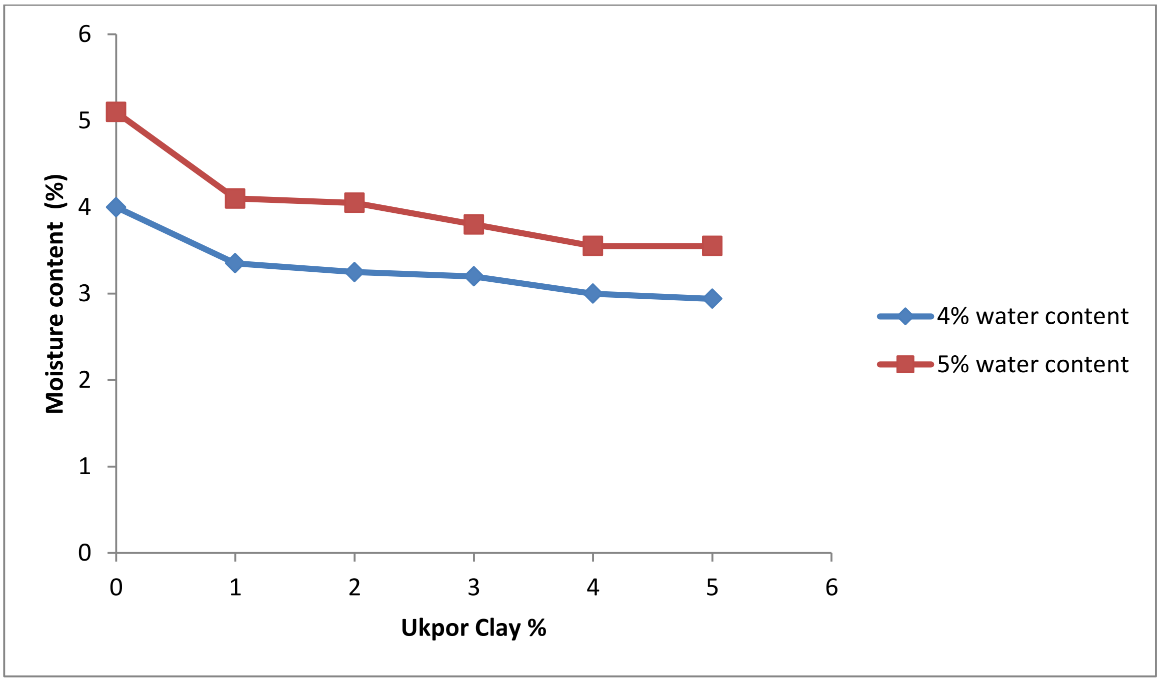


Fig 4.53 Effect of moisture content on Ukpor clay at constant 4%, 5% water content.

Figure 4.53 Illustrates the effect of moisture content on varying percentages of added clay content at 4%, 5% water content. It was observed that the moisture content of the beach sand decreased as the added bentonite introduced increased. For 4% water content sample, the moisture content decreased from 4.0% at 0% clay content to 2.90% at 5% clay content. For 5% water content sample, the moisture content decreased from 5.10% at 0% clay content to 3.55% at 5% clay content.

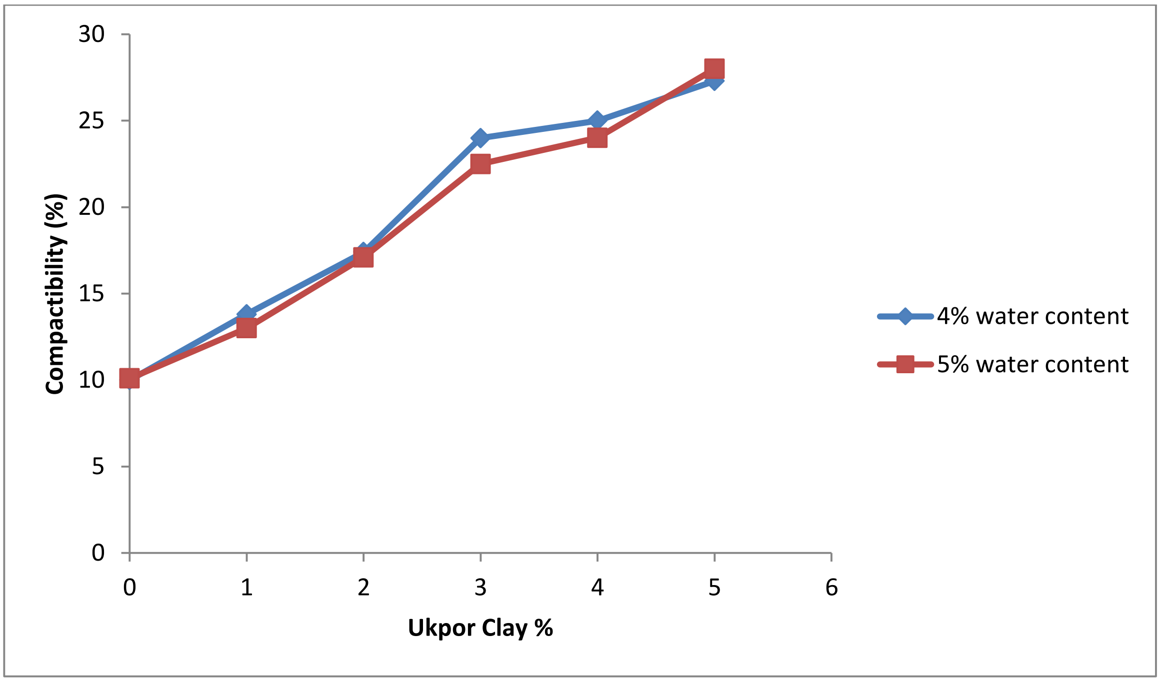


Fig 4.54 Effect of compactibility on Ukpor clay content at 2%, 3% water content.

Figure 4.54 shows the effect of compactibility values on varying percentages of added clay content at 4%, 5% water content. It was observed that the compactibility of the River Niger beach sand increased as the Ukpor clay introduced increased for both 4% and 5% water content samples. When blended with 5% Ukpor clay content, the compactibility values of 24.10% and 28.00% were recorded for 4% and 5% water content samples respectively

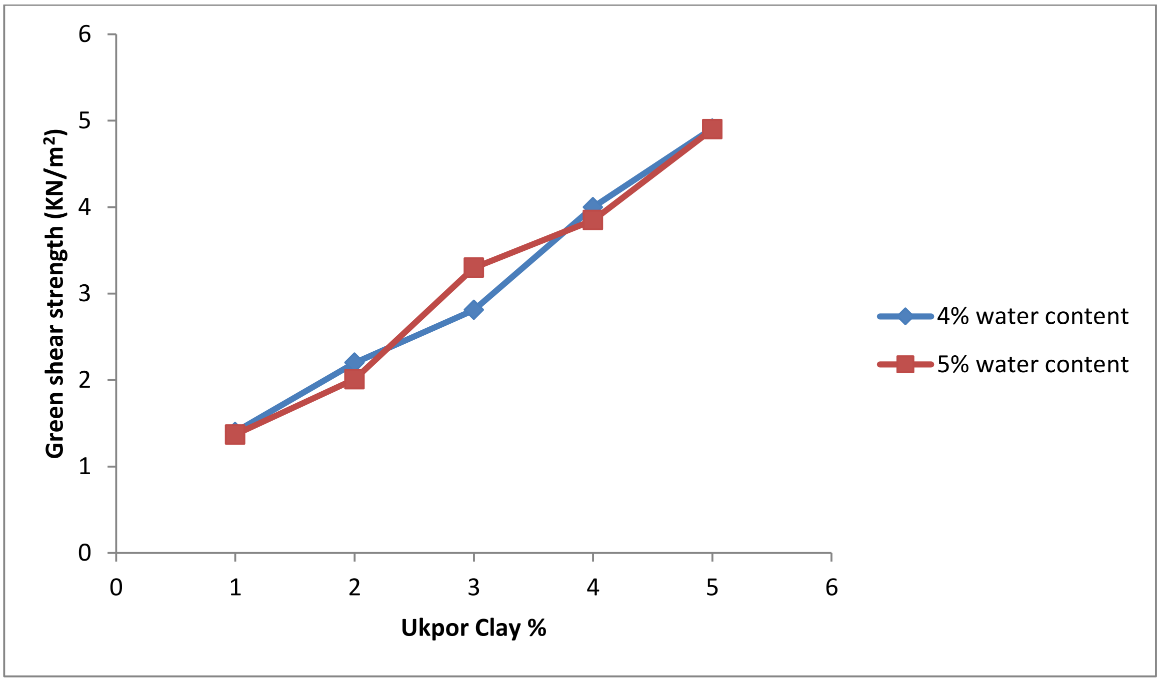


Fig 4.55 Effect of green shear strength on Ukpor clay content at 4%, 5% water content.

Figure 4.55 shows the variation of the green shear strength on Ukpor clay content at 4%, 5% water content. It was observed that the green shear strength increased as the percentage clay content introduced increased. For 4% water content, the green shear strength increased from 1.400KN/m^2 at 1% clay content to 4.91KN/m^2 at 5% clay content. For 5% clay content, the green shear strength increased from 1.37KN/m^2 at 1% Ukpor clay to 4.90KN/m^2 at 5% Ukpor clay content addition.

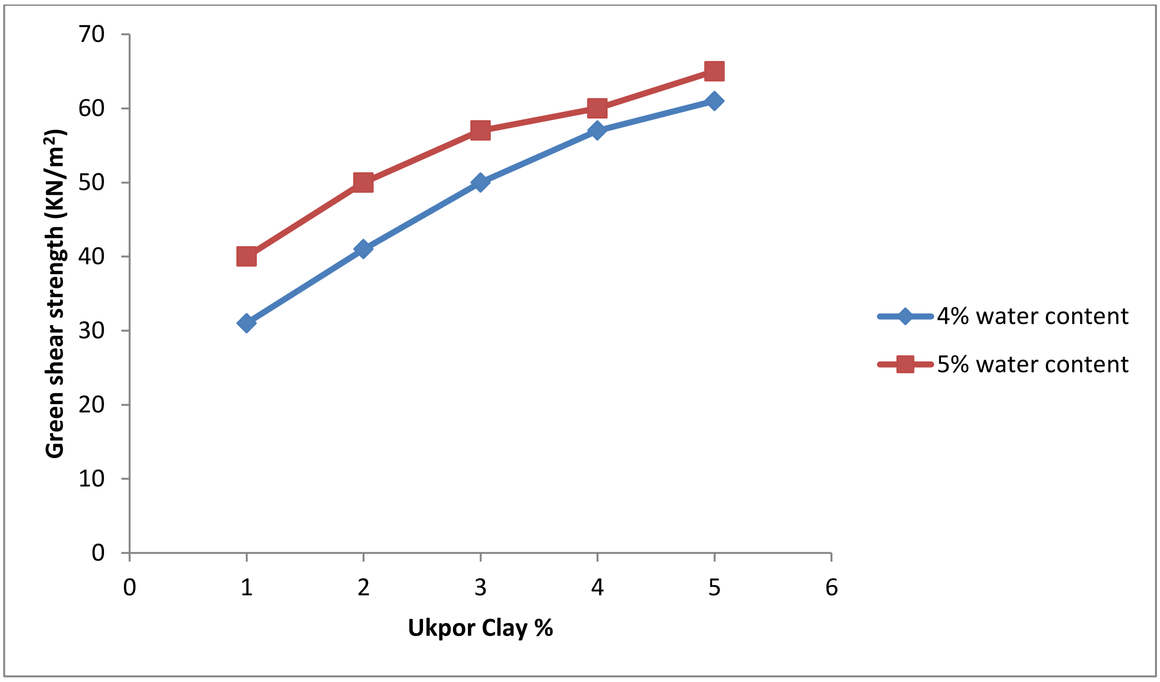


Fig 4.56 Effect of dry shear strength on Ukpor clay content at 4%, 5% water content.

Figure 4.56 shows the effect of varying percentages of Ukpor clay on dry shear strength at 4%, 5% water contents. From the Figure 4.56, it was shown that the dry shear strength of the River beach sand increased as the added Ukpor clay content increased. For 4% water content, the dry shear strength increased from 31.00KN/m^2 at 1% clay to 61.00KN/m^2 at 5% clay content. For 5% water content, the dry shear strength increased from 40.00KN/m^2 at 1% clay content to 65.00KN/m^2 at 5% clay content.

4.13 Comparism Between the Foundry Properties Results Obtained Using Samples Produced with Constant 4% Water and Varying Percentages of Additives

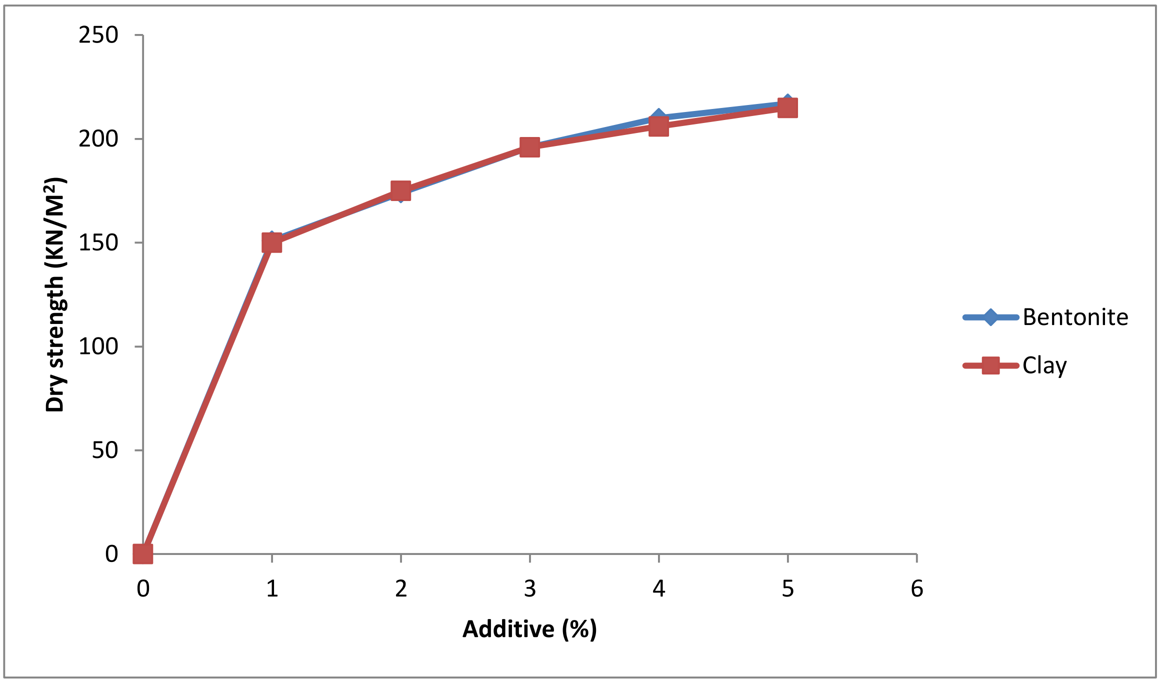


Fig 4.57: Effect of dry compressive strength on binders (bentonite and Ukpor clay) at constant 4% water content

Figure 4.57 shows the variation of the dry compressive strength with binder content for the two samples considered. Gradual increase in the dry compression strength was observed across the two specimens. The bentonite sample was characterized with optimum dry compressive strength which ranged from 151.0kN/m^2 to 217.0kN/m^2, while Ukpor clay sample ranges from 150.0kN/m^2 to 215kN/m^2. The specimens demonstrated increase in strength as binder content introduced increased. The properties exhibited by both samples are in accordance with the American Foundry men Standard (AFS) shown in Table 4.21a in the appendix.

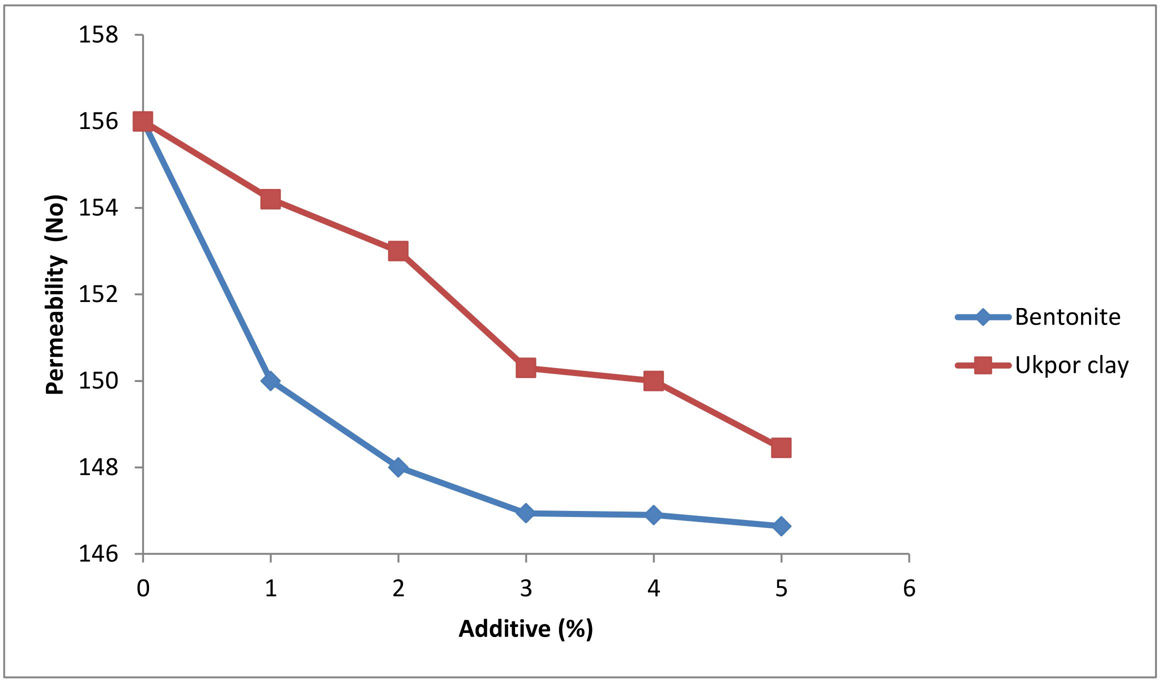


Fig 4.58 Effect of permeability on binders (bentonite and Ukpor clay) at 4% water content

Figure 4.58 shows theeffect of binders on permeability of the natural moulding sand deposits with increase in percentage of additives, the permeability values decreased from a maximum value of 156.0 (No) at 0% binder to 146.64 (No) at 5% addition of additives for bentonite sample. This pattern is also exhibited for Ukpor clay sample with permeability value of 148.45 (No) at 5% addition for Ukpor clay sample. Bentonite and Ukpor clay were expected to bind silica sand and other particles together in the presence of water. This is achieved by filling up the pores between the grains of the silica sand; hence the decrement observed with increase in the binder content was achieved. Thus the permeability is expected to decrease with increase in the binder content (Kubo, 1999).

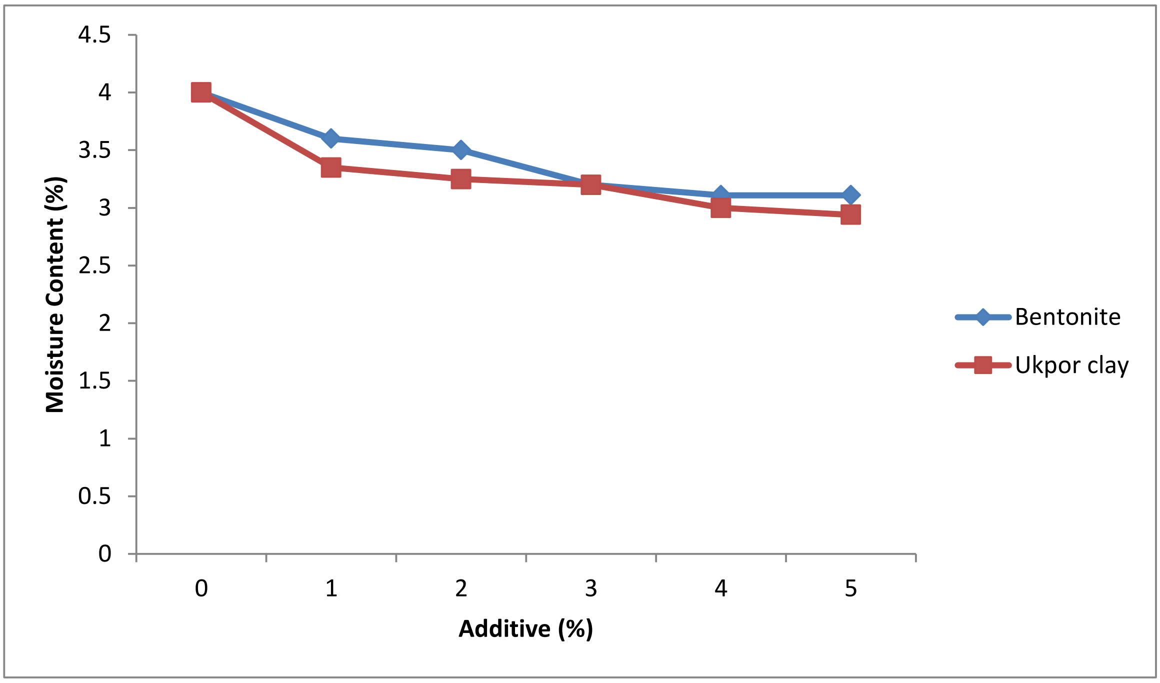


Fig. 4.59 Effect of moisture content on binders(bentonite and Ukpor clay) and 4% water constant

Figure 4.59 shows the effect of additives on moisture content. It was observed that the moisture content decreased as the added percentages of additives increased for both binders. For bentonite sample, moisture content decreased from 4.0% moisture content at 0% binder content to 3.11% moisture at 5% binder content, while moisture in Ukpor clay sample decreased from 4.0% moisture content at 0% binder content to 2.94% moisture content at 5% binder content.

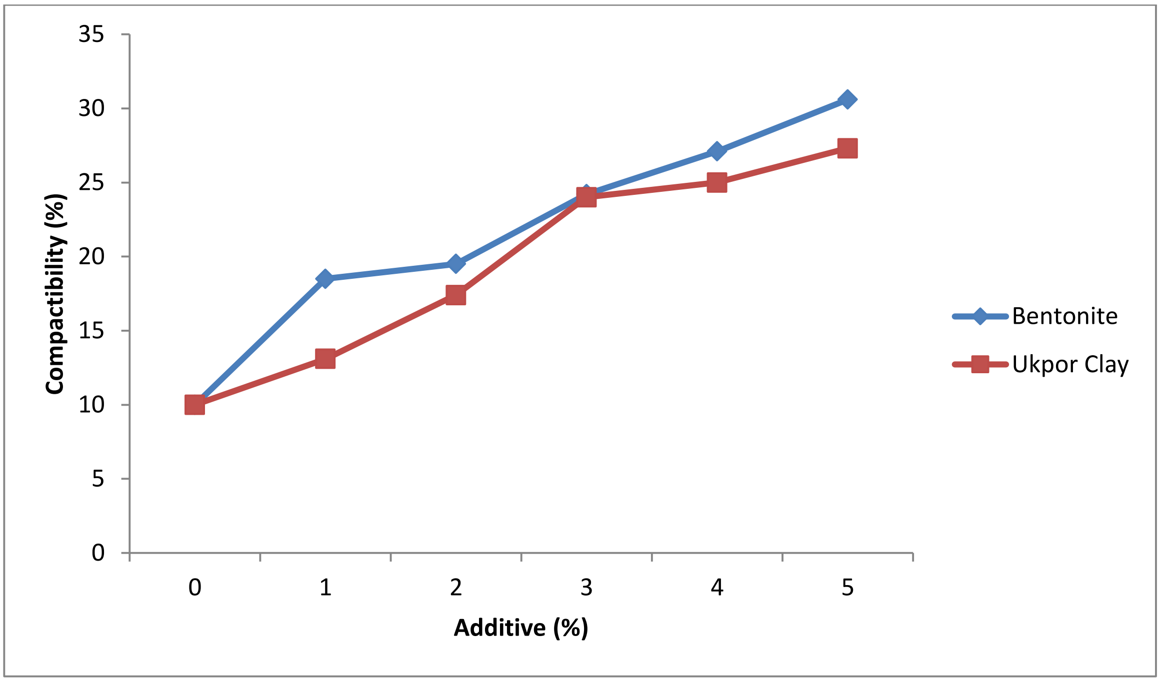


Fig 4.60 Effect of compactibility on binders (bentonite and Ukpor clay) and 4% water content

Figure 4.60 Illustrates the effect of added additives on compactibility values of River Niger sand deposit at constant 4% water content. It was observed that the compactibility increased as the additives introduced increased, for both binders, with bentonite sample having a greater value of 3.30kN/m^2 more than Ukpor clay sample. When mixed with 5% additives (bentonite/clay) the compactibility values of 30.60% and 27.30% were recorded for bentonite sample and Ukpor clay sample respectively. It can be seen from Tables 4.19i, 4.20i in the appendix and Figure 4.60, that as the additives increased, compactibility values increased, as a result of the strong bond forming between the sand particle and additives contents (Tottle 1984).

4.14 Comparism Between the Foundry Properties Results Obtained Using Samples Produced with Constant 4% of Additives (Bentonite and Ukpor Clay) and Varying Percentages of Water

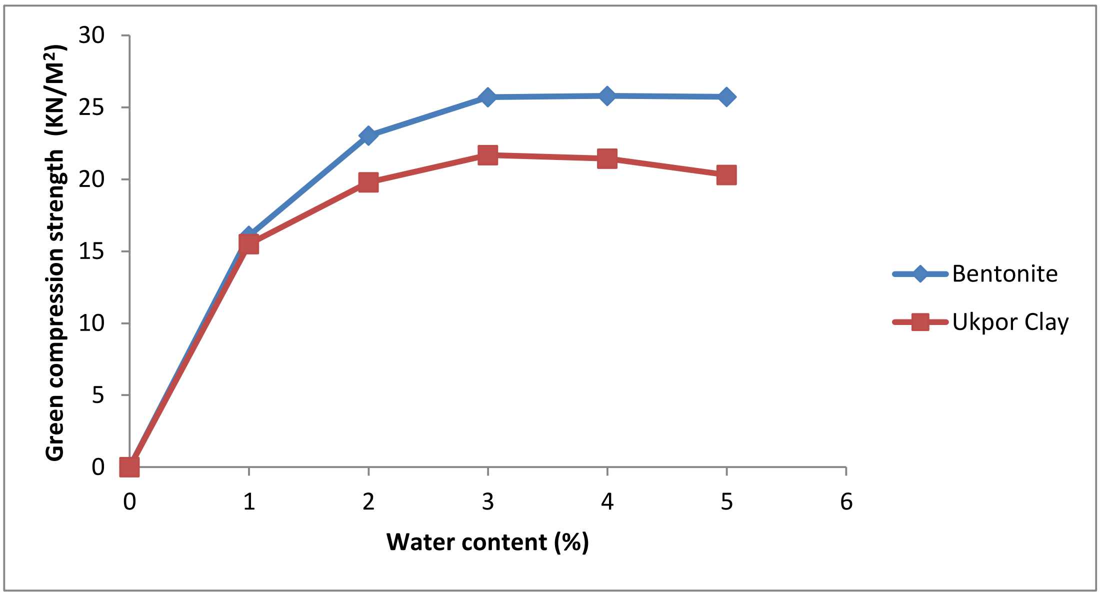


Fig 4.61 Effect of Green compression strength on water content addition at constant 4% additives (bentonite and Ukpor clay)

The variation of water content with the values of green compression strength is shown in the Figure 4.61. For bentonite sample the green compressive strength increased from 16.08kN/m^2 at 1% water content additive to 25.72kN/m^2 at 5% water content addition. The maximum value of green compressive strength of 21.69kN/m^2 was obtained at percentage water content at 3% for Ukpor clay deposit. Further increase in the percentage water addition above 3% leads to a reduction in green compressive strength for the Ukpor clay.

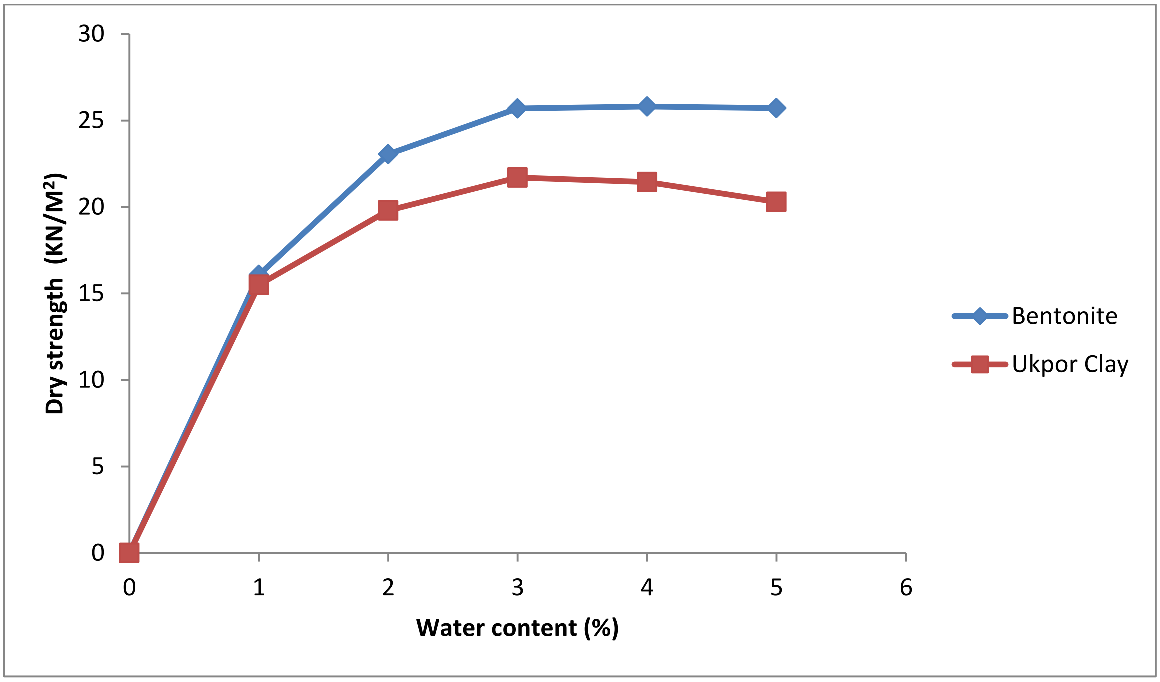


Fig 4.62 Effect of dry compressive strength on water content addition at constant 4% additives(bentonite and Ukpor clay)

The dry compressive strength increased as the percentage of the added water content increased, for both binders, with bentonite having a greater value of about 3kN/m^2 more than Ukpor clay samples. When mixed with 5% water, the dry compression strength of 213kN/m^2 and 210kN/m^2 were recorded for bentonite sample and Ukpor clay sample respectively. The properties evaluated by both samples are in agreement with the American Foundrymen Standard (AFS) shown in Table 4.21a in the appendix and Figure 4.62.

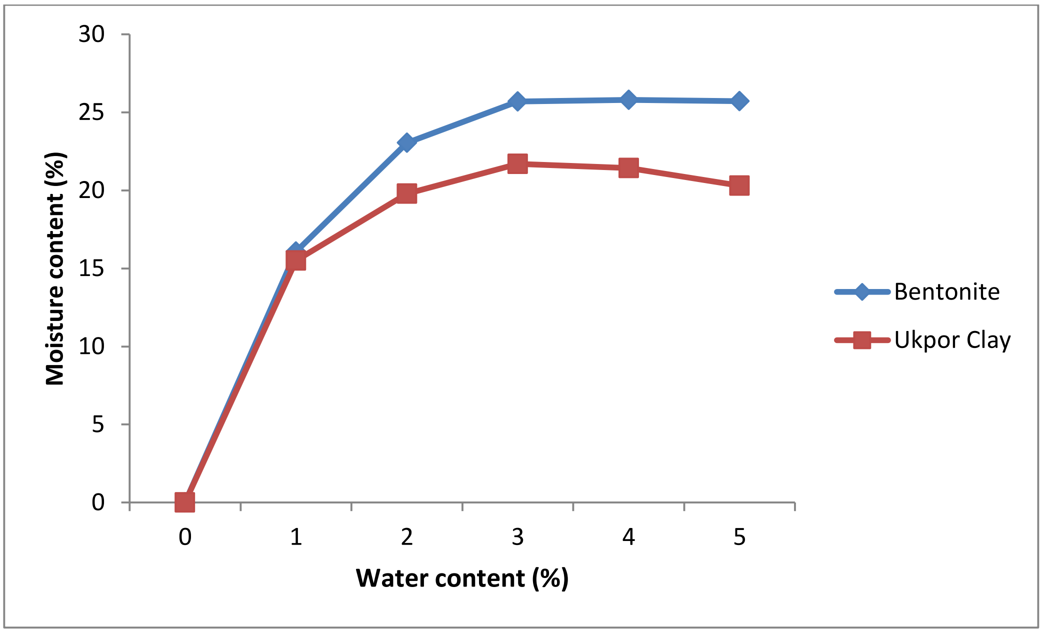


Fig 4.63 Effect of Moisture content on water content addition at constant 4% additives (bentonite and Ukpor clay)

From the Figure 4.63, it was observed that the moisture content of River Niger beach sand increased as the added percentage of water content increased for both binders. For bentonite sample, the moisture content increased from 1.01% at 0% water content to 4.0% moisture content at 5% water content, while moisture in Ukpor clay sample increased from 1.0% moisture content at 0% water content to 3.55% moisture content, which corresponded to 5% added water content. This is consisted with the observation by Ahem and Nuhu (2008) stating that the initial water added to a sand mix is absorbed by the binder till saturation. After water saturation of the sand mix is attained, any more added water is held up as free water thereby accounting for the continuous increase in moisture content observed in Figure 4.63.

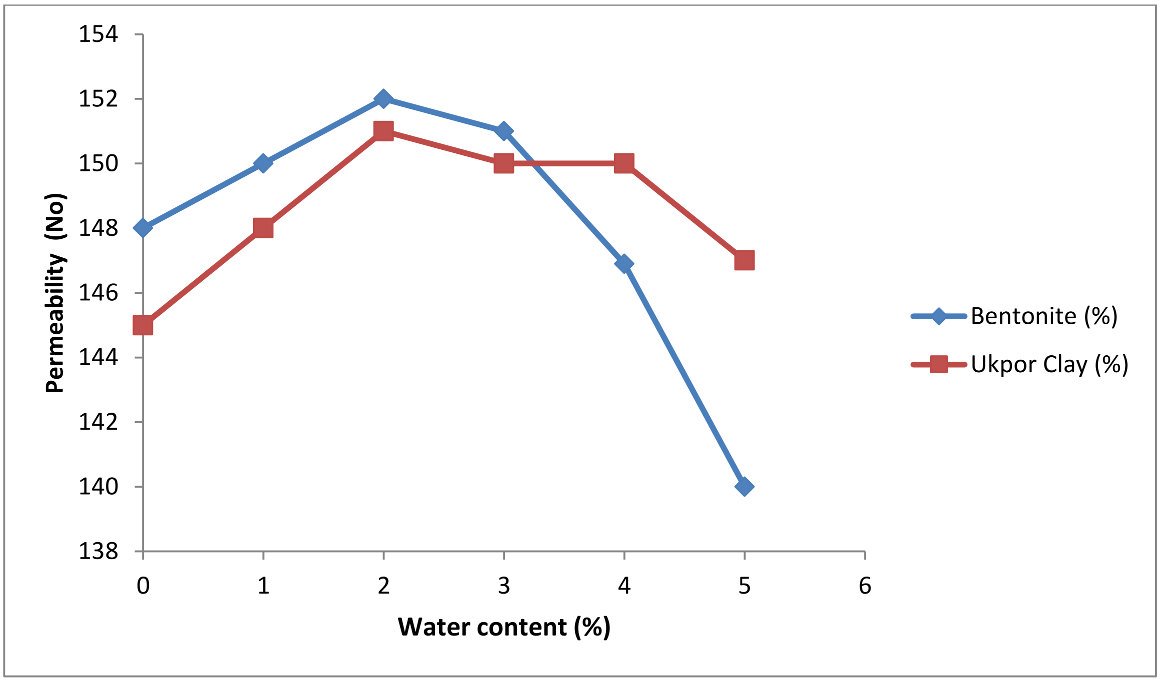


Fig 4.64 Effect of permeability on water content at constant 4% additives (bentonite and Ukpor clay)

It was observed that the permeability of the sand increased with increase in water content addition until maximum value was reached. Thereafter the permeability value decreased as the percentage water content introduced increased. For bentonite sample, the permeability increased from 148.0 (No) at 0% water content addition to 152 (No) at 2% water content, after which decreased to 140 (No) at 5% water content, while permeability value of Ukpor clay sample increased from 145.0 (No) at 0% water content to 151 (No) at the same 2% water content addition; after which decreased to 144.0 (No) at 5% water content addition. This behaviour could be attributed to the fact that water acts as blockage to the air pores in the sand thereby impeding the free passage of air through the sand. As water content increased, the excess moisture available occupies the pores in the sand mould, thus leading to a corresponding decrease in the permeability of the sand. This is illustrated clearly in the Figure 4.64.

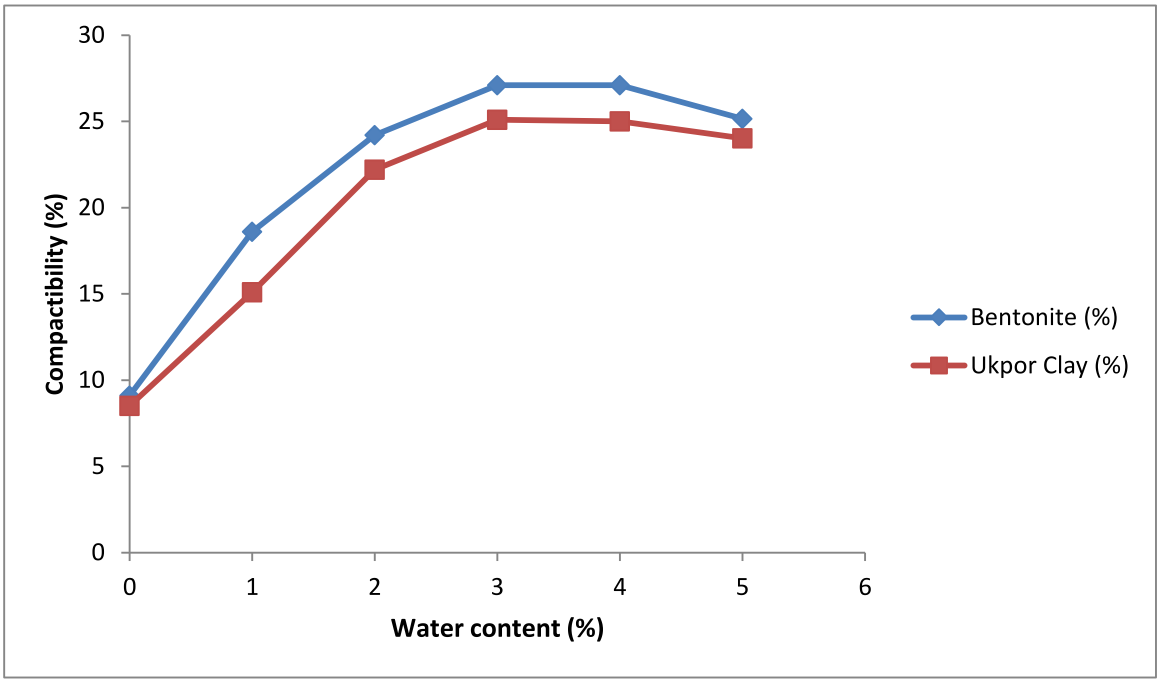


Fig. 4.65 Effect of compactibility on % water content at constant 4% additives(bentonite and Ukpor clay)

It was observed that compactibility value of the River Niger sand increased with increase in percentage water content addition, upto a certain maximum value, after which decreased for both binders. From the Figure 4.65, bentonite sample recorded higher value of 27.10% at 4% water content addition compared to 25.10% recorded for Ukpor clay at 3% water addition. The bentonite sample showed a higher value in compactibility number than the Ukpor clay sample by 2.0%.

4.15 Comparism Between the Foundry Properties Results Obtained Using Constant 5% of Bentonite and Ukpor Clay as Shown in Tables 4.19e And 4.20e Respectively.

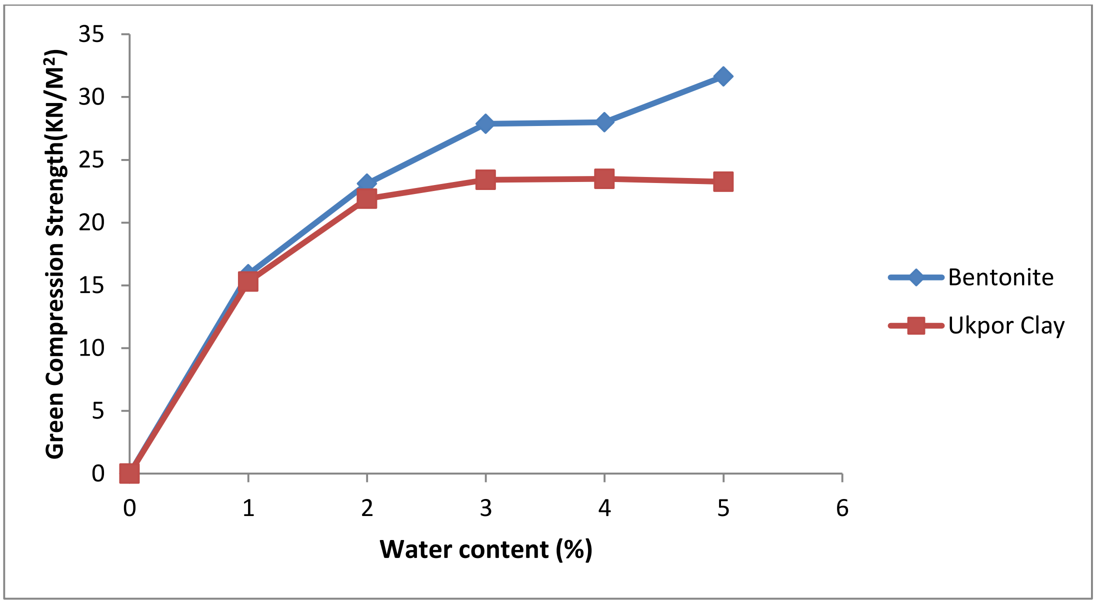


Fig. 4.66 Effect of green compressive strength on water content at 5% additives (bentonite and Ukpor Clay)

Figure 4.66 shows the variation of water content with the green compressive strength. It was observed that the green compressive strength increased with increase in percentage water content addition upto a certain maximum value. Green compressive strength increased from 15.90kN/m^2 at 1% water content reaching a maximum value of 31.65 kN/m^2 at 5% water content for bentonite samples, while the maximum value of green compressive strength of 23.48 kN/m^2 was obtained at percentage water content at 4% for Ukpor clay samples. Further increase in the percentage water content addition above 5% and 4% would leads to reduction in the green compression strength for bentonite and Ukpor clay samples.Decline in green compression strength, with increase in water content suggests the presence of excess moisture in the sand mould for Ukpor clay sample. The optimum water addition of 4% is adequate to obtain sand casting product with Ukpor clay samples based on green sand property as shown in Table 4.19e, 4.20e in the appendix and Figure 4.66.

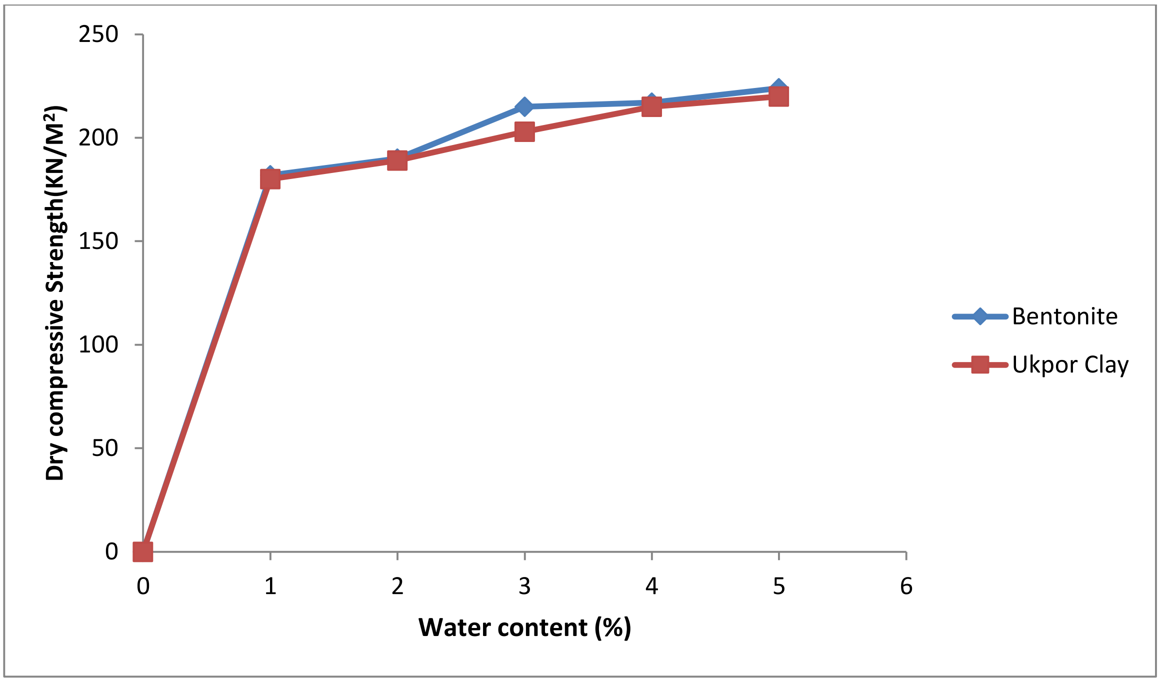


Fig. 4.67 Effect of dry compressive strength on water content at 5% additives (bentonite and Ukpor Clay)

Figure 4.67 shows the variation of water content with the values of the dry compressive strength of the moulding sand for both the bentonite and Ukpor clay samples. It was observed that the dry compressive strength increased with increase in water content concentration for both binders with bentonite sample having greater values at all moisture level as shown in Table

4.19e, 4.20c in the appendix and Figure 4.67, when mixed with 1% water content the dry compressive strength were 182 kN/m^2 and 180 kN/m^2 respectively for bentonite and Ukpor clay. These values increased to 224kN/m^2 and 220 kN/m^2 at 5% water content addition respectively for bentonite and Ukpor clay samples. The increase in the dry compressive strength with increase in water content showed that the sand can absorb more moisture. This indicated that the sand in dry condition can withstand the pressure intensity of 200 kN/m^2 of the molten metal during the period of solidification in the mould, once the moulding water is at the optimum condition. This makes the dry moulding sand to be more suitable for large castings. The bentonite sample showed a higher value in dry compressive strength than the Ukpor clay sample by 4kN/m^2.

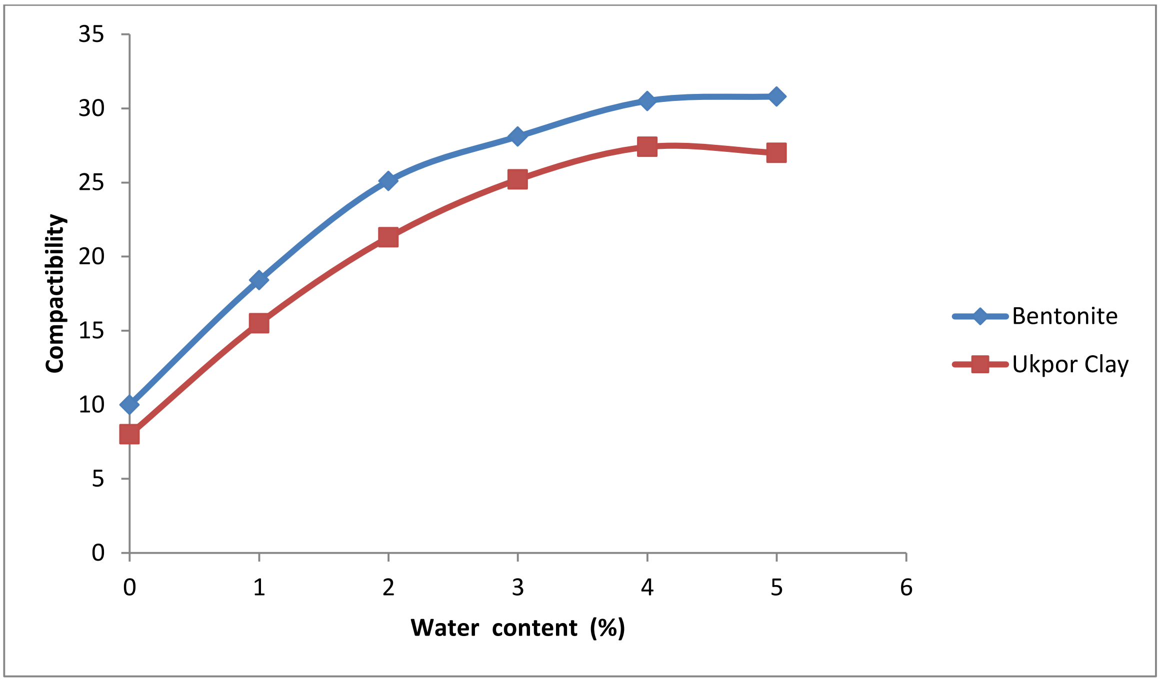


Fig. 4.68 Effect of compatibility onadded water content at 5% additives (bentonite and Ukpor Clay) constant.

Figure 4.68 illustrates the variation of percentage water addition with compactibility of River Niger Onitsha beach sand. It was observed that the increase in the percentage water addition correspond to an increase in the compactibility of the sand for both samples as shown in the Figure 4.68. The bentonite sample recorded higher value of 30.80% at 5% water content addition compared to 27% recorded for Ukpor clay at the same 5% addition. The bentonite sample showed a higher value in compactibility number than the Ukpor clay sample by 3.80%.

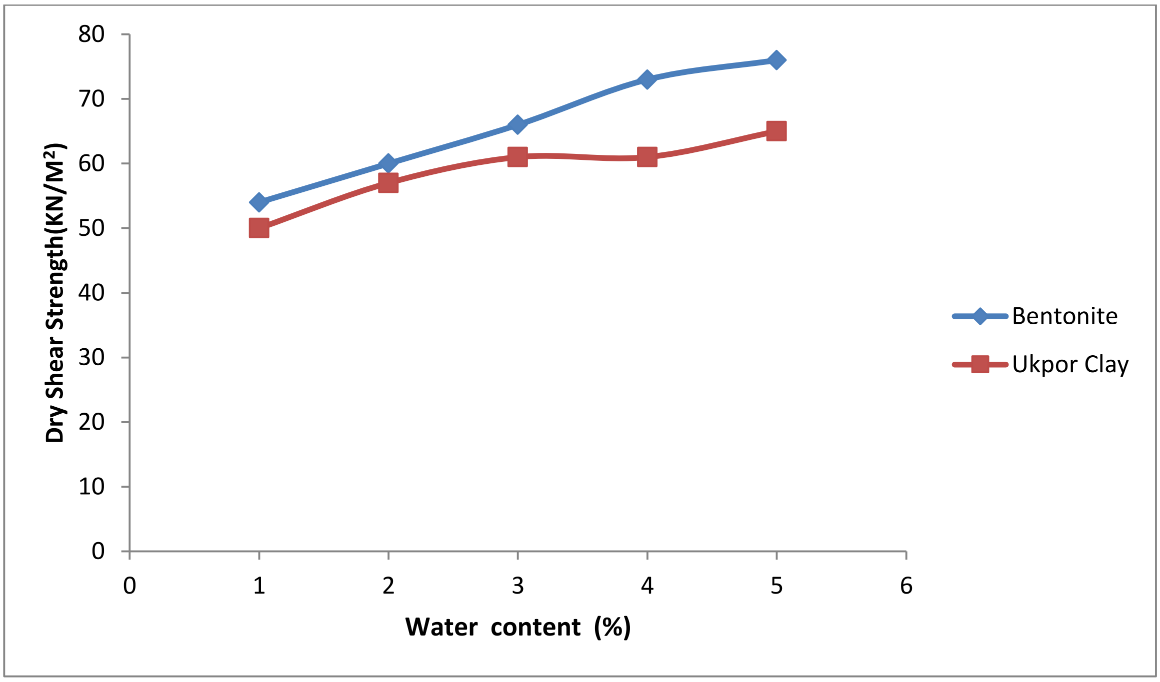


Fig. 4.69 Effect of dry shear strength on % water content at 5% constant additive (bentonite and Ukpor Clay)

Figure 4.69 shows the result of dry shear strength with varying percentages of water content addition for both binders with bentonite sample having higher values at all level. It was observed that when mixed with 1% water, the dry shear strengths were 54 kN/m^2 and 50kN/m^2 respectively for bentonite and Ukpor clay sample. These values increased to 76 kN/m^2 and 65 kN/m^2 at 5% water content addition respectively for bentonite and Ukpor clay samples.

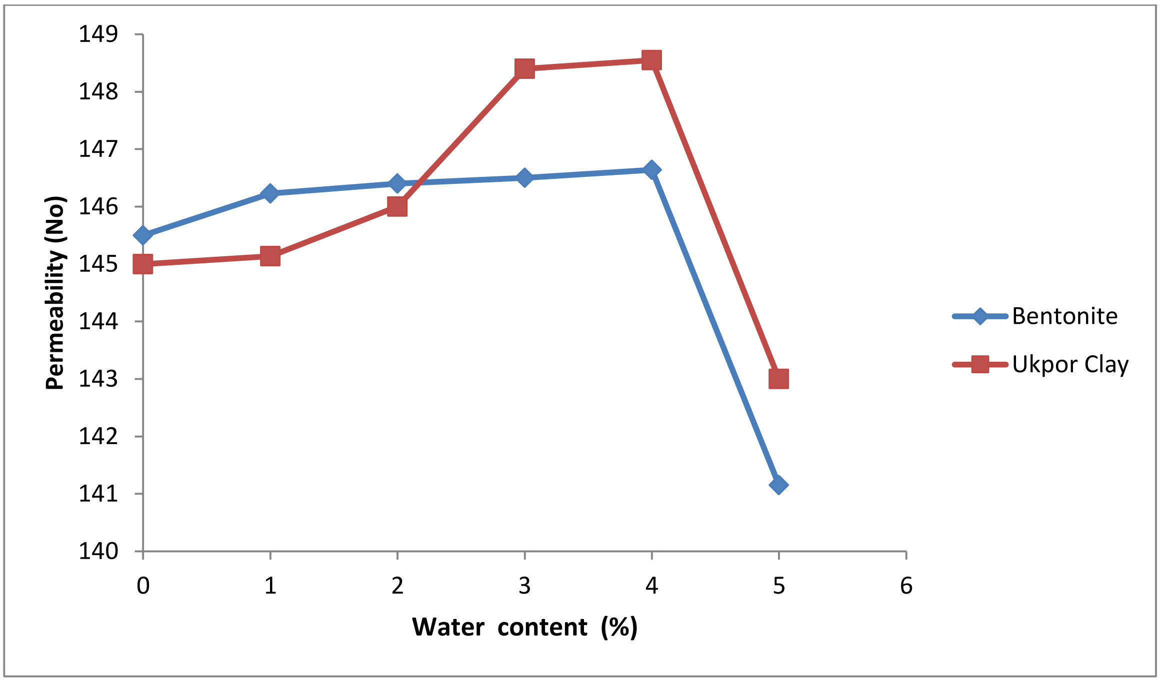


Fig. 4.70 Effect of permeability on % water content at 5% constant additives (bentonite and Ukpor Clay)

Figure 4.70 shows the results of permeability of River Niger Onitsha beach sand with varying percentages of water content addition. It was observed that the increase in water content addition corresponded to an increase in the permeability of moulded sand upto a certain maximum value. Thereafter, decreased for both binders. From the Figure 4.70 bentonite sample recorded a maximum value of 141.15 (No) at 5% water content addition compared to 143.00 (No) recorded for Ukporclay at the same 5% water content addition.The Ukpor clay showed a higher value on permeability number than the bentonite clay sample by 1.85%.

4.16 Effect of Varying Percentages of Water and Constant 2%, 3%, 4% and 5% Bentonite Sample on Foundry Properties of River Niger Onitsha Beach Sand.

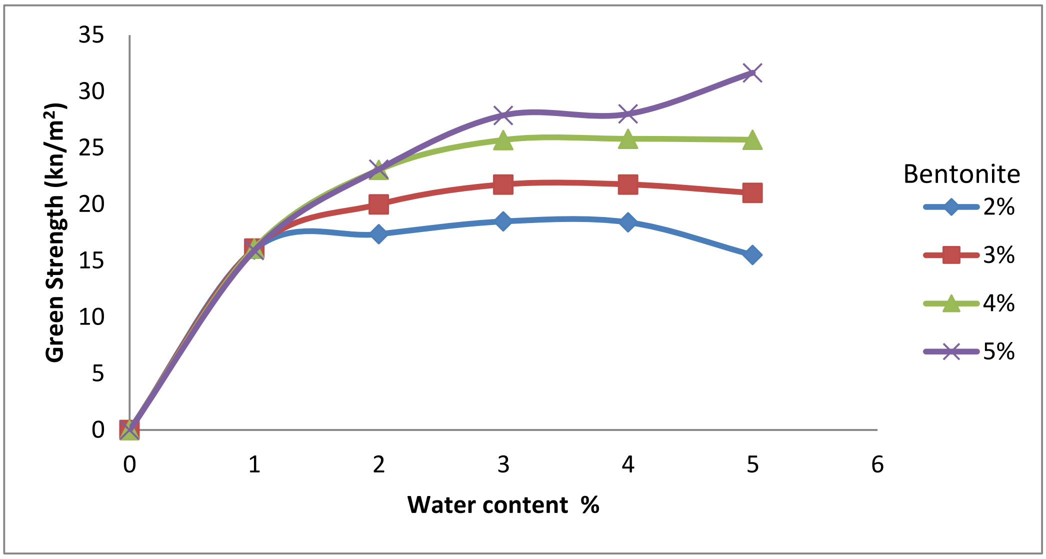


Fig. 4.71 Effect of compatibility on water content at 2%, 3%, 4% and 5% bentonite sample constant

Figure 4.71 shows the effect of green compressive strength on varying percentages of water and constant 2%, 3%, 4% and 5% bentonite sample.For 2% bentonite sample, the green compressive strength increased from 16.08kN/m^{2}at 1% water to 18.48KN/m^{2}at 3% water, after which decreased to 15.50KN/m^2, which corresponded to 5% water content. For 3% bentonite sample, the green strength increased from 16.08KN/m^2 at 1% water content to 21.76kN/m^{2}at 4% water content. But 4% bentonite sample increased from 16.08kN/m^{2}at 1% water content to 25.80kN/m^{2}at 4% water content. Thereafter, decreased to 25.72kN/m^{2}at 5% water content. Also, 5% bentonite sample increased from 15.90kN/m^{2}at 1% water content to 31.65kN/m^2 which corresponded to 5% water content addition. This is shown clearly in Figure 4.71. According to Scott (2000), increasing the water content in sand increases the green compressive strength to a point referred to as temper point. The percentage of added water required to reach the temper point for 3% bentonite were found to be 3% and 4% water content. But decline in green compressive strength with increase in water content suggests the presence of excess water in the sand mould for 2% and 3% bentonite sample. This is clearly shown in Figure 4.71.

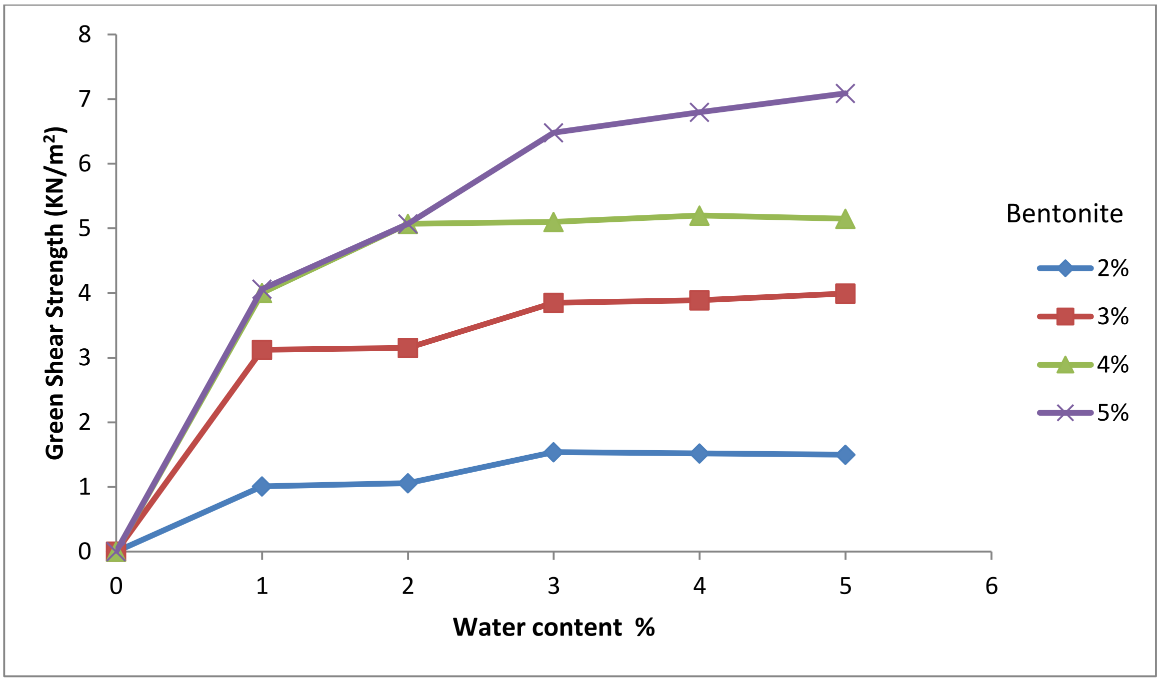


Fig. 4.72 Effect of green shear strength on % added water content at 2%, 3%, 4% and 5% bentonite sample constant

Figure 4.72 illustrates the effect of green shear strength (kN/m^2) on varying percentages of water content at 2%, 3%, 4% and 5% bentonite sample blended with River Niger Onitsha silica sand. For 2% bentonite sample, the green shear strength increased from 1.01kN/m^{2}at 1% water content to 1.54kN/m^{2}at 3% water content. After which decreased to 1.50kN/m^{2}at 5% water content. For 3% bentonite sample, the green shear strength increased from 3.12kN/m^{2}at1% water content to 3.99kN/m^{2}at 5% water content. For 4% bentonite content the green shear strength increased from 4.0kN/m^{2}at1% water content to 5.20kN/m^{2}at 4% water content, after which decreased to 5.15kN/m^2 at 5% water content addition,while with 5% of bentonite sample, the green shear strength increased from 4.06kN/m^{2}at1% water content to 7.09kN/m^{2}at 5% water content.

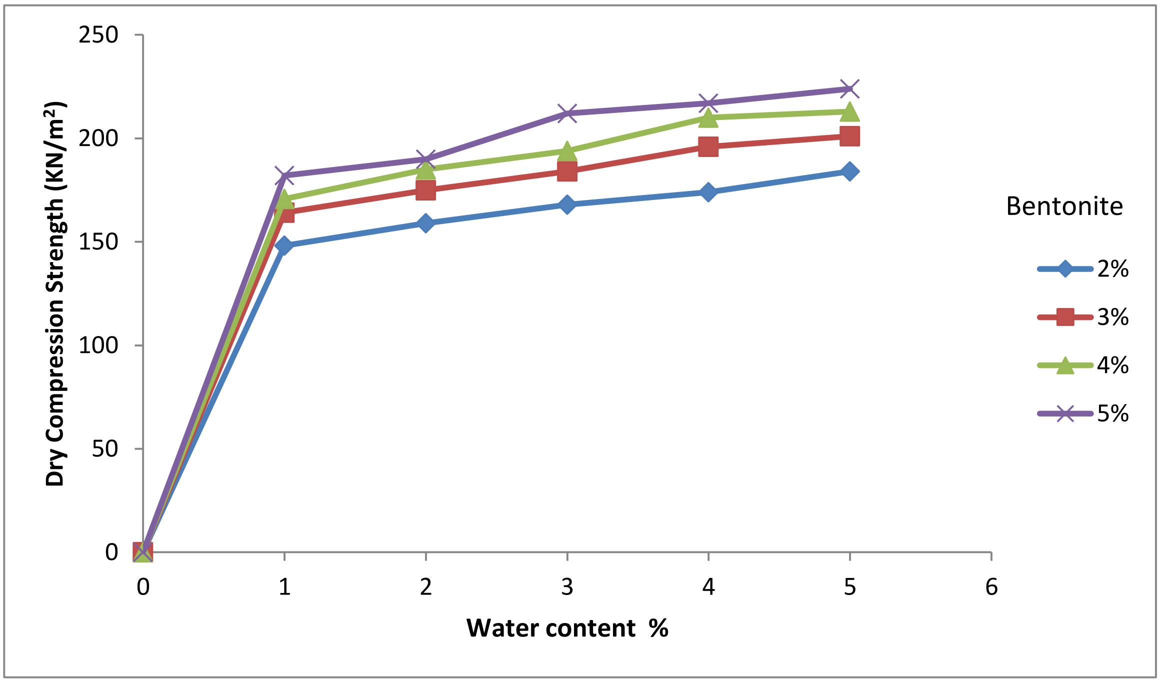


Fig. 4.73 Effect of dry compressive strength on added water content at 2%, 3%, 4% and 5% bentonite sample constant

The variation of water content with the values of dry compressive strength obtained using constant 2%, 3%, 4% and 5% bentonite sample is shown in Figure 4.73. The dry compressive strength increased with increase in water content addition for 2%, 3%, 4% and 5% bentonite sample, with 5% bentonie sample having greater values at all level as shown in Figure 4.73. When mixed with 5% water content, the dry compressive strength, were 184kN/m^2, 201kN/m^2, 213kN/m^2 and 224kN/m^2 respectively for 2%, 3%, 4% and 5% bentonite samples. This increase in the dry compressive strength with increase in water content indicated that the sand can absorb more moisture. This indicated that with 3% - 5% bentonite samples, the sand in dry condition can withstand the pressure intensity of 200kN/m^2 of the molten metal during the period of solidification in the mould once the moulding water is at the maximum condition. This makes the dry mouldingsand to be more suitable for large castings. The values obtained using 3%, 4% and 5% bentonite samples were in agreement with the American Foundry men Standard (AFS) shown in Table 4.21a.

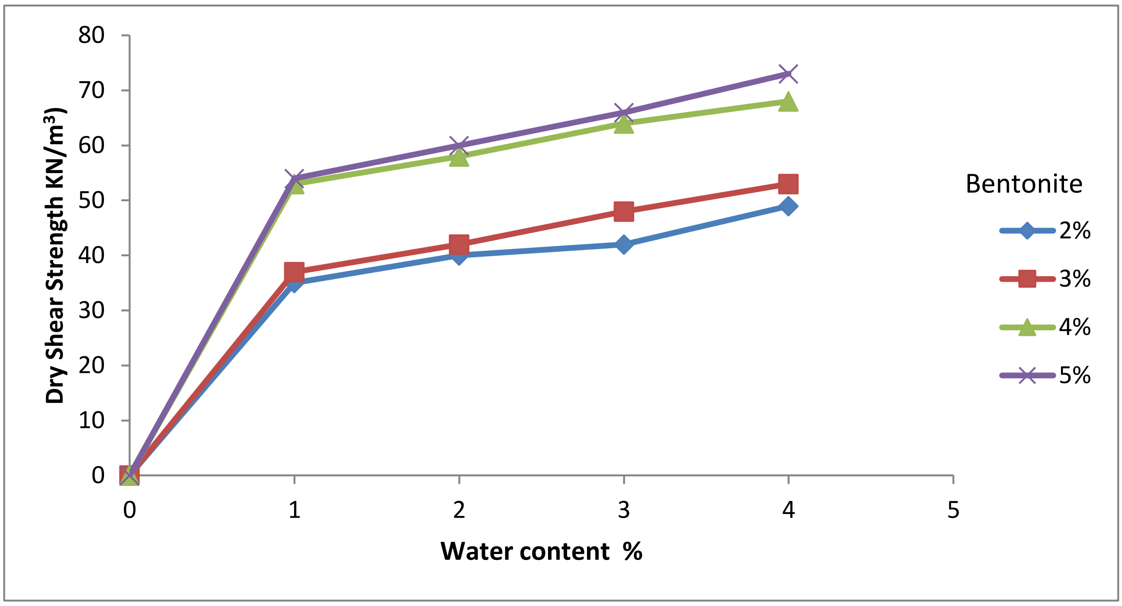


Fig. 4.74 Effect of dry shear strength on added water content at 2%, 3%, 4% and 5% bentonite sample constant

Figure 4.74 illustrate the effect of varying percentages of water content on dry shear strength (kN/m^2) at constant 2%, 3%, 4% and 5% bentonite sample. The dry shear strength increased with increase in water content addition for 2%, 3%, 4% and 5% bentonite sample. For 2% bentonite, the dry shear strength increased from 35kN/m^{2}at 1% water content addition to 54kN/m^2 at 5% water content addition, for 3% bentonite content, the dry shear strength increased from 37kN/m^2 to 57kN/m^{2}at 5% water content. For 4% bentonite sample, the dry shear strength increased from 53kN/m^{2}at 1% water content addition to 75kN/m^{2}at 5% water content. And 54kN/m^2 to 76kN/m^2 corresponded to 1% to 5% water content addition for 5% bentonite sample.

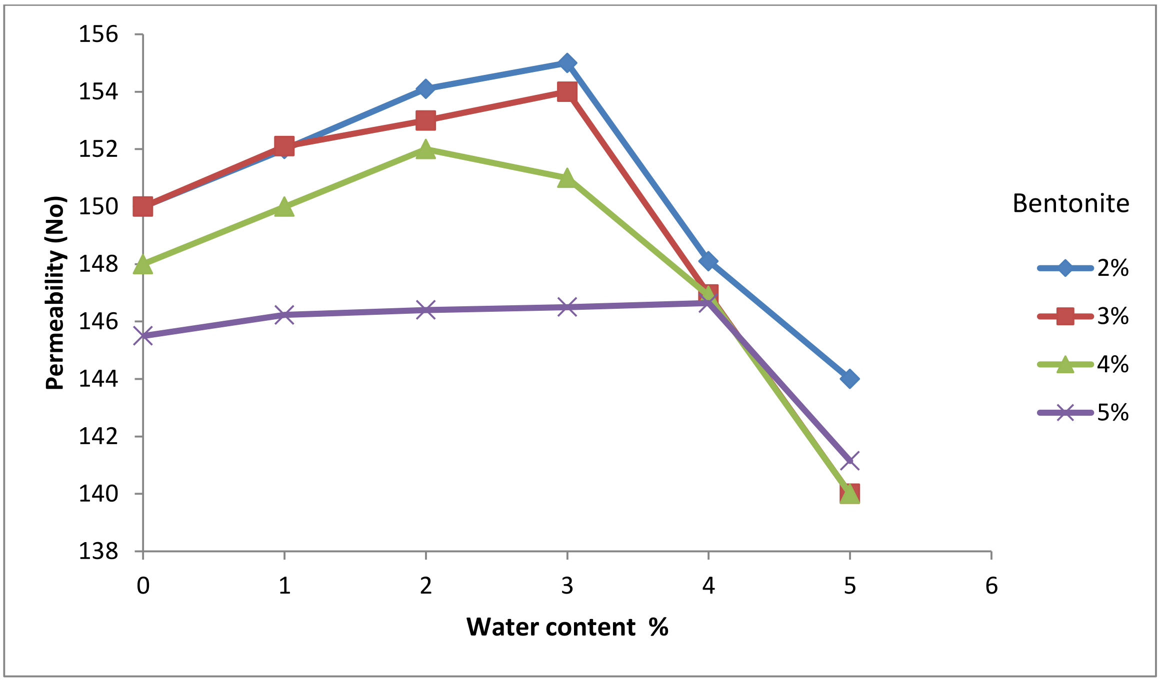


Fig. 4.75 Effect of permeability on added water content at 2%, 3%, 4% and 5% bentonite sample constant

Figure 4.75 represent the effect of varying percentage of water contents at constant 2%, 3%, 4% and 5% bentonite sample on the permeability of the moulded River Niger sand deposits. It was observe that as the added water content introduced, increased, the permeability of River Niger silica sand also increased upto a certain maximum value, and after which decreased. For 2% bentonite, the permeability value increased from 150 (No)at 0% water content to 155 (No)at 3% water content addition, after which it decreased from 155 (No)at 3% water content to 144 (No)at 5% water content addition. For 3% bentonite sample, the permeability increased from the same 150 (No)at 0% water to 154 (No)at 3% water content, after which decreased to 140 (No)at 5% water content. 4% bentonite sample, increased from 148 (No)at 0% water to 146.90 (No)at 4% water content addition, after which decreased to 140 (No) at 5% water content. Also, in 5% bentonite sample, the permeability increased from 145.50 (No)at 0% water content to 146.6 (No)at 4% water content, after which decreased to 141.15 (No)at 5% water content. This trend is seen in some of the work reviewed (Roundman 2009 and Chakraborty 1982). According to Rundman, the permeability increases in a nearly linear manner due to the swelling action of the clay particles, thereby pushing the sand particles further apart and making more room for air passages. Beyond the point where the clay becomes saturated with moisture, the water merely fills space in the void volume, resulting in an increase in density and decrease in permeability.

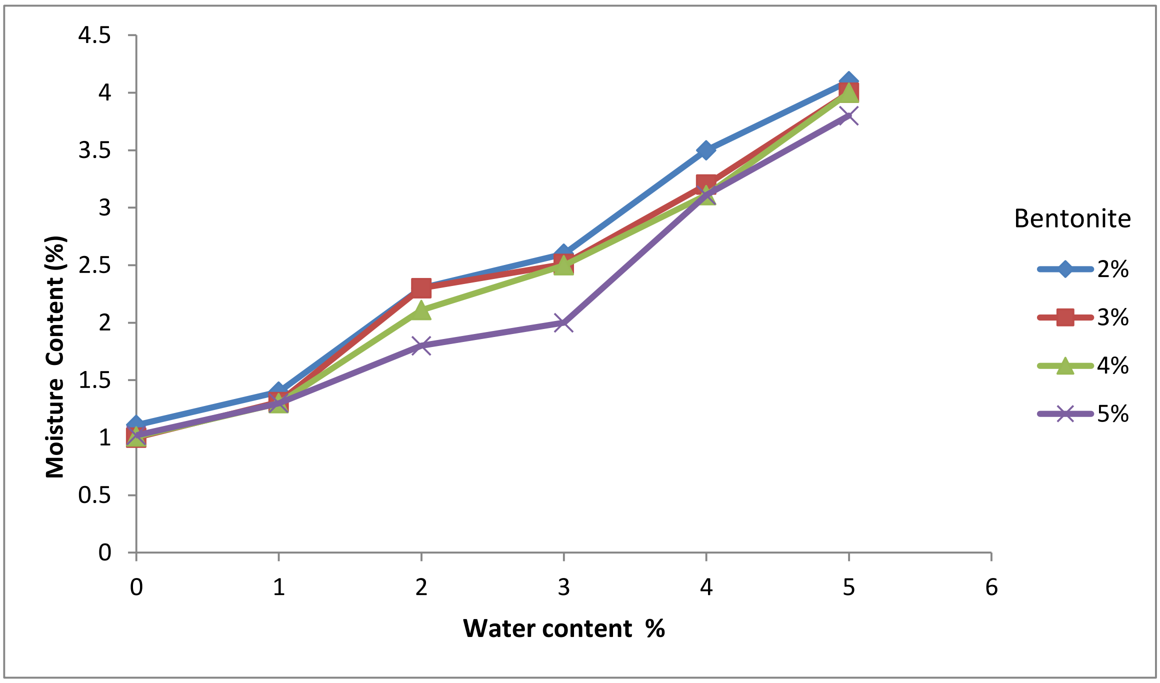


Fig. 4.76 Effect of moisture content on added water content at 2%, 3%, 4% and 5% bentonite sample constant

Figure 4.76 illustrate the effect of moisture content on varying percentages of water content addition at constant 2%, 3%, 4% and 5% bentonite sample. The percentages moisture content increased with increase in water content addition for 2%, 3%, 4% and 5% bentonite sample with 4% bentonite sample having greater values at 5% water content addition as shown in Figure 4.76. When mixed with 5% water content, the moisture content were 4.10%, 4.00%, 4.00% and 3.80% respectively for 2%, 3%, 4% and 5% samples. This is consistent with the observations by Ahem and Nuhu (2008) stating that the initial water added to a sand mix is absorbed by the binder till saturation. After water saturation of the sand mix is attained, any more added water is held up as free water thereby accounting for the continuous increase in moisture content observed in Figure 4.76. But when the moisture is too much, the particles of the sand will not bind; while insufficient moisture will result in defects in castings produced from such formed mould. Thus optimum moisture is essential for good moulding sand.

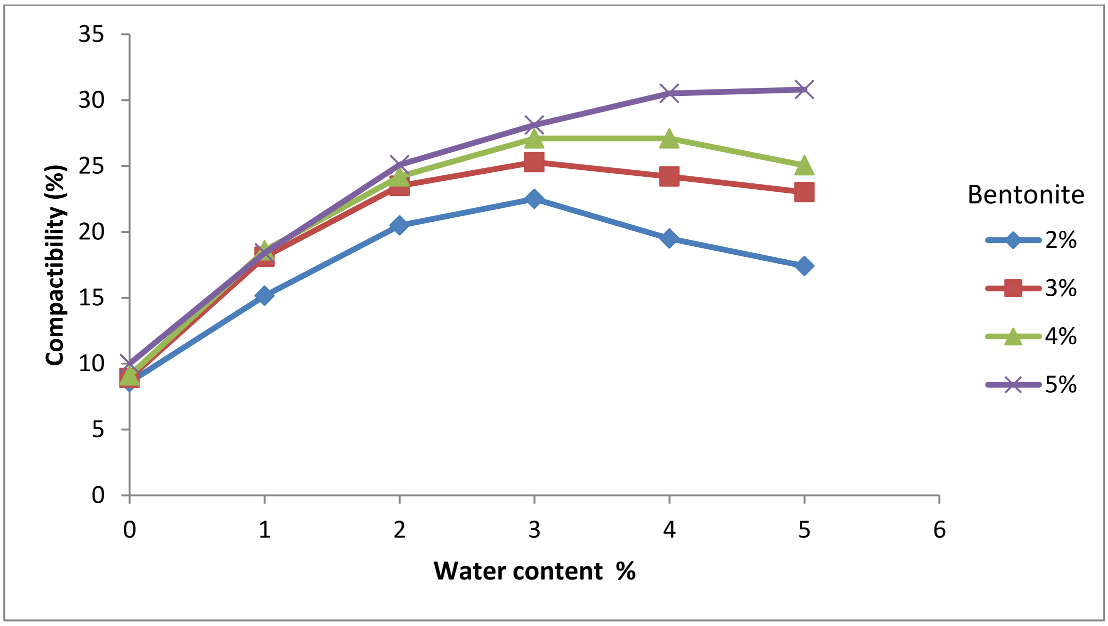


Fig. 4.77 Effect of compatibility on added water content at 2%, 3%, 4% and 5% bentonite samples constant

It was observed that compactibility values increased as the percentages of water content addition increased upto a certain maximum value, after which the compactibilitydecreased for all the binders,except for5% bentonite sample. For 2% bentonite, the compactibility increased from 8.60% at 0% water to 22.50% at 3% water addition, after which decreased to 17.40% at 5% water content addition. For 3% bentonite content, the compactibility increased from 8.90% at 0% water to 25.30% at 3% water addition, after which decreased to 23.00% at 5% water addition . But for 4% bentonite sample, the compactibility increased from 9.10% of 0% water content to 27.10% at 4% water content, after which decreased to 25.05 at 5% water content while for 5% bentonite sample, the compactibility increased from 10.0% at 0% water content to 30.80% at 5% water content addition. The 5% bentonite sample showed a higher value in compactibility number than 2%, 3% and 4%bentonite sample with 5.65% as shown in the Figure 4.77.

4.17 Effect of Varying Percentages of Water and Constant 2%, 3%, 4% and 5% Ukpor Clay Content on Foundry Properties of River Niger Onitsha Beach Sand

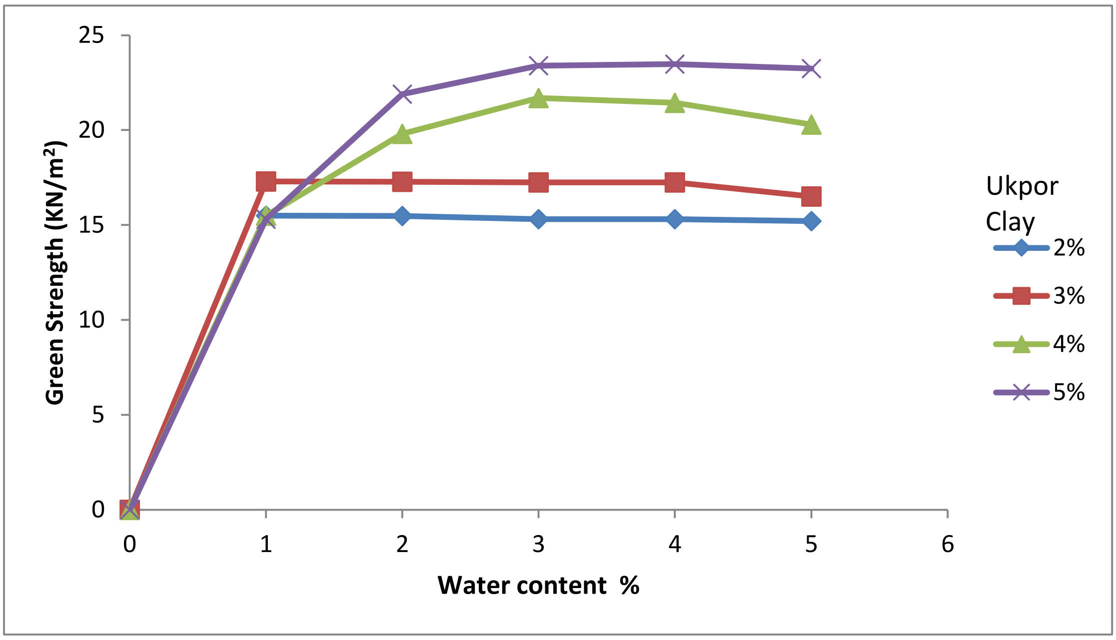


Fig. 4.78 Effect of green strength on added water content at 2%, 3%, 4% and 5% Ukpor clay sample constant

Figure 4.78 illustrates the effect of green compressive strength on varying percentages of water content and constant 2%, 3%, 4% and 5% Ukpor clay sample. It was observed that, for 2% and 3% Ukpor clay sample, the green compressive strength decreased as the water content introduced increased. For 4% Ukpor clay sample, the green compressive strength increased from 15.50kN/m^{2}at 1% water content addition to 21.69kN/m^{2}at 3% water content addition, after which decreased from 21.69kN/m^{2}at 3% water content to 20.30kN/m^{2}at 5% water content, while 5% Ukpor clay sample, increased from 15.30kN/m^{2}at 1% water to 23.48kN/m^{2}at 4% water content, after which decreased to 23.25kN/m²at 5% water content. Decrease in green compressive strength in 2%, 3% and 4% Ukpor clay sample suggests the presence of excess water in the sand mould.

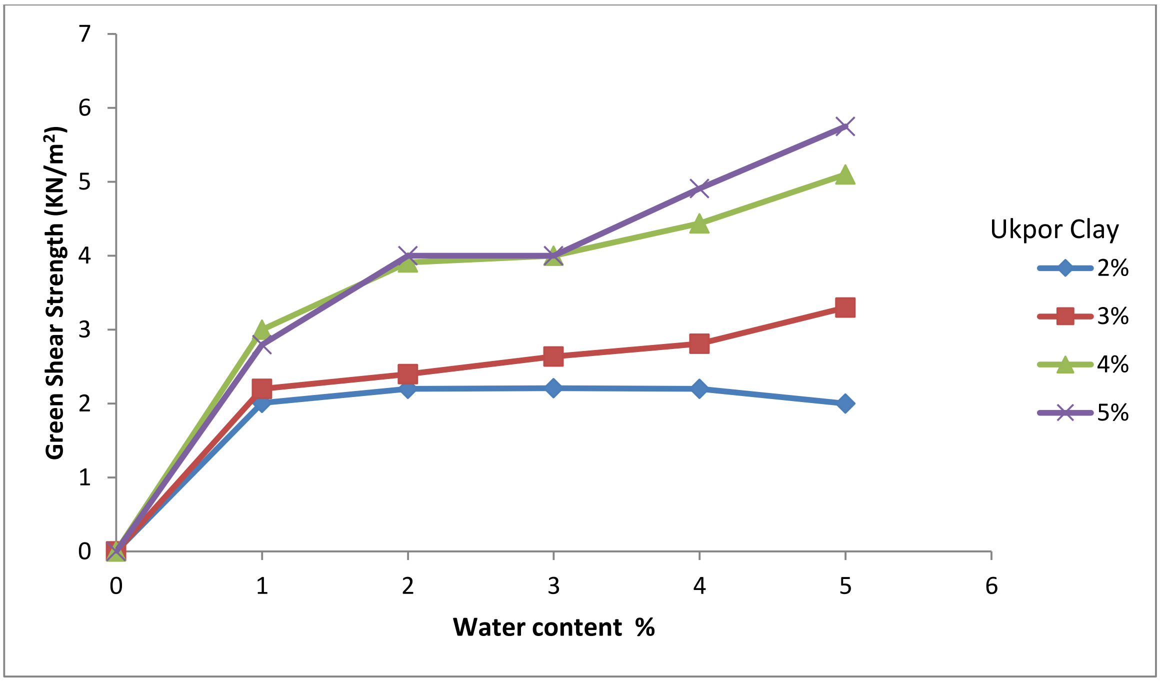


Fig. 4.79 Effect of green shear strength on added water content at 2%, 3%, 4% and 5% Ukpor clay sample constant

From the Figure 4.79, it was observed that the green shear strength increased with increase in water content addition, except for 2% Ukpor clay sample, in which the green shear strength increased from 2.01kN/m²at 1% water content addition to 2.21kN/m² at 3% water content, after which decreased from 2.21kN/m² to 2.0kN/m²at 5% water content addition. For 3%, 4% and 5% Ukpor clay sample, the green shear strength increased with increased in water content introduced as shown in Figure 4.79.

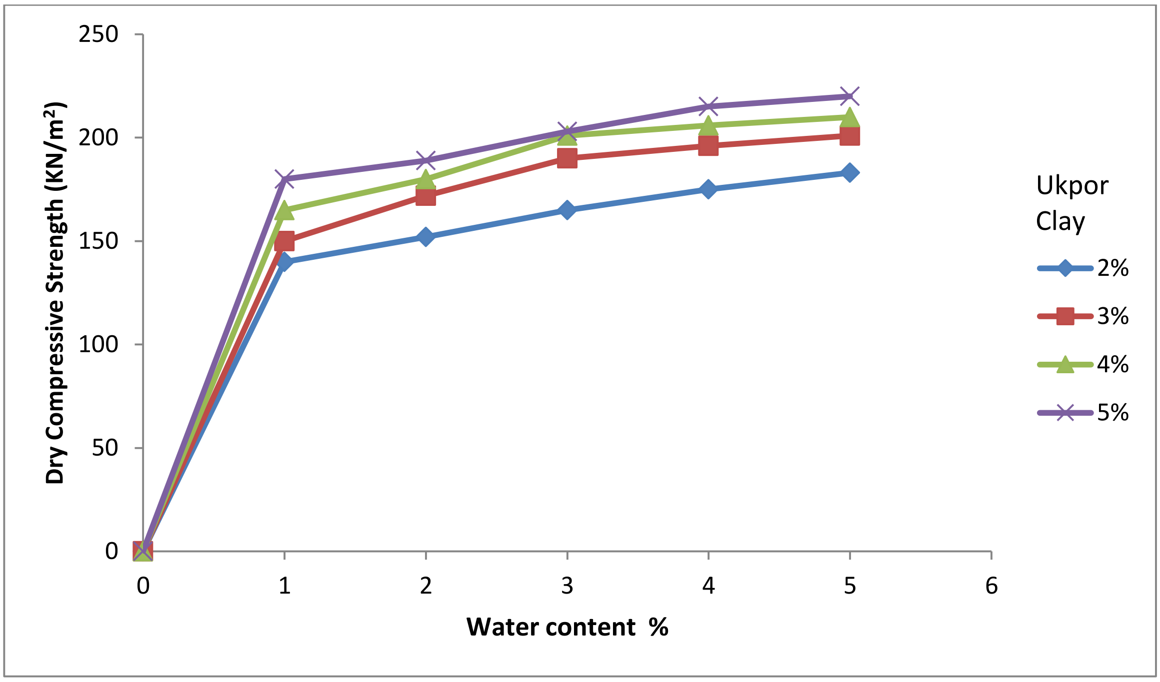


Fig. 4.80 Effect of dry compression strength on added water content at 2%, 3%, 4% and 5% Ukpor clay sample constant

Figure 4.80 illustrates the effect of dry compressive strength (kN/m^2) on varying percentages of water content at constant 2%, 3%, 4% and 5% Ukpor clay sample, it was observed that dry compressive strength increased as the water content introduced increased. For 2% Ukpor clay sample, the dry strength increased from 140kN/m^2 at 1% water content to 183kN/m^{2}at 3% water content. For 3% Ukpor clay, the dry strength increased from 150kN/m^{2}at 1% water content to 201kN/m^{2}at 5% water content. For 4% Ukporclay sample, the dry compressive strength increased from 165kN/m^{2}at 1% water content to 210kN/m^{2}at 5% water content. For 5% Ukpor clay sample, when mixed with 5% water content, the dry compressive strength increased to 220kN/m^2 as shown in the Figure 4.80.

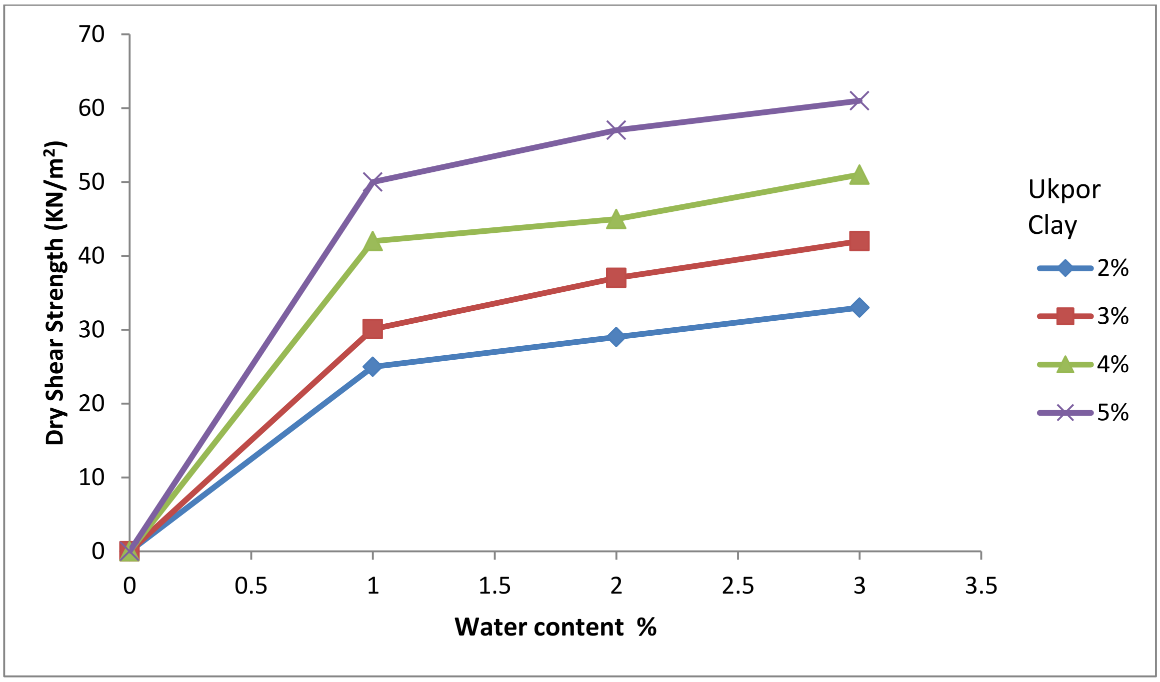


Fig. 4.81 Effect of dry shear strength on water content at 2%, 3%, 4% and 5% Ukpor clay sample constant

Figure 4.81 shows the effect of dry shear strength on varying percentages of water content at constant 2%, 3%, 4% and 5% Ukpor clay content. It was observed that the dry shear strength increased with increase in the water content introduced. For 2%, 3%, 4% and 5% Ukpor clay, when mixed with 5% water content addition, the dry shear strength were 41kN/m^2, 51kN/m^2, 60kN/m^2 and 65kN/m^2 respectively for 2%, 3%, 4% and 5% Ukpor clay sample as shown clearly in the Figure 4.81.

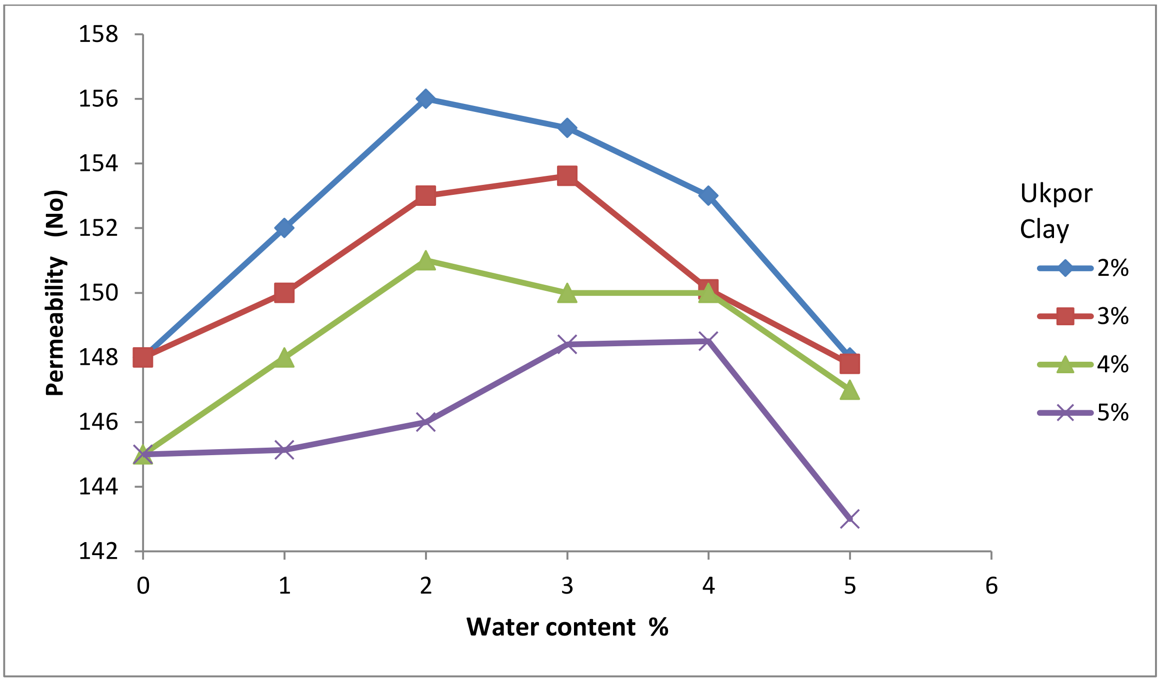


Fig. 4.82 Effect of permeability on water content at 2%, 3%, 4% and 5% Ukpor clay sample

Figure 4.82 shows the effect of permeability on varying percentages of water at 2%, 3%, 4% and 5% Ukpor clay sample. It was observed that the permeability increased as the water content introduced increased, upto a certain maximum point after which decreased. For constant 2%, 3%, 4% and 5% Ukpor clay sample, when mixed with 5% water content the permeability values were 148 (No), 147.80 (No), 147 (No) and 143 (No) respectively for 2%, 3%, 4% and 5% Ukpor clay samples.

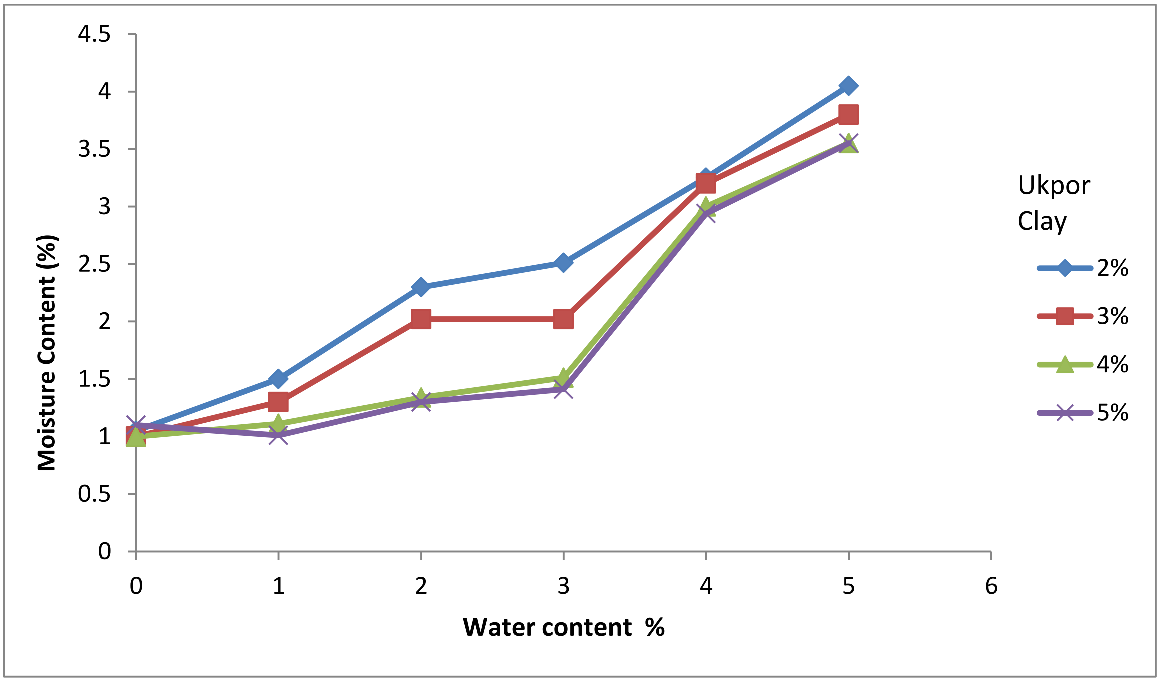


Fig. 4.83 Effect of moisture content on added water content at 2%, 3%, 4% and 5% Ukpor clay sample

Figure 4.83 illustrates the effect of moisture content on varying percentages of water at constant 2%, 3%, 4% and 5% Ukpor clay sample. It was observed that the moisture content increased as the water content introduced increased. When mixed with 5% water content, the moisture content were 4.05%, 3.80%, 3.55% and 3.55% respectively for 2%, 3%, 4% and 5% Ukpor clay sample. It is also consistent with the observations of Ahem and Nuhu (2008), stating that the initial water introduced to a sand mix is absorbed by the binder till saturation. After water saturation of the sand mix is obtained, any more added water is held up as free water thereby accounting for the continuous increase in moisture content observed in the Figure 4.83.

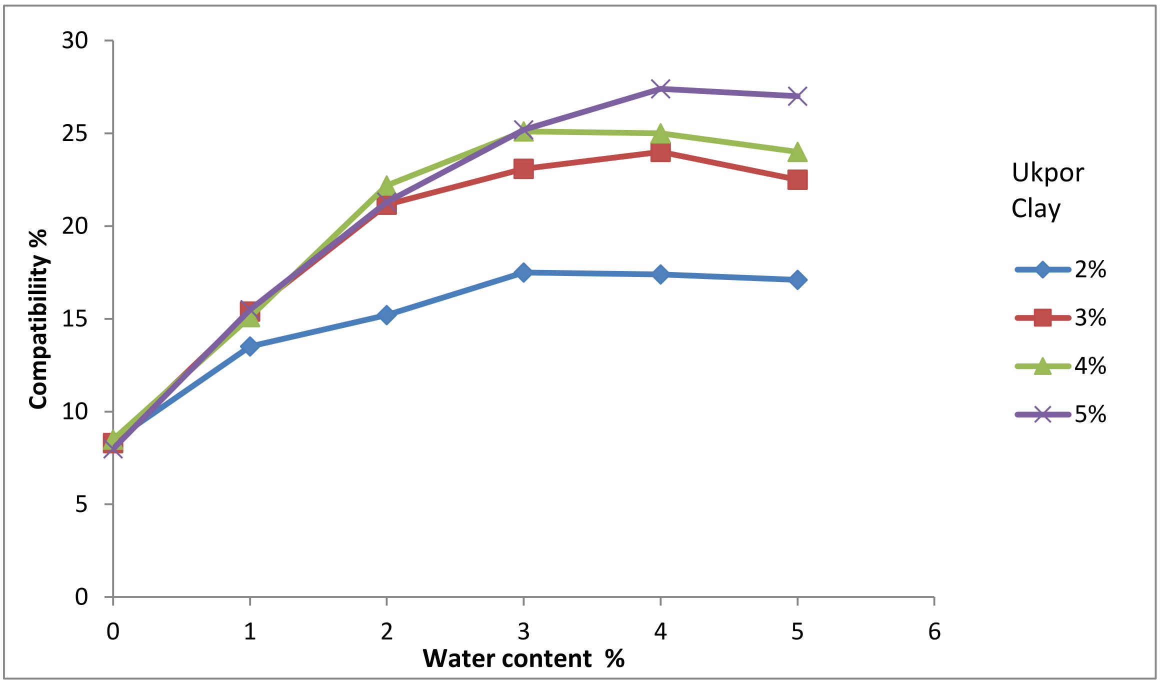


Fig. 4.84 Effect of compatibility on added water content at 2%, 3%, 4% and 5% Ukpor clay sample constant

Figure 4.84 shows the effect of compactibility (%) on varying percentages of water content at constant 2%, 3%, 4% and 5% Ukpor clay sample. It was observed that the compactibility test result increased as the percentage of water content introduced increased upto a certain maximum value, and thereafter decreased. For 2% Ukpor clay sample, the compactibility increased from 8.41% at 0% water content to 17.50% water content addition, after which decreased from 17.50% to 17.10% at 5% water content. For 2%, 3%, 4% and 5% Ukpor clay sample, when mixed with 5% water content, the compactibility values were 22.50%, 24.01, 27.00% respectively for 3%, 4% and 5% Ukpor clay sample.

4.18 Effect of Varying Percentages of Bentonite and Constant 2%, 3%, 4% And 5% Water Content on Foundry Properties of River Niger Beach Sand.

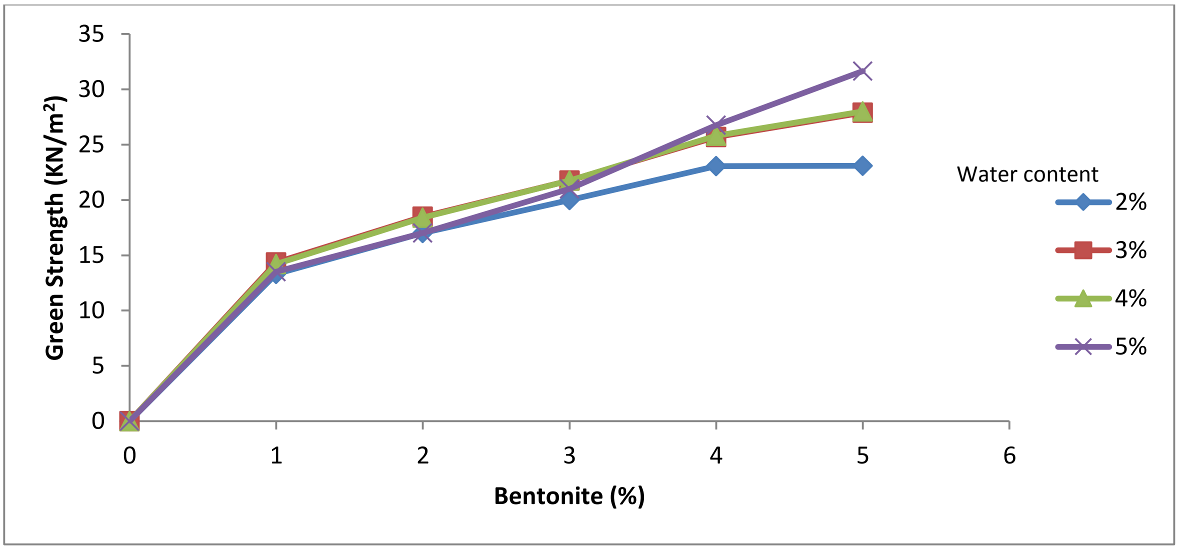


Fig. 4.85 Effect of green compressive strength on bentonite and constant 2%, 3%, 4% and 5% water constant

Figure 4.85 shows the effect of green strength (kN/m^2) on varying percentages of bentonite at constant 2%, 3%, 4% and 5% water content. It was observed that the green compressive strength increased as the additives introduced increased. For 2%, 3%, 4% and 5% water content, when mixed with 1% bentonite content, the green compressive strength were 13.30kN/m^2, 14.35kN/m^2, 14.20kN/m^2 and 13.50KN/m^2 respectively for 2%, 3%, 4% and 5% water content, while when mixed with 5% bentonite content, the green compressive strength were 23.10kN/m^2, 27.88kN/m^2, 28kN/m^2 and 31.65kN/m^2 respectively for 2%, 3%, 4% and 5% water content. This increase in green strength was due to the combined bonding and hardening effect offered by the bentonite sample, added.

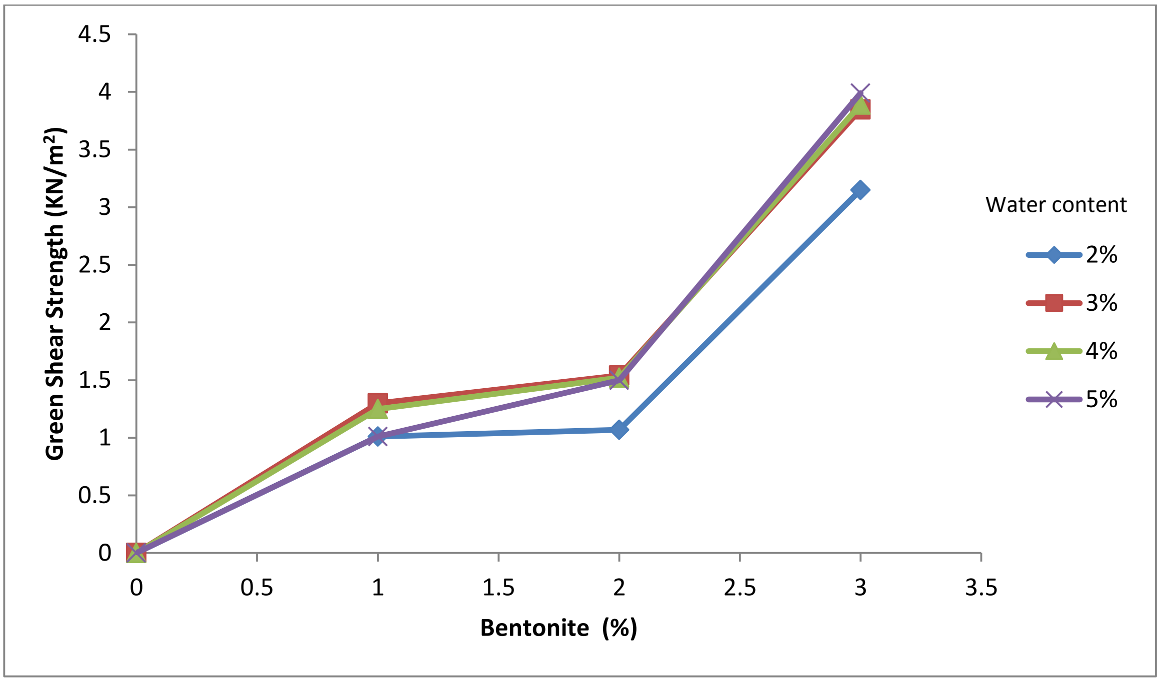


Fig. 4.86 Effect of green shear strength on bentonite at constant 2%, 3%, 4% and 5% water constant

Figure 4.86 illustrates the effect of green shear strength on varying percentages of addedbentonite at constant 2%, 3%, 4% and 5% water content. From the Figure 4.86, it was observed that the green shear strength increased as the percentage of bentonite added increased. When mixed with 5% water content, the green shear strength were 5.07kN/m^2, 6.48kN/m^2, 6.80kN/m^2 and 7.09kN/m^2 respectively for 2%, 3%, 4% and 5% water content.

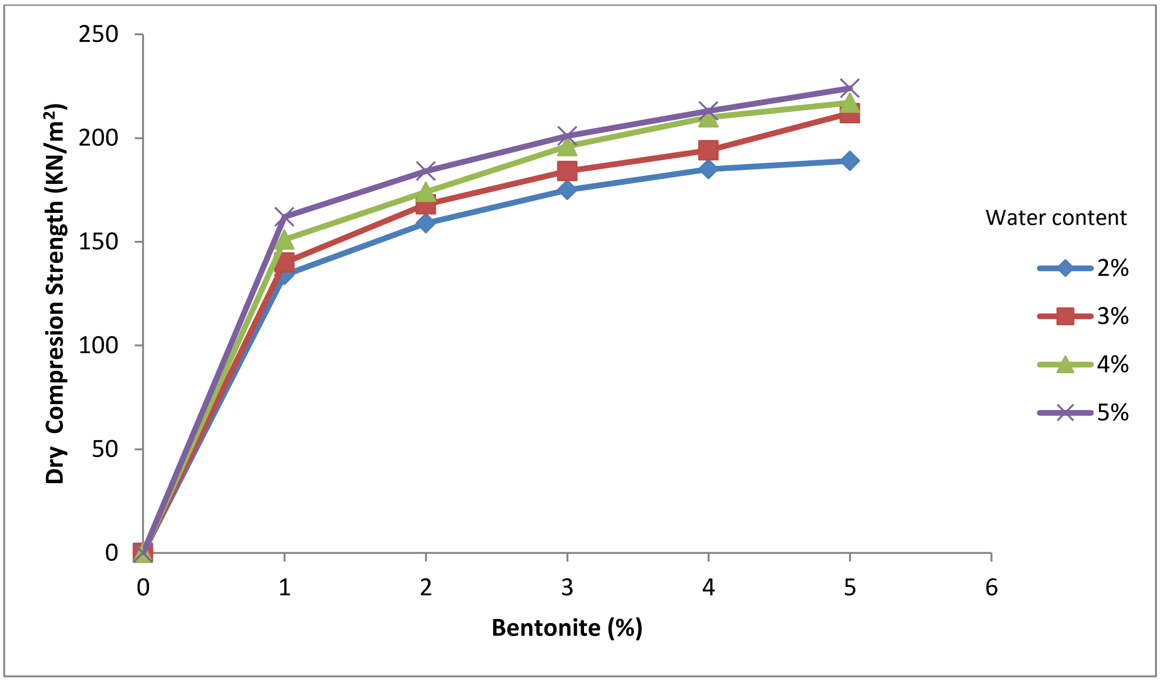


Fig. 4.87 Effect of dry compression strength on bentonite at constant 2%, 3%, 4% and 5% water constant

Figure 4.87 shows the effect of varying percentages of bentonite at constant 2%, 3%, 4% and 5% water content on dry compressive strength (kN/m^2). From the Figure, it was observed that the dry compressive strength increased as the added bentonite content increased. For 2%, 3%, 4% and 5% water content, when mixed with 1% bentonite, the dry compressive strength were 134kN/m^2, 140kN/m^2, 151kN/m^2 and 162kN/m^2 respectively. When mixed with 5% bentonite content, the dry compressive strength were 189kN/m^2, 212kN/m^2, 217kN/m^2, and 224kN/m^2 respectively for 2%, 3%, 4% and 5% bentonite sample. The properties evaluated from 3%, 4% and 5% were in agreement with the American Foundrymen Standard (AFS) shown in Table 4.21a in the appendix.

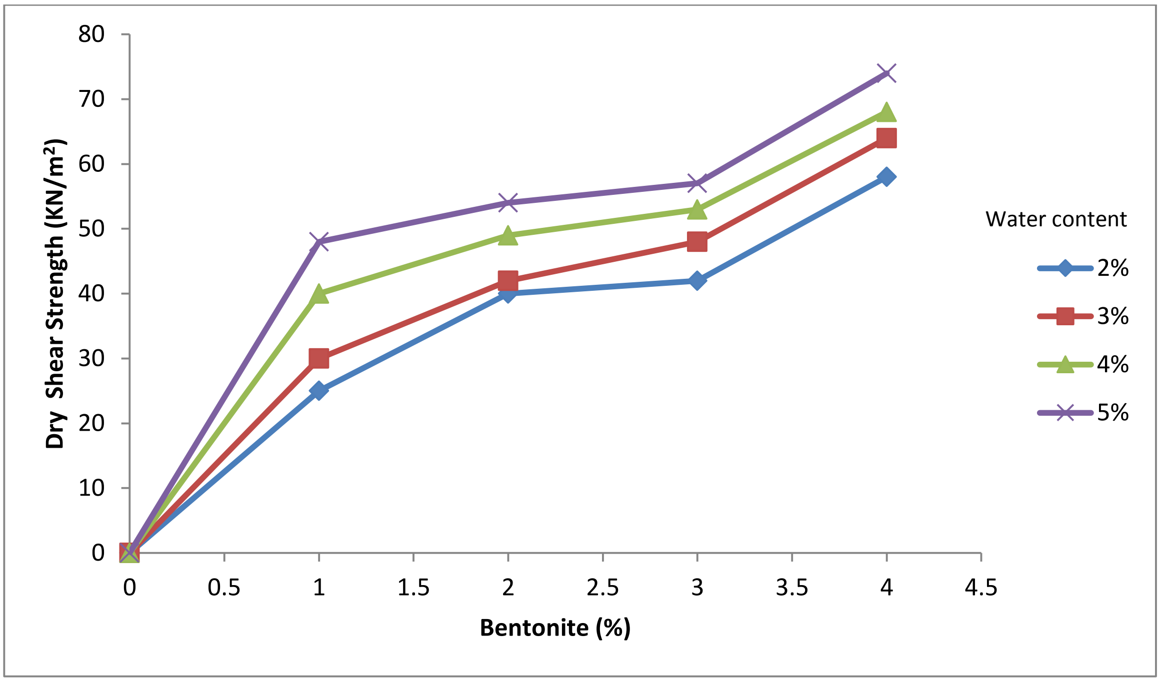


Fig. 4.88 Effect of dry shear strength on bentonite at constant 2%, 3%, 4% and 5% water constant

Figure 4.88 illustrates the effect of dry shear strength on varying bentonite content at constant 2%, 3%, 4% and 5% water content. It was observed that the dry shear strength increased as the bentonite content introduced increased. For 2%, 3%, 4% and 5% bentonite sample, when mixed with 1% of bentonitecontent, the dry shear strength were 25kN/m^2, 30kN/m^2, 40kN/m^2 and 48kN/m^2respectively for 2%, 3%, 4% and 5% bentonite sample. When mixed with 5% bentonite sample, the dry shear strength (kN/m^2) were 60kN/m^2, 66kN/m^2, 73kN/m^2 and 76kN/m^2 respectively for 2%, 3%, 4% and 5% water content.

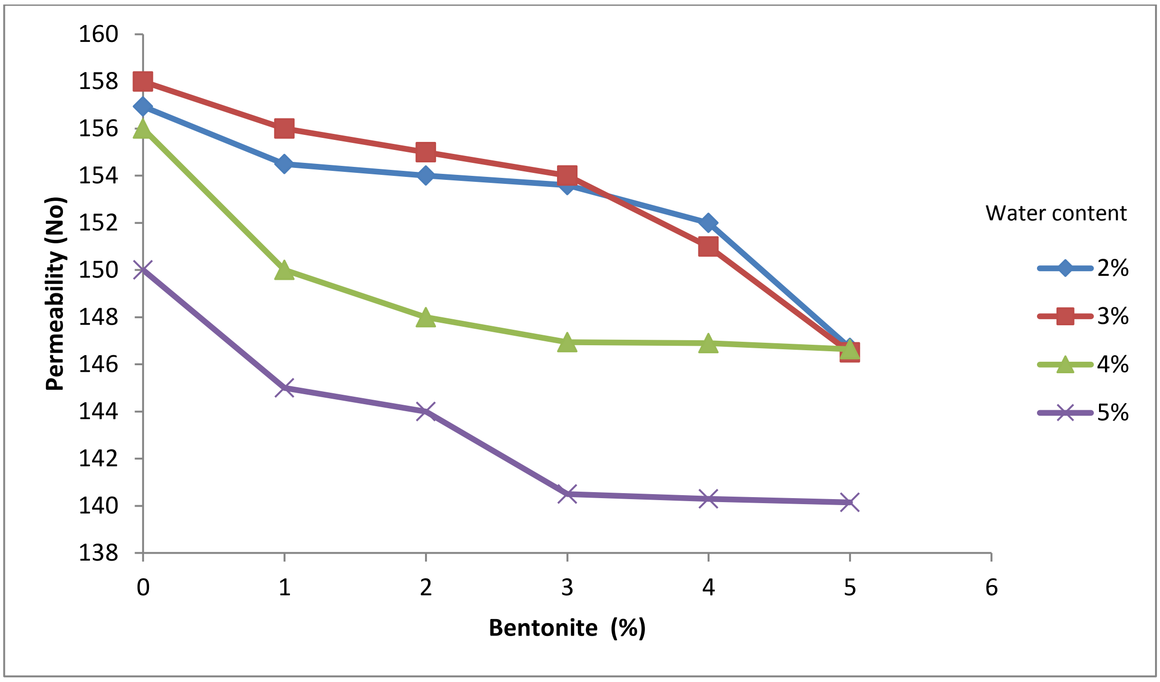


Fig. 4.89 Effect of permeability on added bentonite at constant 2%, 3%, 4% and 5% water constant

Figure 4.89 shows the effect of permeability values on varying percentages of bentonite content at constant 2%, 3%, 4% and 5% water content. It was observed that the permeability values decreased as the additives introduced increased. For 2%, 3%, 4% and 5% water content. When mixed with 1% bentonite sample, the permeability values were 154.50 (No), 156 (No), 150 (No) and 145 (No) respectively for 2%, 3%, 4% and 5% water content. When mixed with 5% bentonite sample, the permeability values were 146.70 (No), 146.50 (No), 146.64 (No), and 140.15 (No), respectively for 2%, 3%, 4% and 5% water content. bentonite is expected to bind silica sand and other particles together in the presence of water. This is achieved by filling up the pores between the grains of the silica sand. Thus the permeability is expected to decrease with increase in the binder content (Kubo, 1999).

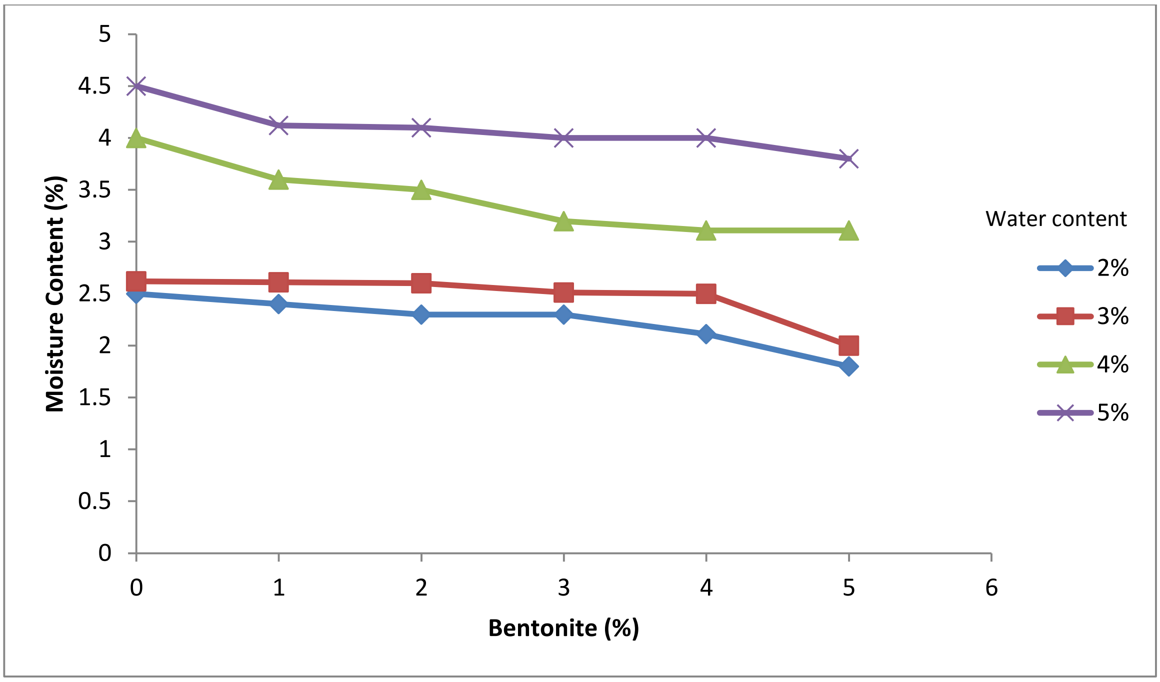


Fig. 4.90 Effect of moisture content on added bentonite at constant 2%, 3%, 4% and 5% water content

Figure 4.90 shows the effect of moisture content (%) on varying percentages of bentonite content at constant 2%, 3%, 4% and 5% water content. It was observed that the moisture content decreased as the additive introduced increased. For 2% water content, the moisture content decreased from 2.50% moisture content at 0% bentonite sample to 1.8% moisture content at 5% water content addition. For 3% water content, the moisture content decreased from 2.62% moisture at 0% bentonite to 2.0% moisture at 5% bentonite content. For 4% and 5% water content, when mixed with 5% bentonite content, the moisture content were 3.11% and 3.80% respectively for 4% and 5% water content as shown in the Figure 4.90.

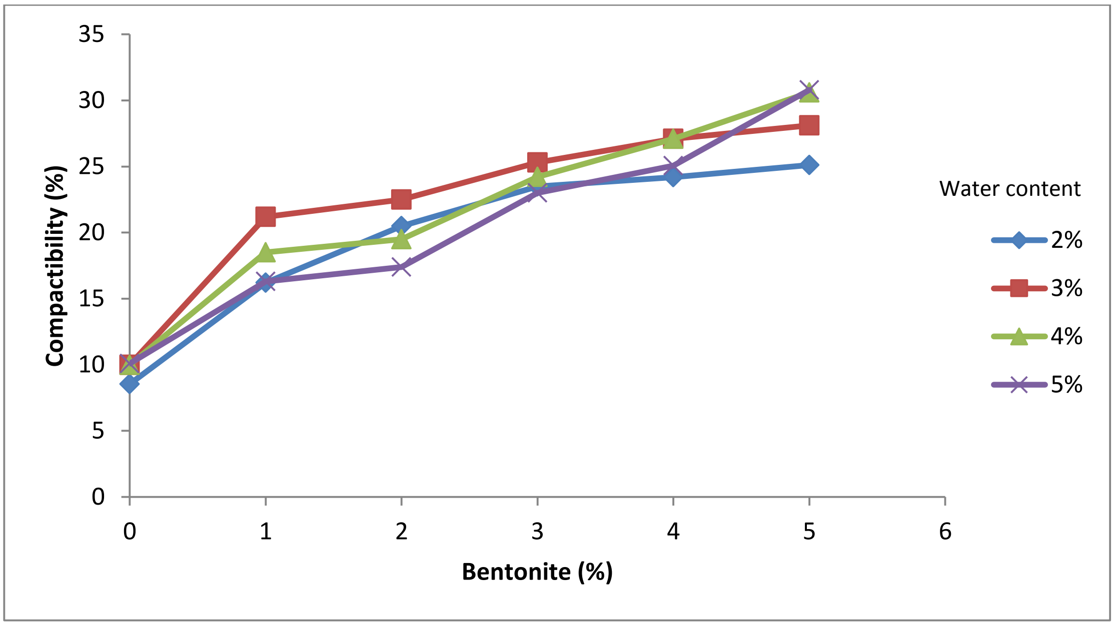


Fig. 4.91 Effect of compatibility on added bentonite at constant 2%, 3%, 4% and 5% water constant

Figure 4.91 shows the effect of compactibility on varying percentages of bentonite and constant 2%, 3%, 4% and 5% water content. It was observed that the compactibility values increased as the additive introduced increased. For 2%, 3%, 4% and 5% water content, when mixed with 5% bentonite sample, the compactibility values were 25.10%, 28.11%, 30.60% and 30.8% respectively for 2%, 3%, 4% and 5% water content. It can be seen from Tables 4.19h, 4.19i in the appendix and Figure 4.91,that as the bentonite content increased, compactibility increased as a result of the strong bond forming between the sand particles and bentonite content and compaction under pressure (Tottle, 1984).

4.19 Effect of Varying Percentages of Ukpor Clay and Constant 2%, 3%, 4% and 5% Water Content on Foundry Properties of River Niger Onitsha Beach Sand

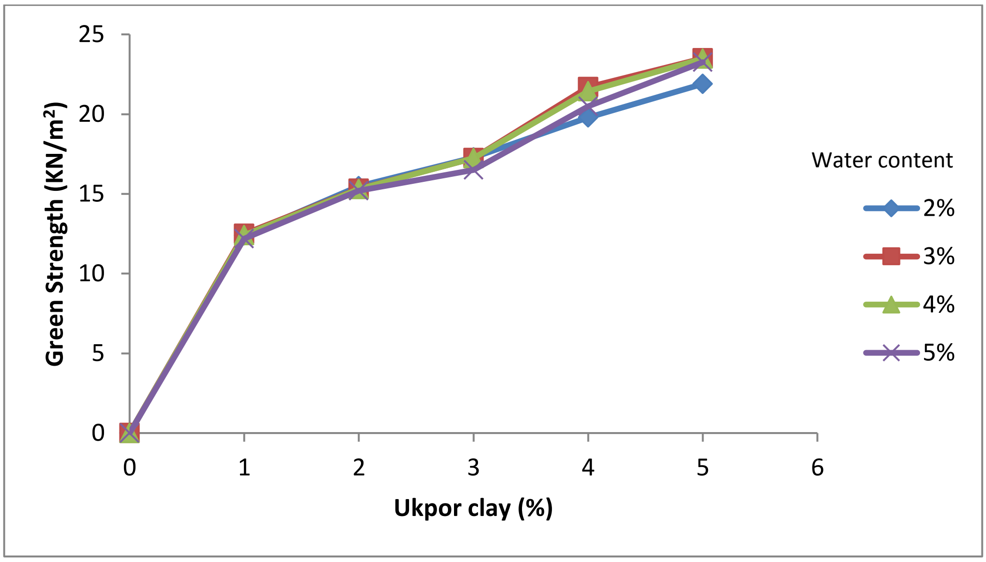


Fig. 4.92 Effect of permeability on added Ukpor clay at constant 2%, 3%, 4% and 5% water content

Figure 4.92 shows the effect of green compressive strength on varying percentages of Ukpor clay (%) at constant 2%, 3%, 4% and 5% water content. It was observed that the green compressive strength increased as the additive (Ukpor clay) introduced increased. For 2% water content, the green strength increased from 12.40kN/m^{2}at 1% Ukpor clay to 21.90kN/m^{2}at 5% Ukpor clay content. For 3% water content, the green strength increased from 12.50kN/m^{2}at1% water content to 23.50kN/m^{2}at 5% water content. For 4% and 5% water content, when mixed with 5% Ukpor clay content, the green compressive strength

(kN/m^2) were $23.48kN/m^2$ and $23.25kN/m^2$ respectively for 4% and 5% water content.

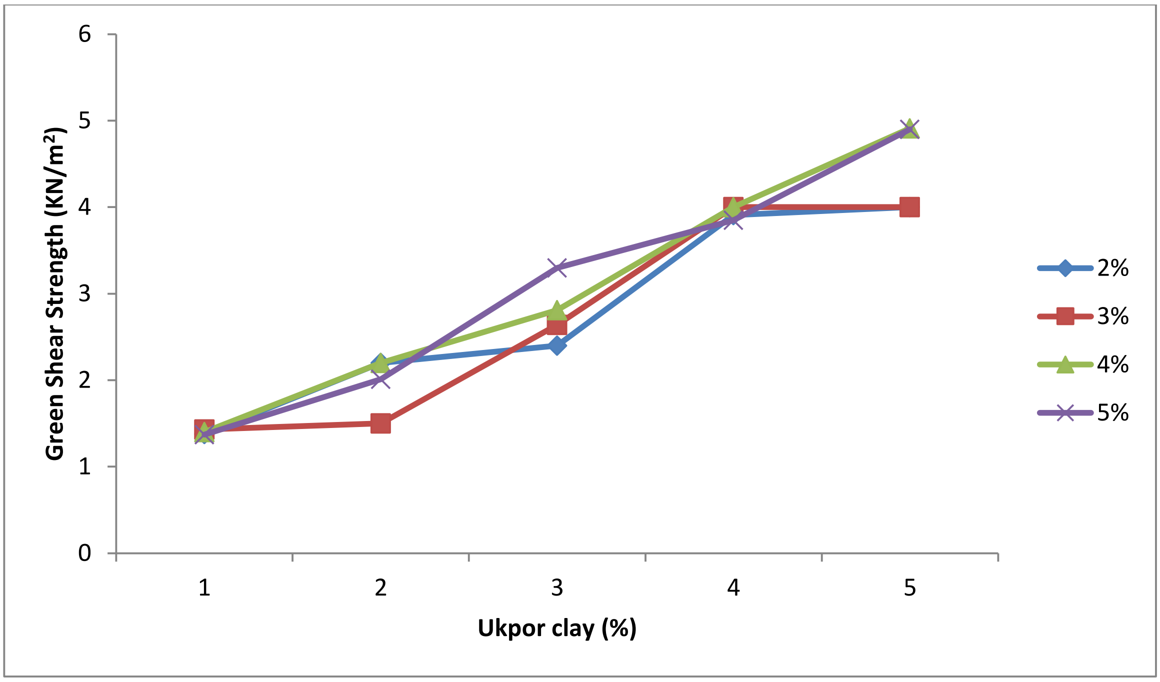


Fig. 4.93 Effect of green shear strength on added Ukpor clay at constant 2%, 3%, 4% and 5% water content

Figure 4.93 illustrates the effect of green shear strength on varying percentages of Ukpor clay and constant 2%, 3%, 4% and 5% water content. It was observed that the green shear strength increased with the increase in Ukpor clay content. For 2%, 3%, 4% and 5% water content. When mixed with 5% Ukpor clay content, the green shear strength were $4.0KN/m^2$, $4.0KN/m^2$, $4.91KN/m^2$ and $4.90KN/m^2$respectively for 2%, 3%, 4% and 5% water content.

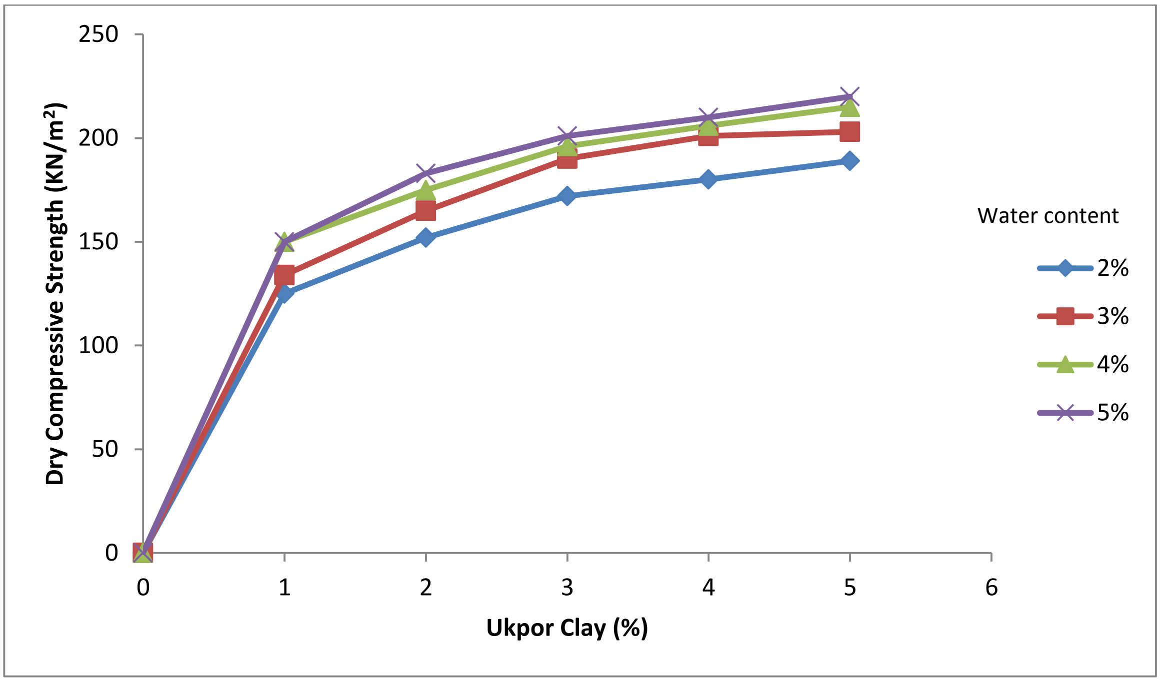


Fig. 4.94 Effect of dry compressive strength on Ukpor clay at constant 2%, 3%, 4% and 5% water constant

Figure 4.94 shows the effect of dry compression strength on varying percentages of Ukpor clay at constant 2%, 3%, 4% and 5% water content. It was observed that the dry compressive strength increased as the additive (Ukpor clay) introduced increased. For 2% water constant, the dry compressive strength increased from 125kN/m^2at 1% Ukpor clay content to 189kN/m^2 at 5% Ukpor clay. For 3% water content, the dry compression strength increased from 134kN/m^2 at 1% Ukpor clay content to 203kN/m^2at 5% Ukpor clay content. For 4% water content, the dry compression strength increased from 150kN/m^2at 1% Ukpor clay to 215kN/m^2at 5% Ukpor clay content. Also, for constant 5% water content, the dry strength increased from 150kN/m^2 at 1% Ukpor clay content, to 220kN/m^2 which corresponded to 5% Ukpor clay content.

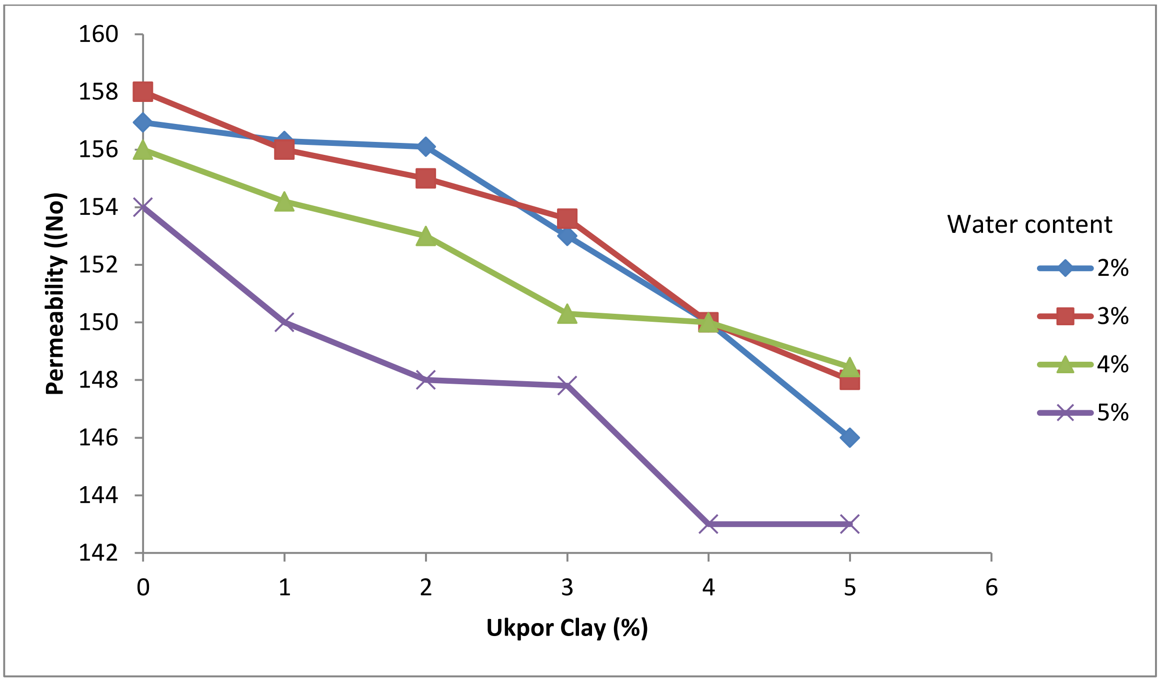


Fig. 4.95 Effect of permeability on Ukpor clay at constant 2%, 3%, 4% and 5% water content

Figure 4.95 shows the effect of permeability on varying percentages of Ukpor clay and 2%, 3%, 4% and 5% water content constant. It was observed that the permeability decreased as the additive (Ukpor clay) introduced increased. For 2% water content, the permeability decreased from 156.94 (No) to 146 (No)at 0% to 5% Ukpor clay content introduced. For 3% water content, the permeability decreased from 158 (No) to 148 (No) at 0% to 5% Ukpor clay content. For 4% water content, the permeability decreased from 156 (No) to 148.45 (No)at 0% to 5% Ukpor clay content. Also, for 5% water content, the permeability values decreased from 154 (No) to 143 (No)at 0% to 5% Ukpor clay content as shown in the Figure 4.95.

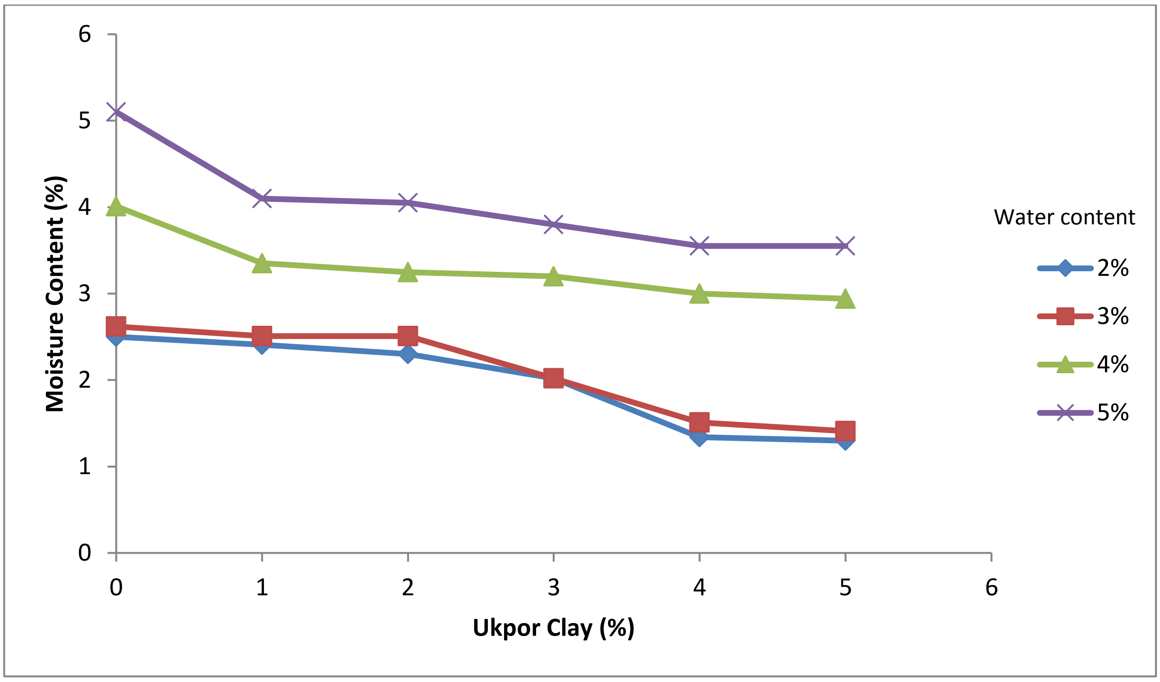


Fig. 4.96 Effect of moisture content on added Ukpor clay at constant 2%, 3%, 4% and 5% water constant

Figure 4.96 shows the effect of moisture content on varying percentages of Ukpor clay content and constant 2%, 3%, 4% and 5% water content. It was observed that, the moisture content decreased as the additive (Ukpor clay) introduced increased. For 2% water content, the moisture content decreased from 2.50% to 1.30% at 0% to 5% Ukpor clay content. For 3% water content, the moisture content decreased from 2.62% to 1.41% at 0% to 5% Ukpor clay content. For 4% water content the moisture decreased from 4.01% to 2.94% at 0%to 5% Ukpor clay content. For 5% water content, the moisture decreased from 5.10% to 3.55% at 0% to 5% Ukpor clay content as shown in figure 4.96.

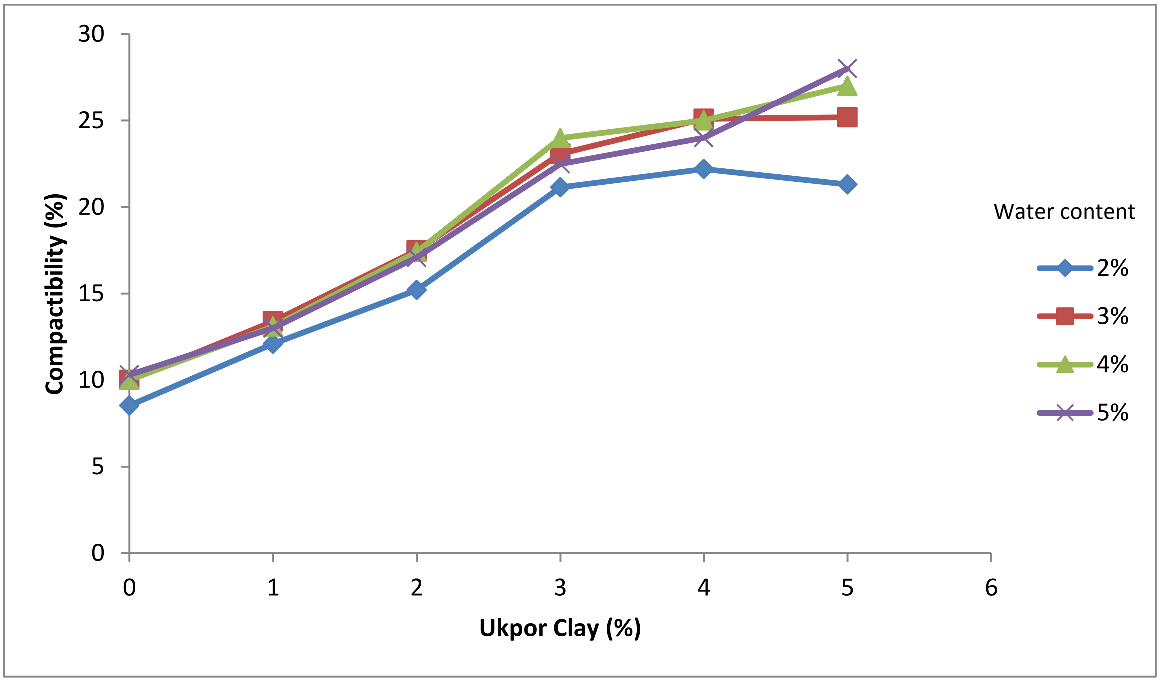


Fig. 4.97 Effect of compatibility on Ukpor clay at constant 2%, 3%, 4% and 5% water constant

Figure 4.97 illustrates the effect of compactibility value on varying percentages of Ukpor clay content and constant 2%, 3%, 4% and 5% water content. For 3% water content, the compactibility value increased from 8.53% to 22.20% at 0% to 4% Ukpor clay content and thereafter decreased to 21.30% at 5% water content, when mixed with 5% Ukpor clay content, the compactibility recorded were 25.20%, 27.0% and 28.0% respectively for constant 3%, 4% and 5% water content.

4.20 Tensile Test Result of Al-10% Cu Alloy Produced From Four Different Moulding Mixtures

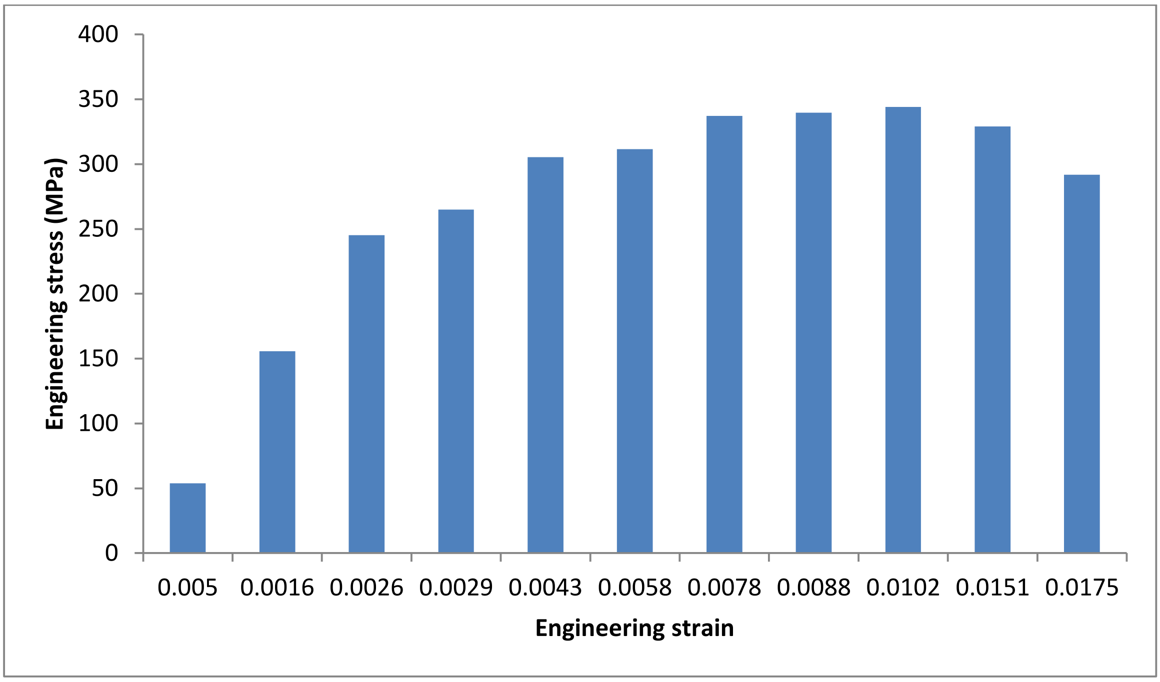


Fig 4.98: Engineering stress versus strain of Al-10% Cu alloy produced from moulding mixture of 5% bentonite and 5% water.

Figure 4.98 represents the tensile test result of cast Al-10% Cu alloy prepared from the moulding mixture of 5% bentonite and 5% water content, from the Figure, it was observed that the engineering tensile stress increased as the engineering strain increased, upto a certain maximum stress value, after which decreased. The tensile stress increased from 53.89Mpa at strain value of 0.0005 and initial load of 1525N to ultimate tensile stress of 344.17MPa at strain value of 0.0102 and a maximum load of 9740N, after which decreased to tensile stress value of 291.88MPa at engineering strain value of 0.0175.

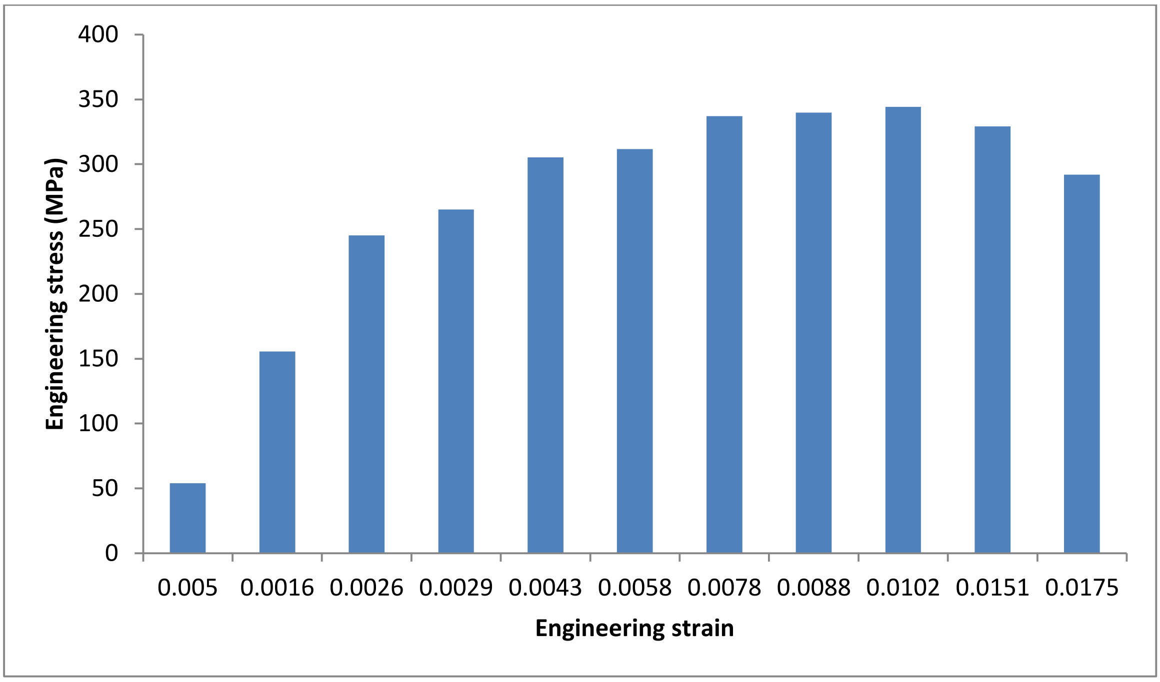


Fig 4.99: Engineering stress versus strain of Al-10% Cu alloy produced from moulding mixture of 5% Ukpor clay and 5% water.

Figure 4.99 shows the tensile test results of cast Al-10% Cu alloy prepared from the moulding mixture of 5% Ukpor clay and 5% water content. From the Figure, it was revealed that the engineering stress increased as the strain value increased upto a certain ultimate tensile value, after which decreased. The engineering tensile stress increased from 50.53MPa at strain value of 0.0008 with initial load of 1430N to the maximum stress value of 337.10MPa at strain value of 0.0118 and load of 9540N. After which decreased to 261.13MPa at strain value of 0.01040.

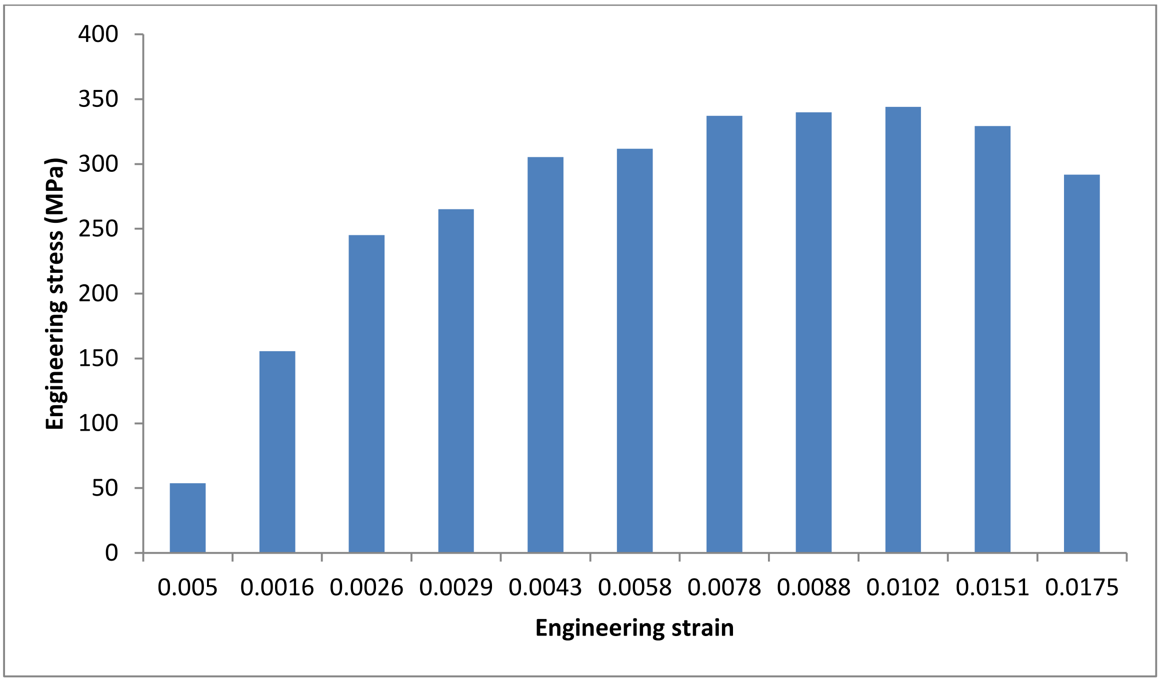


Fig 4.100: Engineering stress versus strain of Al-10% Cu alloy produced from moulding mixture of 4% Ukpor clay and 3% water.

Figure 4.100 illustrates the tensile test results of Al-10% alloy produced from the moulding mixture of 4% Ukpor clay and 3% water content. It was observed that the engineering tensile stress increased upto a certain maximum point and decreased as the engineering strain increased. The engineering stress increased from 49.82 MPa at strain value of 0.0026 and initial load of 1410N to the maximum tensile stress value of 298.59MPa at strain value of 0.0160 with maximum load of 8450N. After which decreased to 230.92MPa at strain value of 0.0290.

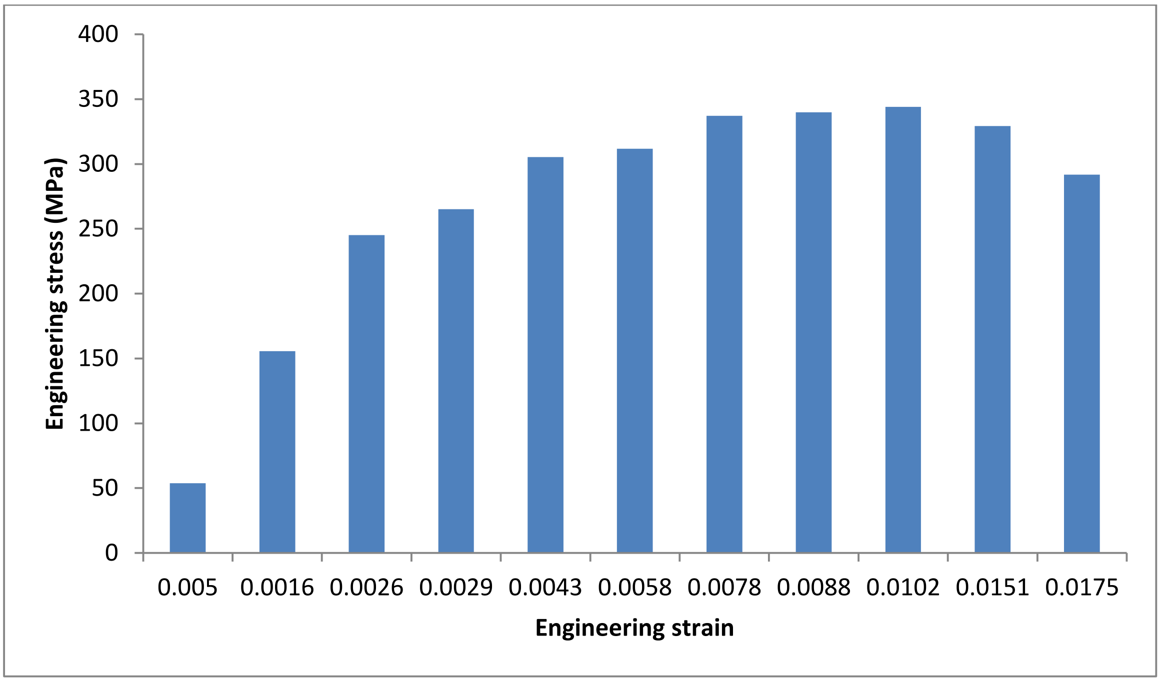


Fig 4.101: Engineering stress versus strain of Al-10% Cu alloy produced from moulding mixture of 3% bentonite and 5% water.

Figure 4.101 shows the tensile test results of Al-10% Cu alloy produced from the moulding mixture of 3% bentonite and 5% water content. From the Figure, it was revealed that the tensile stress of Al-10% Cu alloy produced from the moulding mixture of 3% bentonite and 5% water content, increased from 47.70MPa at strain value of 0.0014 to the maximum engineering stress value of 291.34MPa at strain value of 0.0174. After which decreased to 220.00MPa at strain value of 0.02390.

4.21 Experimental Design and Optimization for Foundry Properties of River Niger Beach Sand Using Ukpor Clay as Binder

The result of 20 experimental responses for the River Niger beach sand blended with Ukpor clay and water content using central composite design (CCD) are tabulated in Table 4.1a

Table 4.1a CCD table of experimental factors and responses for optimization of the moulding properties of River Niger beach sand for foundry application.

Std	Run	Factor 1 A: Sand%	Factor 2 B: Ukpo Clay %	Factor 3 C: Water%	Response 1 Green Com KN/M^2	Response 2 green shear KN/M^2	Response 3 Dry Com KN/M^2	Response 4 Dry shear KN/M^2	Response 5 permeability KN/M^2	Response 6 moisture con KN/M^2	Response 7 compatibility yKN/M^2
6	1	97	1	2	13.7	1.6	179.64	37.66	151.89	2.1	12.75
5	2	95	2	3	13.9	1.6	198.34	34.59	154.40	3.5	16.90
15	3	94	3	3	19.0	3.3	193.90	45.96	150.33	2.6	23.76
10	4	98	1	1	0.1	0.1	155.77	60.32	152.81	1.5	12.09
2	5	96	2	2	15.3	2.0	178.40	38.24	152.40	2.2	15.36
8	6	96	3	1	16.9	2.4	155.74	30.83	151.09	1.6	15.67
13	7	95	4	1	15.2	3.2	147.80	66.85	153.21	1.2	15.14
4	8	93	4	3	22.2	4.4	177.93	55.73	149.30	2.0	27.44
16	9	94	3	3	19.9	3.3	195.10	43.96	149.60	3.8	25.00
17	10	94	3	3	20.0	4.1	198.96	41.96	153.48	2.5	22.00
20	11	94	3	3	19.5	3.1	192.00	50.96	151.40	2.1	28.00
7	12	92	4	4	21.0	4.0	175.96	32.50	149.96	3.0	24.37
14	13	94	2	4	16.2	4.9	212.85	68.55	157.11	1.2	16.70
11	14	95	1	4	11.1	1.6	207.70	38.14	156.56	3.5	12.45
9	15	91	4	5	19.7	3.7	177.20	42.65	147.77	3.6	22.80
1	16	93	3	4	16.9	2.5	197.00	34.59	152.97	3.9	21.03
12	17	94	5	1	14.1	1.9	127.68	33.75	151.47	2.7	12.75
3	18	94	4	2	18.7	3.2	161.73	48.40	150.92	2.0	21.45
19	19	94	3	3	18.2	3.4	195.96	47.96	150.40	2.1	21.00
18	20	94	3	3	21.0	3.2	195.00	49.96	150.92	2.5	24.00

The responses obtained from different experimental runs carried out by combinations of the three variables unique to each of the runs are tabulated on the response column of Table 4.1a above. The three experimental variable interaction gave a total of 20 experimental runs. The responses obtained from various runs are significantly exceptional, which implies that each of the factors have substantial effect on the response.

Table 4.1b: Fit summary table

Response	**1**	**Green com**	**Transform:**	**None**	
	Sequential	**Lack of Fit**	**Adjusted**	**Predicted**	
Source	**p-value**	**p-value**	**R-Squared**	**R-Squared**	
Linear	0.0006	0.0037	0.5842	-0.0974	
2FI	0.0178	0.0116	0.7583	-0.0937	
Quadratic	< 0.0001	0.9826	0.9786	0.9694	Suggested
Cubic	0.9826		0.9616		Aliased

Table 4.1c: Sequential model sum of squares

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Mean vs Total	5535.58	1	5535.58			
Linear vs Mean	294.06	3	98.02	9.90	0.0006	
2FI vs Linear	83.61	3	27.87	4.84	0.0178	
Quadratic vs 2FI	69.73	3	23.24	45.51	< 0.0001	Suggested
Cubic vs Quadratic	0.54	5	0.11	0.12	0.9826	Aliased
Residual	4.57	5	0.91			
Total	5988.09	20	299.40			

Table 4.1d: Lack of fit tests

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Linear	153.88	11	13.99	15.31	0.0037	
2FI	70.27	8	8.78	9.61	0.0116	
Quadratic	0.54	5	0.11	0.12	0.9826	Suggested
Cubic	0.000	0				Aliased
Pure Error	4.57	5	0.91			

Table 4.1e**: Model summary statistics**

Model Summary Statistics						
Source	**Std. Dev.**	**R-Squared**	**Adjusted R-Squared**	**Predicted R-Squared**	**PRESS**	
Linear	3.15	0.6498	0.5842	-0.0974	496.57	
2FI	2.40	0.8346	0.7583	-0.0937	494.92	
Quadratic	0.71	0.9887	0.9786	0.9694	13.86	Suggested
Cubic	0.96	0.9899	0.9616		+	Aliased

4.22.1 ANOVA Analysis and Model Fitting

The F-value tests were performed using analysis of variance (ANOVA) to calculate the significance of each type of model. Based on the results of F-value, the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 4.1c, the quadratic vs 2FI and the linear vs mean models have significant F-value of 45.51 and 9.90, respectively while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 4.84 and 0.12, respectively.

Besides evaluating the significance, the adequacy of the model was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicated that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. This test measured the adequacy of the different models based on response surface analysis. As shown in Table 4.1d, there was a significant difference (F-value = 15.31 and 9.61) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 0.12) for quadratic models. The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.1c and 4.1d showed that the quadratic model can well describe the green compressive strength of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.9887, 0.9786, 0.9694 and 0.9899, 0.9616 respectively when compared to other models (2FI and linear) as shown on Table 4.1e. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

The closer the R^2 value is to unity, the better the model predicts the response. Adjusted-R^2 is a measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model. The adjusted-R^2 decreases as the number of terms in the model increases, if those additional terms don't add value to the model. Predicted-R^2 is a measure of the amount of variation in new data explained by the model.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.1f.

Table 4.1f: ANOVA for response surface quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	447.40	9	49.71	97.33	< 0.0001	significant
A-Sand	*46.01*	*1*	*46.01*	*90.08*	*< 0.0001*	
B-ukpo clay	*27.62*	*1*	*27.62*	*54.08*	*< 0.0001*	
C-Water	*23.00*	*1*	*23.00*	*45.02*	*< 0.0001*	
AB	*39.36*	*1*	*39.36*	*77.07*	*< 0.0001*	
AC	*39.04*	*1*	*39.04*	*76.44*	*< 0.0001*	
BC	*34.80*	*1*	*34.80*	*68.13*	*< 0.0001*	
A^2	*46.09*	*1*	*46.09*	*90.24*	*< 0.0001*	
B^2	*37.60*	*1*	*37.60*	*73.61*	*< 0.0001*	
C^2	*32.98*	*1*	*32.98*	*64.58*	*< 0.0001*	
Residual	5.11	10	0.51			
Lack of Fit	*0.54*	*5*	*0.11*	*0.12*	*0.9826*	*not significant*
Pure Error	*4.57*	*5*	*0.91*			
Cor Total	452.51	19				

Std. Dev.	**0.71**		**R-Squared**	**0.9887**
Mean	**16.64**		**Adj R-Squared**	**0.9786**
C.V. %	**4.30**		**Pred R-Squared**	**0.9694**
PRESS	**13.86**		**Adeq Precision**	**44.531**
-2 Log Likelihood	**29.46**		**BIC**	**59.41**
			AICc	**73.90**

DF = degree of freedom

CV = Coefficient of variance

PRESS = Predicted residual sum of squares

From the Table 4.1f, it could be seen that the model F-value of 97.33 implies the model is significant. In this case, A, B, C, AB, AC, BC, A^2,B^2, C^2 are significant model terms.There is only a 0.01% chance that an F-value this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicated that the model terms are significant.Values greater than 0.1000 indicated that the model terms are not significant.The independent variables in the specified model and the effect of each variable was evaluated. For this reason and in order to evaluate the adequacy of the selected model several appraisal techniques were used. The coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to weigh the adequacy of the model as used by other researchers (Chen *et al.,* 2010; The "Lack of Fit F-value" of 0.12 implies the Lack of Fit is not significant relative to the pure error. There is a 98.26% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good because it means the model will be well fitted. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the green compressive strength from River Niger Onitsha beach sand using Ukpor clay. The F-value of the independent variables such assand, Ukpor clay and water content were estimated as 90.08, 54.08 and 45.02 respectively. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.9887 and 0.9786, respectively which illustrates that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The predicted R^2 of 0.9694 is in reasonable agreement with adjusted R^2 of 0.9786 i.e. the difference is less than 0.2. The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimate to the mean value of the observed response is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated that the CV value of 4.30% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) (Chen et al., 2011). The signal to noise ratio which is given as the value of the adequacy precision is 44.531. This indicated that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$$Y = +19.68-19.89A-12.25B-7.98C-111.93AB-79.25AC-49.49BC-86.54A^2-34.89B^2-18.68C^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.1)$$

In terms of actual values, the model terms are given by the green compressive strength = -2.00028E+005+3998.83703*sand+4516.59492 *Ukpor clay+3203.50966 *water -45.22622 *sand *Ukpor clay – 32.02090 *sand *water – 34.99493 *Ukpor clay*water – 19.98230 *sand^2– 24.67177 *Ukpor clay^2 – 13.20946 *water^2……………………………(4.2)

Where y = green compressive strength, A = sand, B = Ukpor clay, C = water

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients, while the equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels are to be specified in the original units for each factor.

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison was shown in the Figure 4.102.

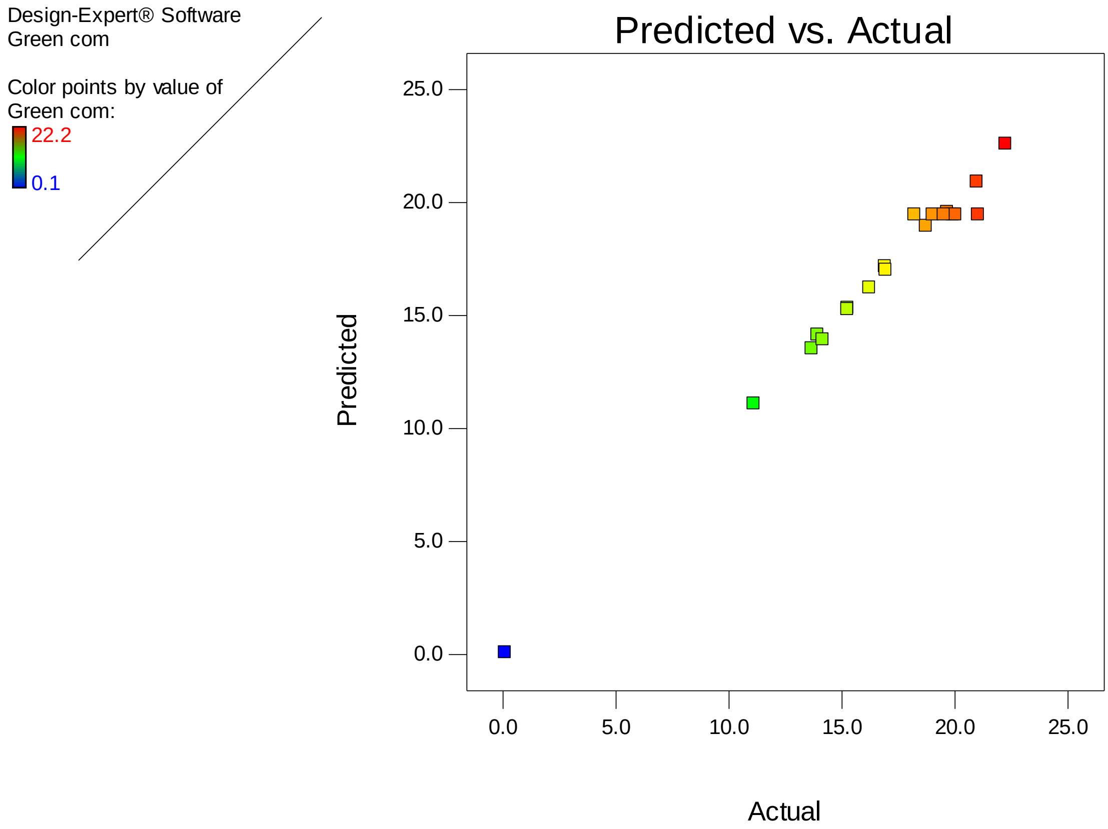


Figure 4.102 Linear correlation between predicted vs. actual values for green compressive strength of River Niger Beach sand using Ukpor claycontent.

As it can be seen in Figure 4.102, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.103. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with

the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

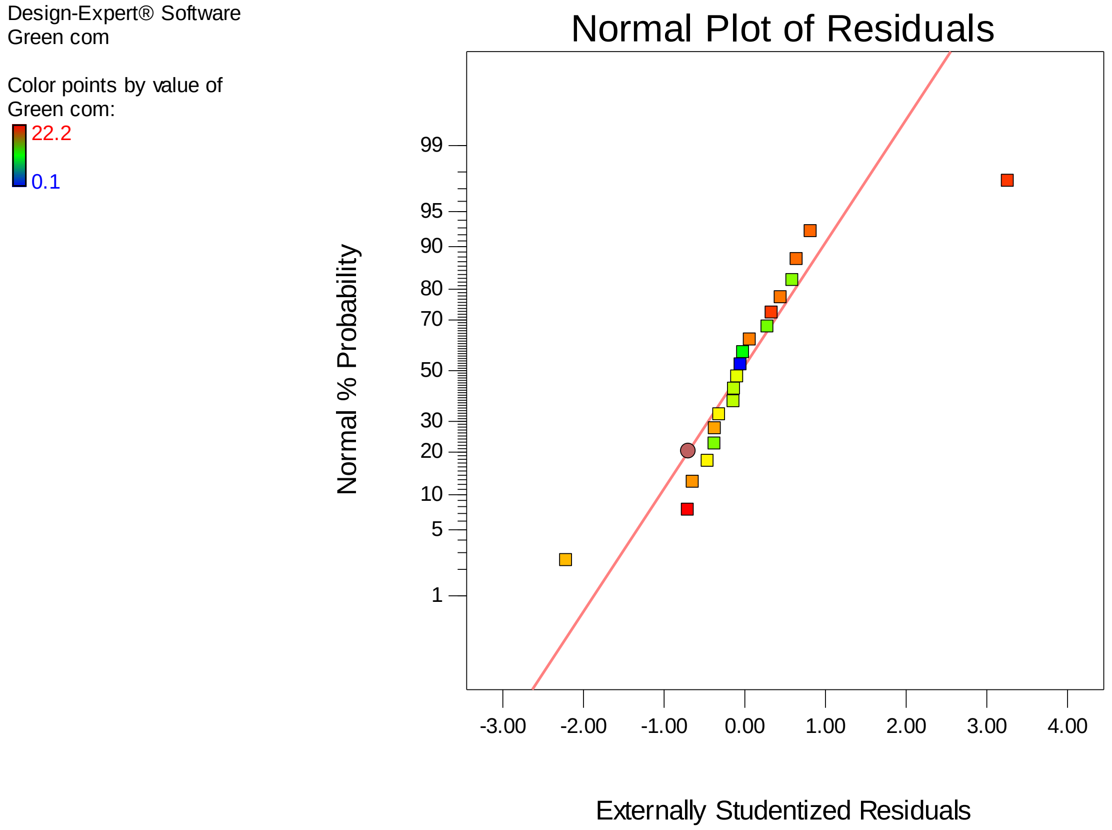
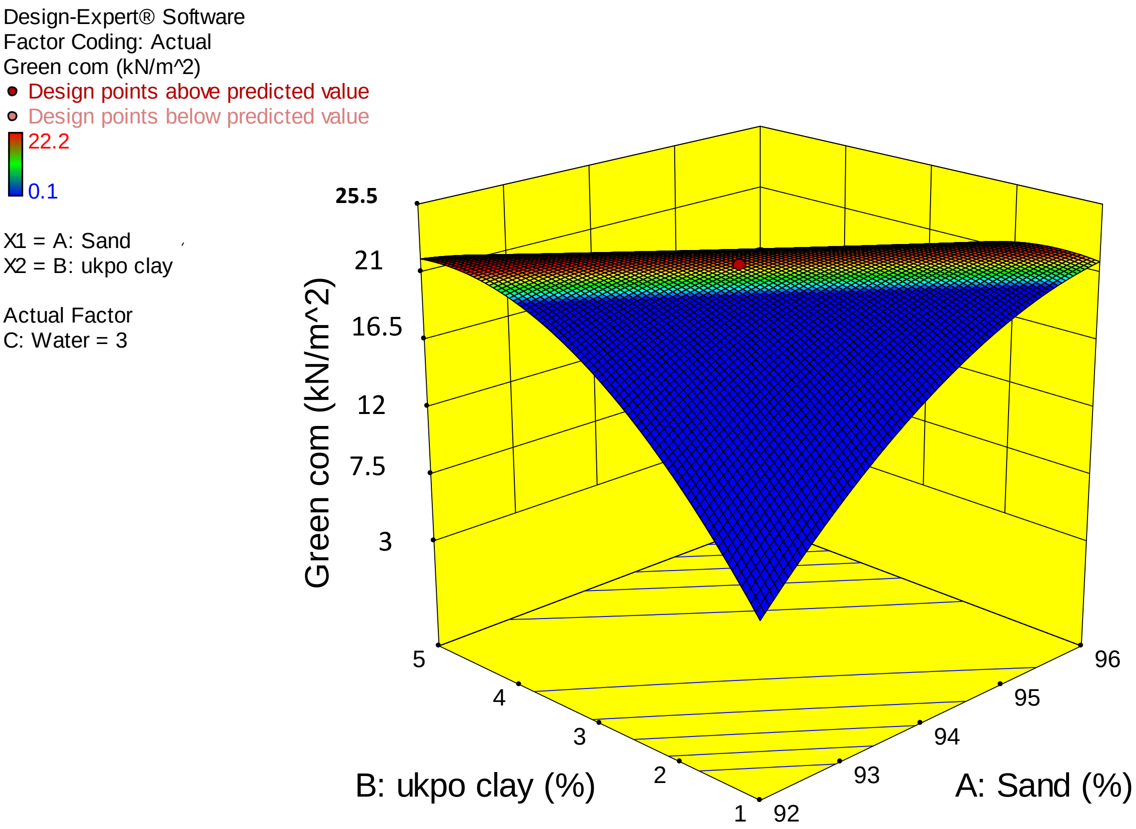


Figure 4.103 Normal probability plot of residuals obtained from the green strength of Ukpor clay sample

4.22.2 3D Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the Ukpor clay and water content. Response surfaces and single effect plots were generated from the quadratic model, as shown in Figure 4.104. This Figure illustrates the response of different experimental variables and can be used to identify the major interactions between the variables.

(a)



b)

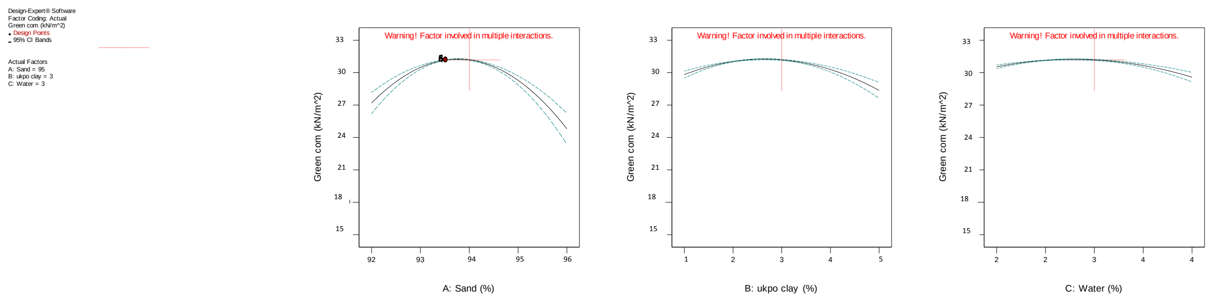


Figure 4.104: 3D surface (a) and single effect plotfor thecombine effect of Ukpor clay, sand and water (b), carried out at 3% water content.

Figure 4.104: 3D plot and its corresponding single effects plot to show the effect of sand and Ukpor clay on the response at water content of 3%. From the graph, it was shown that the maximum green compressive strength of 21.0KN/m^2 at 5% Ukpor clay content and 92% of sand, is in accordance with the model. As green compressive strength increased from 17.0KN/m^2 at 1% Ukpor clay to 21.0KN/m^2 at 5% Ukpor clay. This increase in green compressive strength was as a result of increase in binder content that comes with 3% water content.

Table 4.2a: Fit summary table

Response	2	Green shear strength	Transform:	None	
	Sequential	**Lack of Fit**	**Adjusted**	**Predicted**	
Source	**p-value**	**p-value**	**R-Squared**	**R-Squared**	
Linear	0.0046	0.0181	0.4621	-0.1032	
2FI	0.3248	0.0175	0.4883	-0.6441	
Quadratic	< 0.0001	0.9982	0.9496	0.9533	Suggested
Cubic	0.9982		0.9033		Aliased

Table 4.2b: Sequential model sum of squares

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Mean vs Total	164.79	1	164.79			
Linear vs Mean	13.75	3	4.58	6.44	0.0046	
2FI vs Linear	2.58	3	0.86	1.27	0.3248	
Quadratic vs 2FI	8.13	3	2.71	40.64	< 0.0001	Suggested
Cubic vs Quadratic	0.027	5	5.465E-003	0.043	0.9982	Aliased
Residual	0.64	5	0.13			
Total	189.91	20	9.50			

Table 4.2c: Lack of fit tests

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Linear	10.74	11	0.98	7.63	0.0181	
2FI	8.16	8	1.02	7.97	0.0175	
Quadratic	0.027	5	5.465E-003	0.043	0.9982	Suggested
Cubic	0.000	0				Aliased
Pure Error	0.64	5	0.13			

Table 4.2d: Model summary statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.84	0.5470	0.4621	-0.1032	27.72	
2FI	0.82	0.6499	0.4883	-0.6441	41.31	
Quadratic	0.26	0.9735	0.9496	0.9533	1.17	Suggested
Cubic	0.36	0.9745	0.9033		+	Aliased

4.22.3 ANOVA Analysis and Model Fitting

The F-value tests were performed using analysis of variance (ANOVA) to calculate the significance of each type of model. Based on the results of F-value, the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 4.2b, the quadratic vs 2FI and the linear vs mean models have significant F-value of 40.64 and 6.44 respectively, while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 1.27 and 0.043, respectively.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. This test measured the adequacy of the different models based on response surface analysis. As shown in Table 4.2c there was a significant difference (F-value =

7.63 and 7.97) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 0.043) for quadratic models. The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.2b and 4.2c showed that the quadratic model can well describe the green shear strength of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.9735, 0.9496, 0.9533 and 0.9745, 0.9033 respectively when compared to other models (2FI and linear) as shown on Table 4.2d. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

The closer the R^2 value is to unity, the better the model predicts the response. Adjusted-R^2 is a measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model. The adjusted-R^2 decreases as the number of terms in the model increases, if those additional terms don't add value to the model. Predicted-R^2 is a measure of the amount of variation in new data explained by the model.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.2e .

Table 4.2e: ANOVA for response surface quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	24.46	9	2.72	40.75	< 0.0001	significant
A-Sand	*1.20*	*1*	*1.20*	*18.06*	*0.0017*	
B-ukpo clay	*2.13*	*1*	*2.13*	*31.87*	*0.0002*	
C-Water	*0.083*	*1*	*0.083*	*1.25*	*0.2902*	
AB	*4.19*	*1*	*4.19*	*62.82*	*< 0.0001*	
AC	*2.42*	*1*	*2.42*	*36.22*	*0.0001*	
BC	*3.29*	*1*	*3.29*	*49.38*	*< 0.0001*	
A^2	*3.53*	*1*	*3.53*	*52.86*	*< 0.0001*	
B^2	*4.71*	*1*	*4.71*	*70.68*	*< 0.0001*	
C^2	*1.57*	*1*	*1.57*	*23.56*	*0.0007*	
Residual	0.67	10	0.067			
Lack of Fit	*0.027*	*5*	*5.465E-003*	*0.043*	*0.9982*	*not significant*
Pure Error	*0.64*	*5*	*0.13*			
Cor Total	25.13	19				

Std. Dev.	0.26		R-Squared	0.9735
Mean	2.87		Adj R-Squared	0.9496
C.V. %	9.00		Pred R-Squared	0.9533
PRESS	1.17		Adeq Precision	25.912
-2 Log Likelihood	-11.26		BIC	18.70
			AICc	33.19

From the Table 4.2e, it could be seen that the model F-value of 40.75 implies that the model is significant. In this case, A, B, C, AB, AC, BC, A^2,B^2, C^2 are significant model terms.There is onlya 0.01% chance that an F-value this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicated that the model terms are significant.Values greater than 0.1000 indicate the model terms are not significant.The independent variables in the specified model and the effect of each variable was evaluated. For this reason and in order to evaluate the adequacy of the selected model several appraisal techniques were used. The coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to weigh the adequacy of the model as used by other researchers (Chen *et al.,* 2010; The "Lack of Fit F-value" of 0.04 implies the Lack of Fit is not significant relative to the pure error. There is a 99.82% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good because it means the model will be well fitted. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the dry shear strength from River Niger Onitsha beach sand using Ukpor clay. The F-value of the independent variables such as sand, Ukpor clay and water content were estimated as 18.06, 31.87 and 1.25 respectively as shown Table 4.5e. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.9735 and 0.9496, respectively which illustrates that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The predicted R^2 of 0.9533 is in reasonable agreement with adjusted R^2 of 0.9496 i.e. the difference is less than 0.2. The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimated mean value of the observed response is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value of 9.00% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) (Chen et al., 2011). The signal to noise ratio which is given as the value of the adequacy precision is 25.912. This indicated that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$Y = +3.99-3.22A-3.40B-0.48C-36.52AB -19.79AC -15.23BC -23.94A^2 -12.36B^2 -4.08C^2$ ……………………………………(4.3)

In terms of actual values, the model terms are given by the green shear strength = -55840.21147 + 1111.211292*sand+1476.31061 *Ukpor clay +80193795*water - 14.75606 *sand *Ukpor clay – 7.96551 *sand *water – 10.76661 *Ukpor clay*water – 5.52696 *sand^2 – 8.73671 *Ukpor clay^2 – 2.88354 *water^2……………………………(4.4)

Where y = green compressive strength, A = sand, B = Ukpor clay, C = water

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients, while the equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels are to be specified in the original units for each factor.

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the figure 4.105.

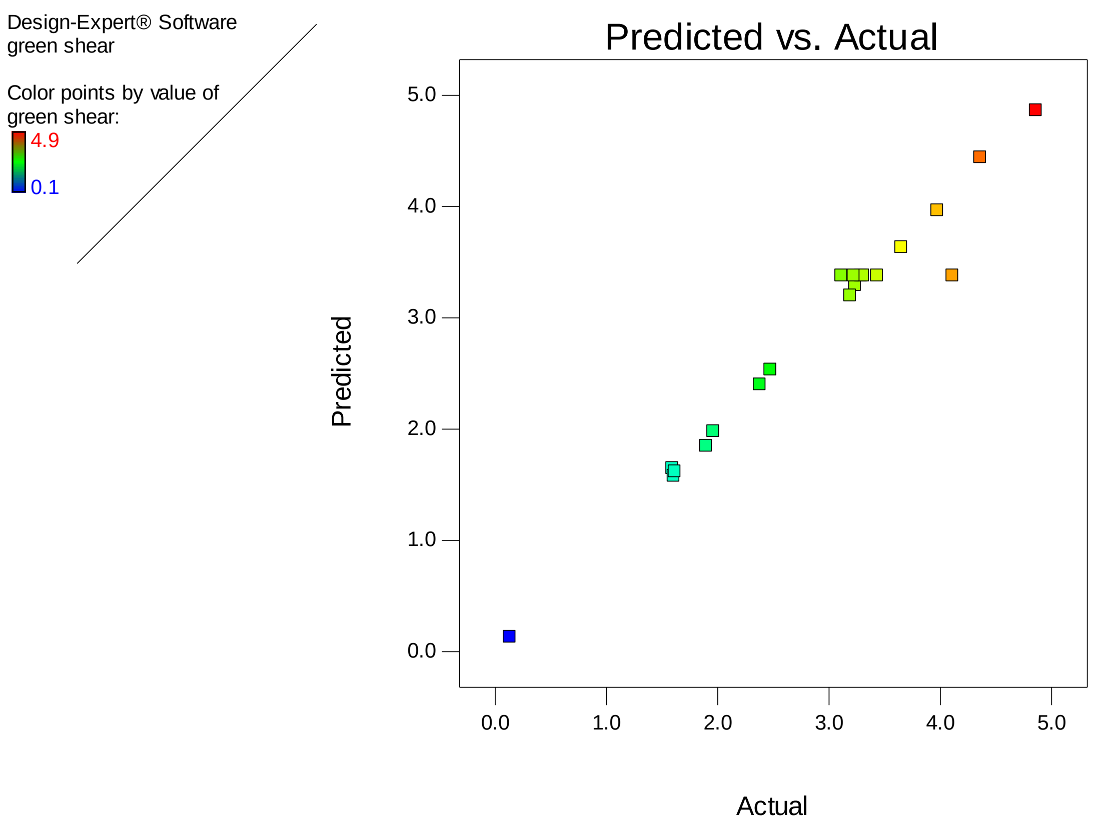


Figure 4.105 Linear correlation between predicted vs. actual values for green shear strength of River Niger beach sand using Ukpor clay content.

As it can be seen in Figure 4.105, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.106. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are alsoseen to be mostly interlocked with the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

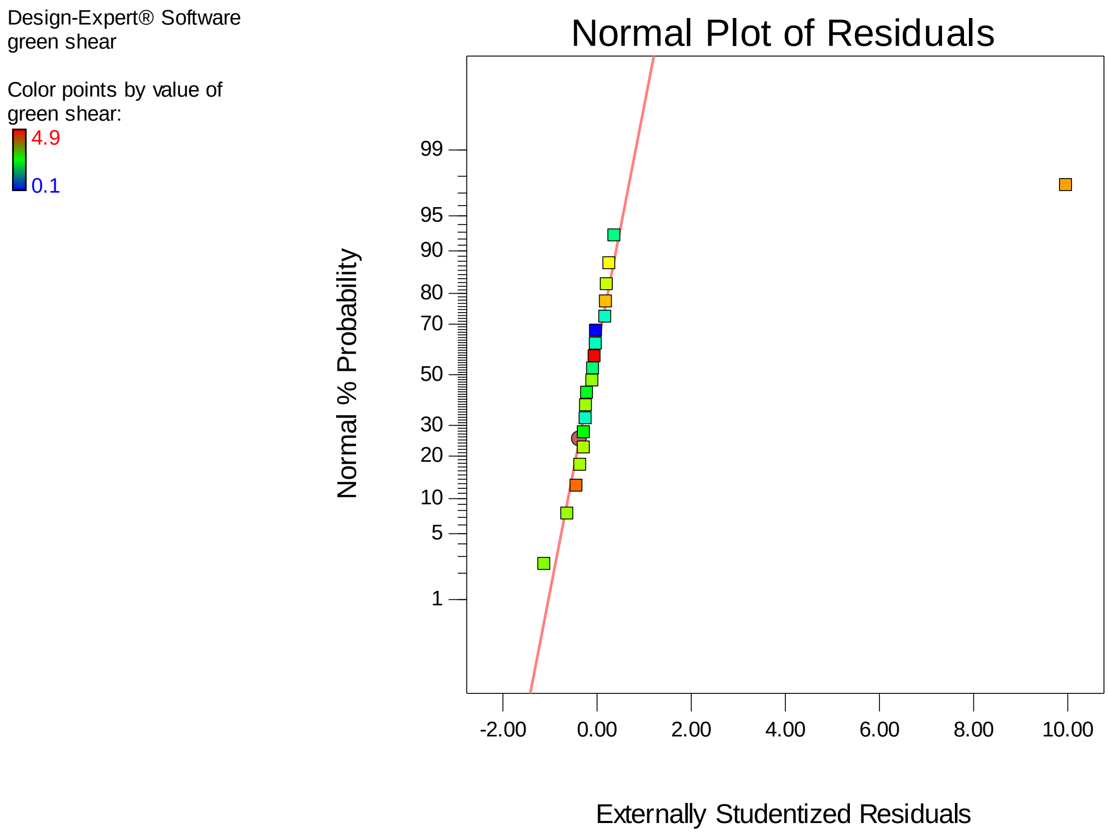


Figure 4.106 Normal probability plot of residuals obtained from the green shearofUkpor clay sample

4.22.4 3D Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the Ukpor clay and water content. Response surfaces and single effect plots were generated from the quadratic model, as shown in Figure 4.107. This figure illustrates the response of different experimental variables and can be used to identify the major interactions between the variables.

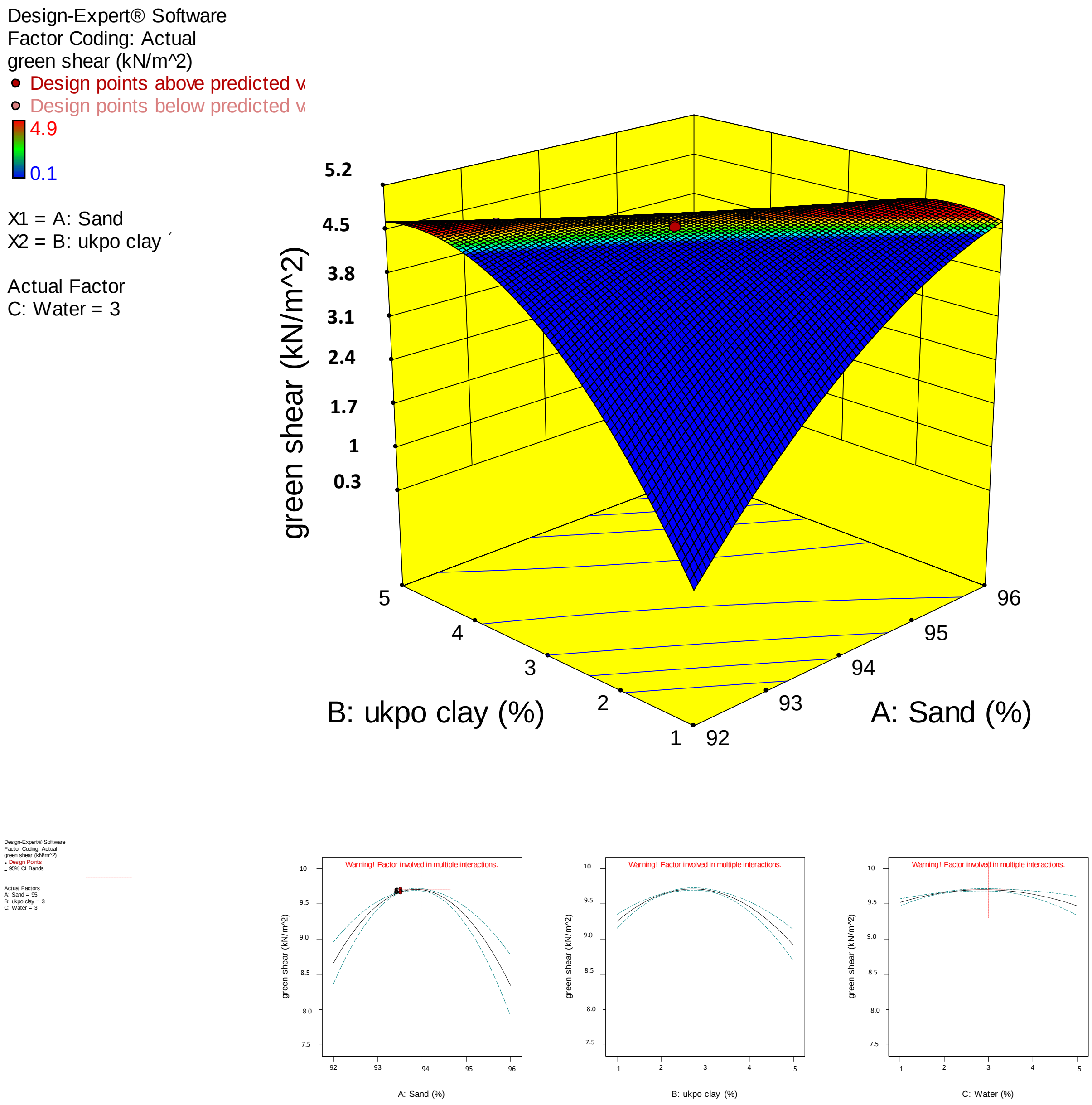


Figure 4.107: 3D surface (a) and single effect plot for the combine effect of Ukpor clay, sand and water (b), carried out at 3% water content.

Figure 4.107: 3D plot and its corresponding single effect plot to show the effect of sand and Ukpor clay on the response at water content of 3%. From the graph, it was shown that the maximum green shear strength of 4.6KN/m^2 at 5% Ukpor clay content and 92% of sand, is in accordance with the model. As green shear strength increased from 2.4KN/m^2 at 1% Ukpor clay to 4.6KN/m^2 at 5% Ukpor clay.

Table 4.3a: Fit summary table

Response	3	Dry com strength	Transform:	None	
	Sequential	Lack of Fit	Adjusted	Predicted	
Source	p-value	p-value	R-Squared	R-Squared	
Linear	< 0.0001	0.0007	0.7544	0.6433	
2FI	< 0.0001	0.0602	0.9659	0.7988	
Quadratic	0.0001	0.9905	0.9940	0.9924	Suggested
Cubic	0.9905		0.9889		Aliased

Table 4.3b: Sequential model sum of squares

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob> F	
Mean vs Total	6.569E+005	1	6.569E+005			
Linear vs Mean	7266.67	3	2422.22	20.46	< 0.0001	
2FI vs Linear	1680.40	3	560.13	34.04	< 0.0001	
Quadratic vs 2FI	184.82	3	61.61	21.18	0.0001	Suggested
Cubic vs Quadratic	2.38	5	0.48	0.089	0.9905	Aliased
Residual	26.70	5	5.34			
Total	6.661E+005	20	33302.74			

Table 4.3c: Lack of fit tests

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob> F	
Linear	1867.60	11	169.78	31.79	0.0007	
2FI	187.20	8	23.40	4.38	0.0602	
Quadratic	2.38	5	0.48	0.089	0.9905	Suggested
Cubic	0.000	0				Aliased
Pure Error	26.70	5	5.34			

Table 4.3d: Model summary statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	10.88	0.7932	0.7544	0.6433	3267.78	
2FI	4.06	0.9767	0.9659	0.7988	1843.64	
Quadratic	1.71	0.9968	0.9940	0.9924	69.74	Suggested
Cubic	2.31	0.9971	0.9889		+	Aliased

4.22.5 ANOVA Analysis and Model Fitting

The F-value tests were performed using analysis of variance (ANOVA) to calculate the significance of each type of model. Based on the results of F-value, the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 4.3b, the quadratic vs 2FI and the linear vs mean models have significant F-value of 21.18 and 20.46, respectively while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 34.04 and 0.089, respectively.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. This test measured the adequacy of the different models based on response surface analysis. As shown in Table 4.3c there was a significant difference (F-value = 31.79 and 4.38) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 0.089) for quadratic models. The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.3b and 4.3c show that the quadratic model can well describe the dry compressive strength of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.9968, 0.9940, 0.9924 and 0.9971, 0.9889 respectively when compared to other models (2FI and linear) as shown in Table 4.3d. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.3e.

Table 4.3e: ANOVA for response surface quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	9131.89	9	1014.65	348.90	< 0.0001	significant
A-Sand	*14.94*	*1*	*14.94*	*5.14*	*0.0469*	
B-ukpo clay	*106.88*	*1*	*106.88*	*36.75*	*0.0001*	
C-Water	*17.87*	*1*	*17.87*	*6.15*	*0.0326*	
AB	*26.03*	*1*	*26.03*	*8.95*	*0.0135*	
AC	*15.99*	*1*	*15.99*	*5.50*	*0.0410*	
BC	*26.78*	*1*	*26.78*	*9.21*	*0.0126*	
A^2	*20.42*	*1*	*20.42*	*7.02*	*0.0243*	
B^2	*41.17*	*1*	*41.17*	*14.16*	*0.0037*	
C^2	*30.82*	*1*	*30.82*	*10.60*	*0.0086*	
Residual	29.08	10	2.91			
Lack of Fit	*2.38*	*5*	*0.48*	*0.089*	*0.9905*	*not significant*
Pure Error	*26.70*	*5*	*5.34*			
Cor Total	9160.97	19				

Std. Dev.	1.71		R-Squared	0.9968
Mean	181.23		Adj R-Squared	0.9940
C.V. %	0.94		Pred R-Squared	0.9924
PRESS	69.74		Adeq Precision	71.034
-2 Log Likelihood	64.24		BIC	94.20
			AICc	108.69

The independent variables in the specified model and the effect of each variable was also evaluated. To evaluate the adequacy of the selected model, several appraisal techniques were used. The coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to weigh the adequacy of the model as used by other researchers (Chen *et al.,* 2010). From the Table 4.3e, it could be seen that F-value of 348.90 implies the model is significant. There is onlya 0.01% chance that an F-value this large could occur due to noise.Values greater than 0.1000 indicate the model terms are not significant. The “Lack of Fit F-value” of 0.089 implies the Lack of Fit is not significant relative to the pure error. There is a 99.05% chance that a “Lack of Fit F-value” this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicates the model terms are significant.In this case A, B, C, AB, AC, BC, A^2, B^2, C^2 are significant model terms. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the dry compressive strength from River Niger Onitsha beach sand using Ukpor clay. The F-value of the independent variables sand, Ukpor clay and water content were estimated as 5.14, 36.75 and 6.15 respectively as shown in table 4.3e. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.9968 and 0.9940, respectively which illustrates that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The pred R-squared of 0.9968 is in reasonable agreement with the Adj R-squared of 0.9940 ie the difference is less than 0.2. The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimated mean value of the observed response, was independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value of 0.94% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) (Chen et al., 2011). The signal to noise ratio which is given as the value of the adequacy precision is 71.034. This indicated that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$$Y = 195.44-11.33A - 24.09B+7.03C - 91.02AB-50.72AC - 43.42BC - 57.60A^2- 36.51B^2- 18.06C^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.5)$$

In terms of actual values, the model terms are given by the dry compressivestrength = -1.34882E+005+2680.11998*sand+3702.34946 *Ukpor clay +2111.35344 *water – 36.77883 *sand *Ukpor clay – 20.49441 *sand *water – 30.70222 *Ukpor clay*water – 13.30025 *sand^2 – 25.81682 *Ukpor clay^2 – 12.76877 *water^2 ……………………………..(4.6)

Where y = dry compressive strength, A = sand, B = Ukpor clay, C = water

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients, while the equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels are to be specified in the original units for each factor.

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the Figure 4.108.

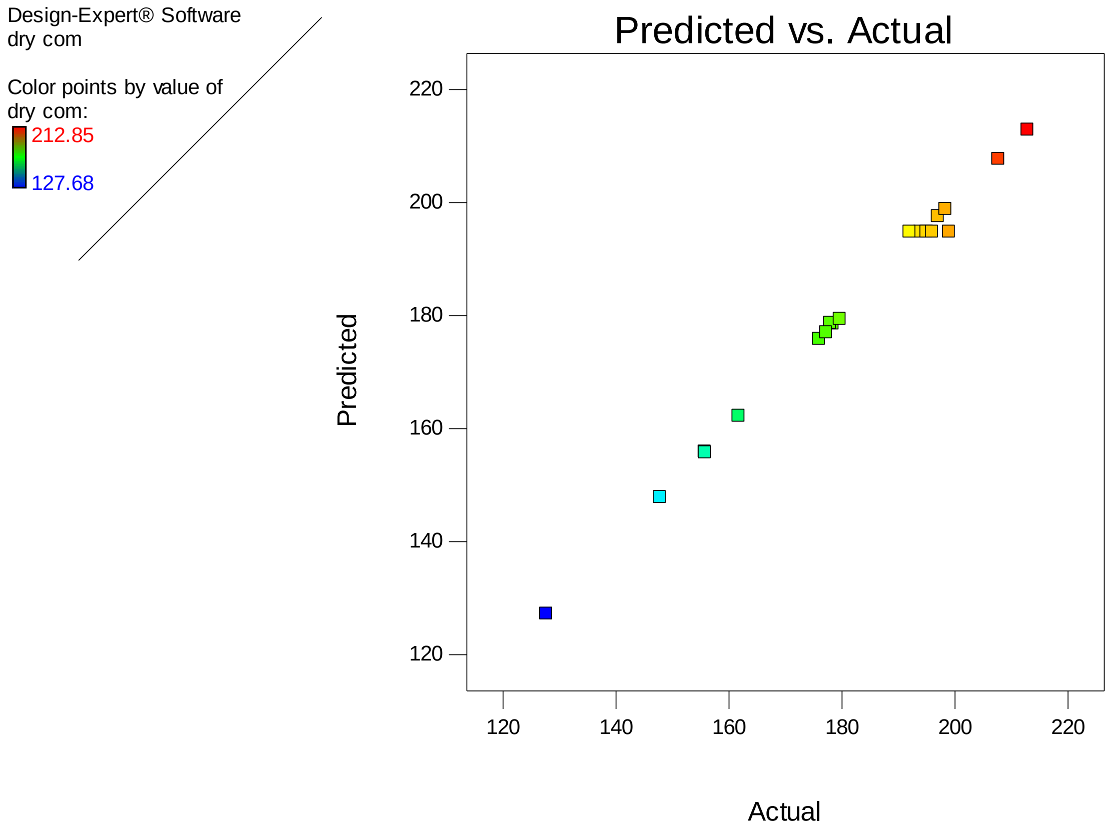


Figure 4.108 Linear correlation between predicted vs. actual values for dry compressive strength of River Niger Beach sand using Ukpor clay content.

As it can be seen in Figure 4.108, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.109. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with

the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

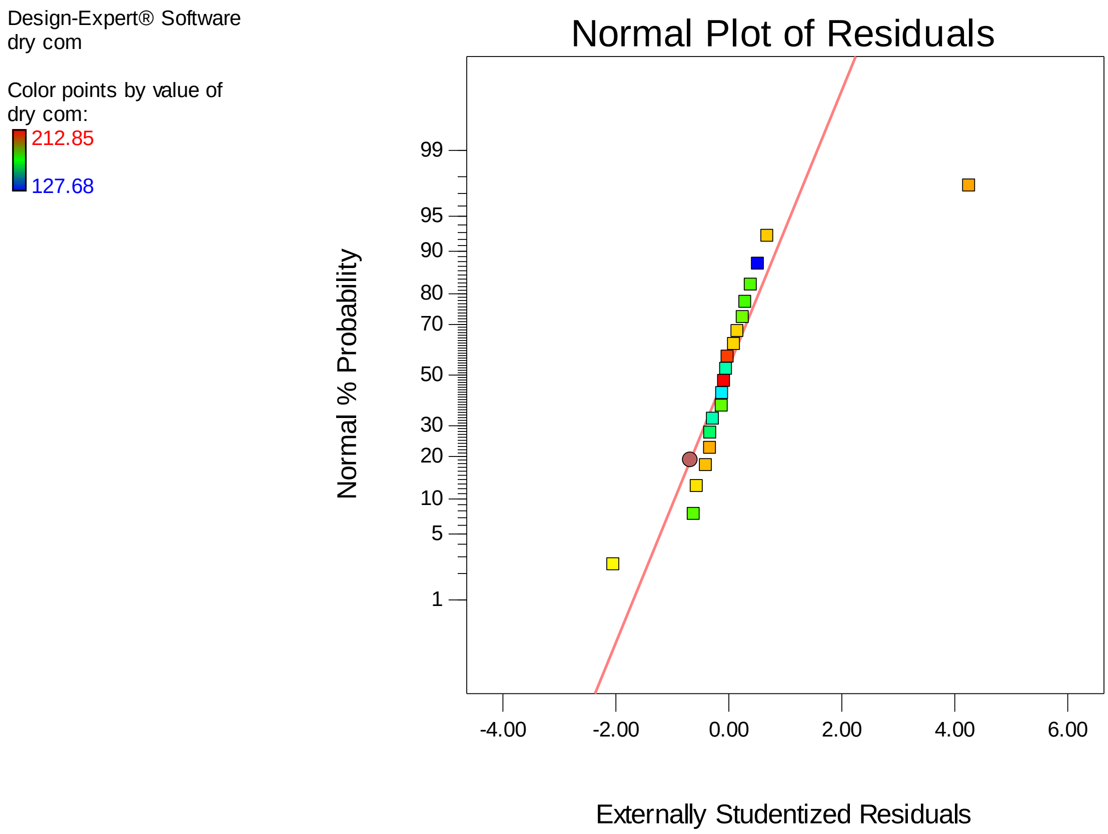
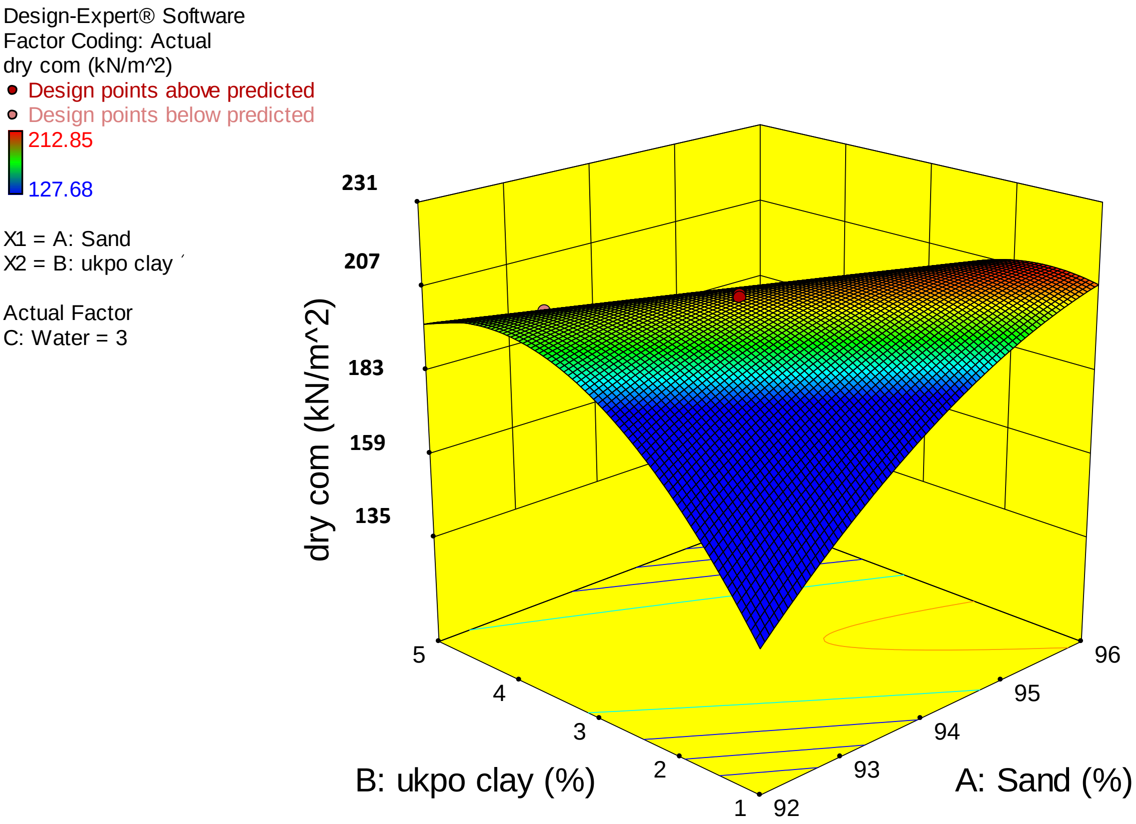


Figure 4.109 Normal probability plot of residuals obtained from the dry compressive strength of Ukpor clay sample

4.22.6 3D Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the Ukpor clay and water content. Response surfaces and interaction plots were generated from the quadratic model, as shown in Figure 4.110. This Figure illustrates the response of different experimental variables and can be used to identify the major interactions between the variables.

(a)



b.

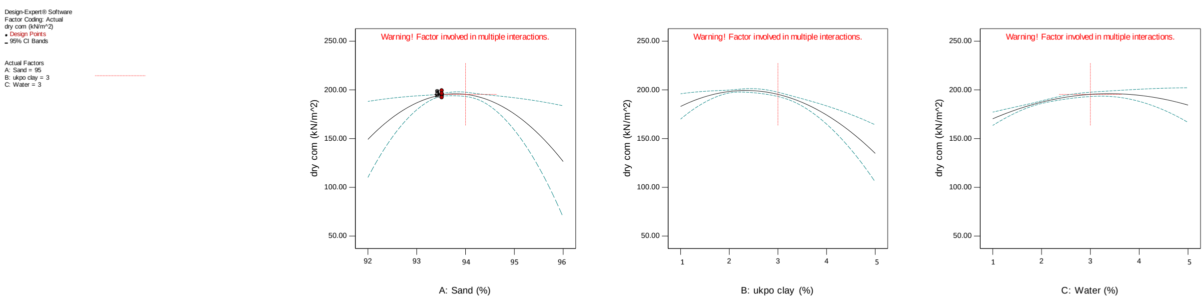


Figure 4.110: 3D surface (a) and single effect plot for the combine effect of Ukpor clay, sand and water (b),carried out at 3% water content.

Figure 4.110: 3D plot and its corresponding single effect plot to show the effect of sand and Ukpor clay on the response at water content of 3%. From the graph, it was shown that the maximum

dry compressive strength of 211.00KN/m^2 at 5% Ukpor clay content and 92% of sand, is in accordance with the model. As dry compressive strength increased from 170.00KN/m^2 at 1% Ukpor clay to 211.00KN/m^2 at 5% Ukpor clay. This increase in dry compressive strength was as a result of increase in binder content that comes with 3% water content.

Table 4.4a: Fit summary table

Response	**4**	**Dry shear strength**	**Transform:**	**None**	
	Sequential	**Lack of Fit**	**Adjusted**	**Predicted**	
Source	**p-value**	**p-value**	**R-Squared**	**R-Squared**	
Linear	0.8523	0.0033	-0.1321	-1.0764	
2FI	0.6737	0.0022	-0.2432	-3.1018	
Quadratic	< 0.0001	0.9990	0.9486	0.9528	Suggested
Cubic	0.9990		0.9006		Aliased

Table 4.4b: Sequential model sum of squares

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Mean vs Total	40821.75	1	40821.75			
Linear vs Mean	108.56	3	36.19	0.26	0.8523	
2FI vs Linear	238.98	3	79.66	0.52	0.6737	
Quadratic vs 2FI	1915.53	3	638.51	101.50	< 0.0001	Suggested
Cubic vs Quadratic	2.08	5	0.42	0.034	0.9990	Aliased
Residual	60.83	5	12.17			
Total	43147.74	20	2157.39			

Table 4.4c: Lack of fit tests

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**Df**	**Square**	**Value**	**Prob> F**	
Linear	2156.59	11	196.05	16.11	0.0033	
2FI	1917.61	8	239.70	19.70	0.0022	
Quadratic	2.08	5	0.42	0.034	0.9990	Suggested
Cubic	0.000	0				Aliased
Pure Error	60.83	5	12.17			

4.4d: Model summary statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	11.77	0.0467	-0.1321	-1.0764	4829.64	
2FI	12.34	0.1494	-0.2432	-3.1018	9540.77	
Quadratic	2.51	0.9730	0.9486	0.9528	109.80	Suggested
Cubic	3.49	0.9738	0.9006		+	Aliased

4.22.7 ANOVA Analysis and Model Fitting

The F-value tests were performed using analysis of variance (ANOVA) to calculate the significance of each type of model. Based on the results of F-value, the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 4.4b, the quadratic vs 2FI and the linear vs mean models have significant F-value of 101.50 and 0.26, respectively while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 0.52 and 0.034, respectively.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. This test measured the adequacy of the different models based on response surface analysis. As shown in Table 4.4c there was a significant difference (F-value = 16.11 and 19.70) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 0.034) for quadratic models. The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.4b and 4.4c showed that the quadratic model can well describe the dry shear strength of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.9730, 0.9486, 0.9528 and 0.9738, 0.9006 respectively when compared to other models (2FI and linear) as shown on Table 4.4d. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.4e.

Table 4.4e: ANOVA for response surface quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	2263.08	9	251.45	39.97	< 0.0001	significant
A-Sand	*3.47*	*1*	*3.47*	*0.55*	*0.4747*	
B-ukpo clay	*225.54*	*1*	*225.54*	*35.85*	*0.0001*	
C-Water	*16.85*	*1*	*16.85*	*2.68*	*0.1328*	
AB	*248.57*	*1*	*248.57*	*39.51*	*< 0.0001*	
AC	*16.61*	*1*	*16.61*	*2.64*	*0.1352*	
BC	*156.50*	*1*	*156.50*	*24.88*	*0.0005*	
A^2	*70.74*	*1*	*70.74*	*11.24*	*0.0073*	
B^2	*393.75*	*1*	*393.75*	*62.59*	*< 0.0001*	
C^2	*1.95*	*1*	*1.95*	*0.31*	*0.5895*	
Residual	62.91	10	6.29			
Lack of Fit	*2.08*	*5*	*0.42*	*0.034*	*0.9990*	*not significant*
Pure Error	*60.83*	*5*	*12.17*			
Cor Total	2325.99	19				

Std. Dev.	2.51		R-Squared	0.9730
Mean	45.18		Adj R-Squared	0.9486
C.V. %	5.55		Pred R-Squared	0.9528
PRESS	109.80		Adeq Precision	21.348
-2 Log Likelihood	79.68		BIC	109.63
			AICc	124.12

From the Table 4.4e, it could be seen that the Model F-value of 39.97implies the model is significant. There is onlya 0.01% chance that an F-value this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicates the model terms are significant.In this case B, AB, BC, A^2, B^2are significant model terms.Values greater than 0.1000 indicate the model terms are not significant.

The Lack of Fit F value of 0.03 implies the Lack of Fit is not significant relative to the pure error. There is a 99% chance that a Lack of Fit this large could occur due to noise. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the dry shear strength from River Niger Onitsha beach sand using Ukpor clay as binder. The F-value of the independent variables sand, Ukpor clay and water content was estimated as 0.55, 35.85 and 2.68 respectively as shown in Table 4.4e. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.9730 and 0.9486, respectively which illustrates that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimate to the mean value of the observed response is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value of 5.55% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) (Chen et al., 2011). The signal to noise ratio which is given as the value of the adequacy precision is 21.348. This indicates that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$Y = 51.97 – 5.46A – 34.99B + 6.83C – 281.27AB – 51.70AC – 104.96BC – 107.22A^2 – 112.91B^2 – 4.55C^2$ …………………………………………(4.7)

In terms of actual values, the model terms are given by the dry shear strength = -2.6026E + 005+5079.85475 *sand +11412.12387 *Ukpor clay +2221,70799 *water – 113.64922 *sand *Ukpor clay – 20.88912 *sand *water – 74.21720 *Ukpor clay*water – 24.75590 *sand^2 – 79.84133 *Ukpor clay^2 – 3.21565 *water^2 ……………………………(4.8)

Where y = dry shearstrength, A = sand, B = Ukpor clay, C = water

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the Figure 4.111.

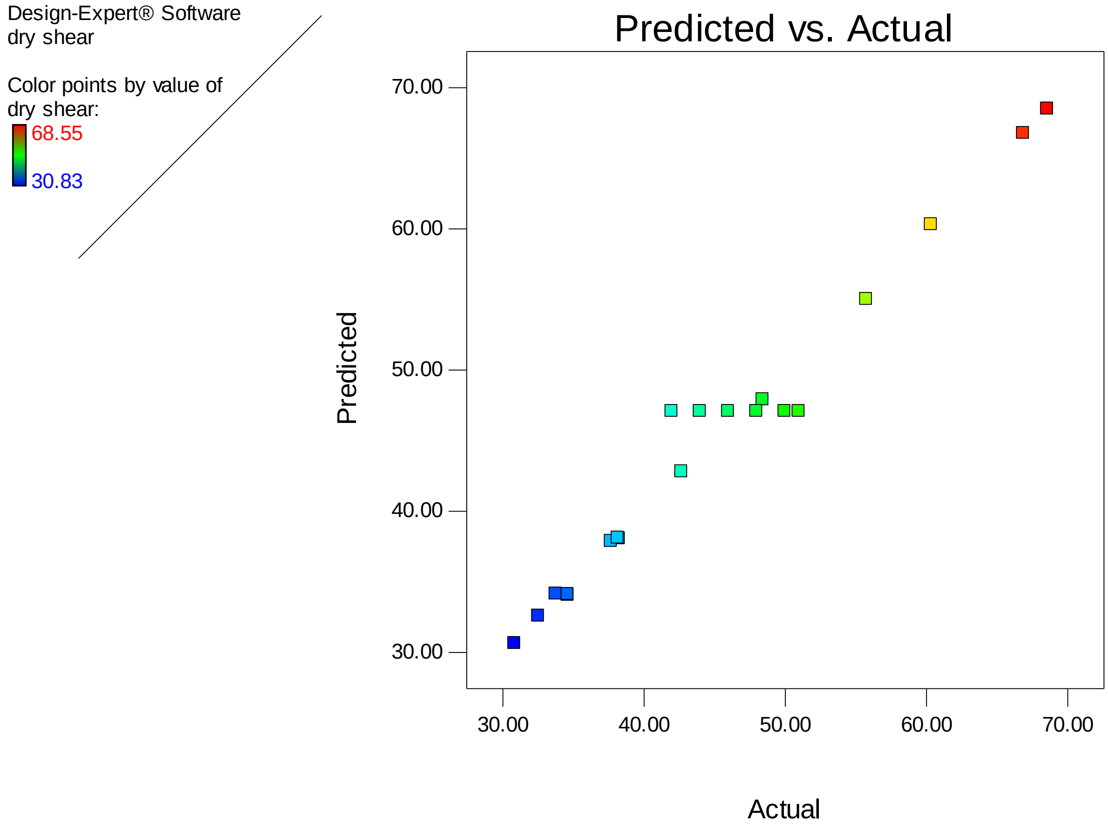


Figure 4.111 Linear correlation between predicted vs. actual values for dry shear strength of River Niger beach sand using Ukpor clay content.

From the Figure 4.111, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.112.

From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

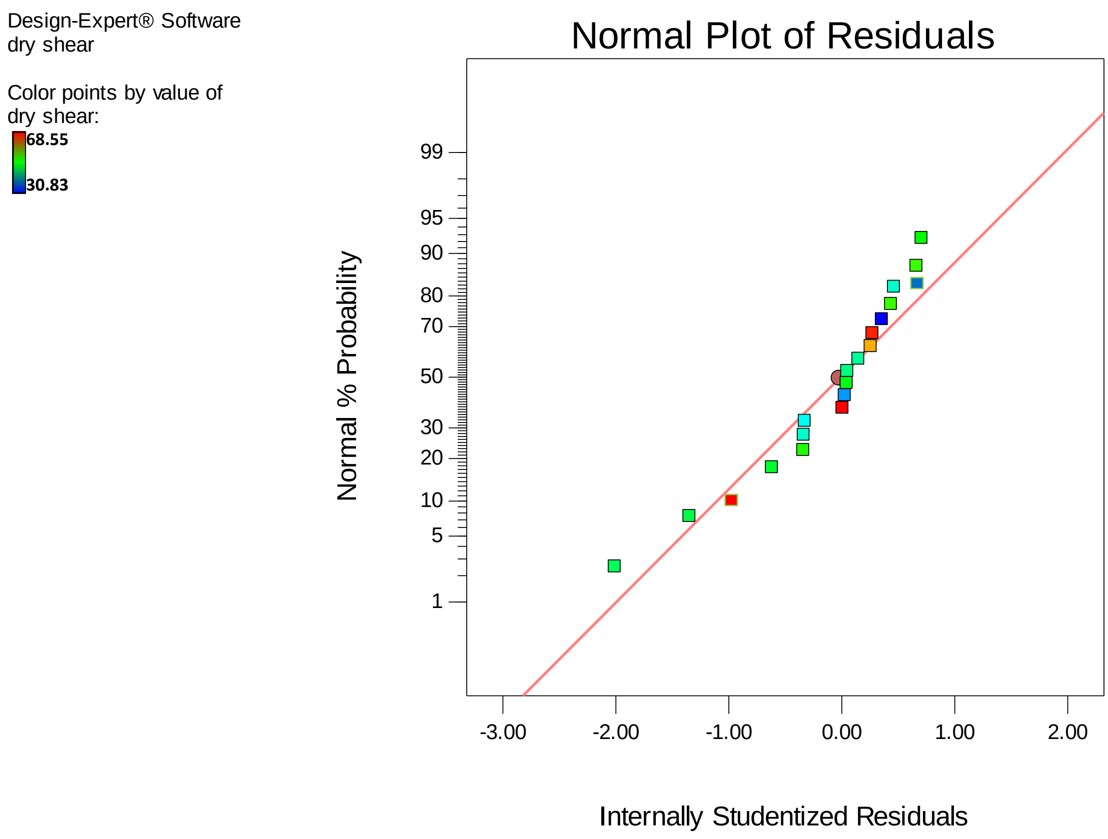
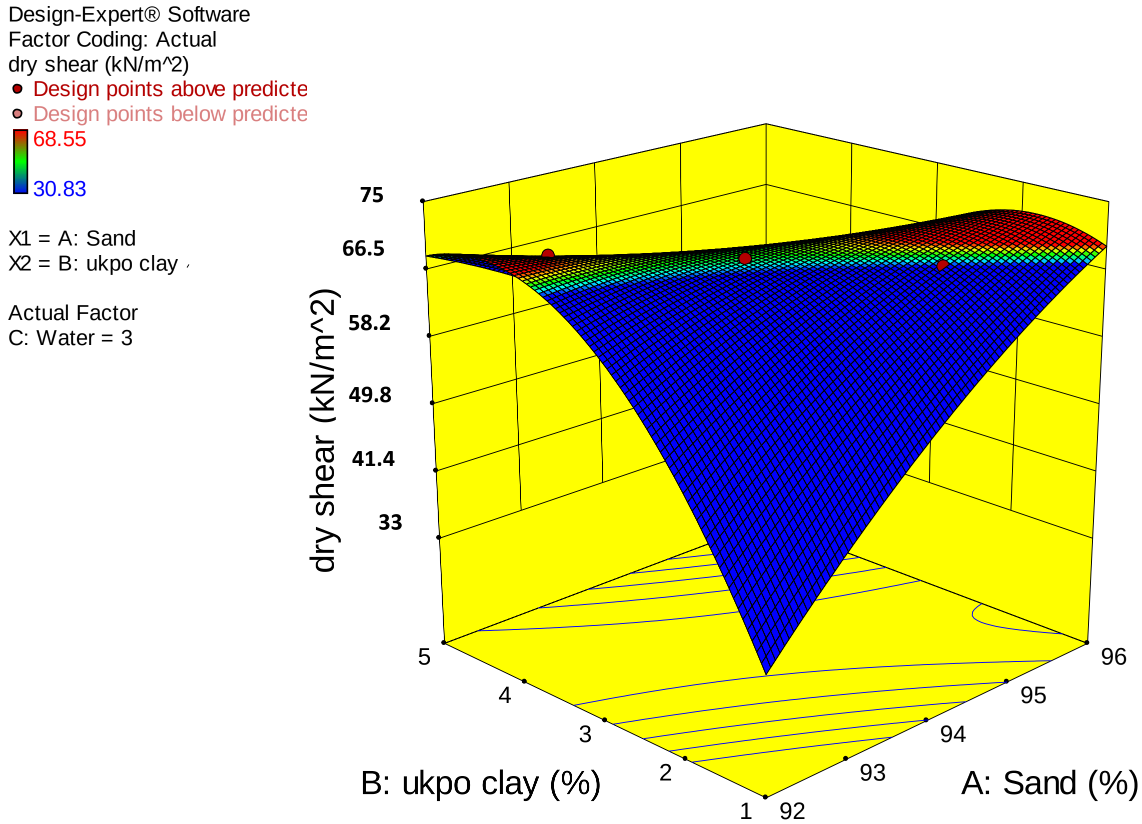


Figure 4.112 Normal probability plot of residuals obtained from the dryshear strength of Ukpor clay sample

4.22.8 3D Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the Ukpor clay and water content. Response surfaces and interaction plots were generated from the quadratic model, as shown in Figure 4.113. This Figure illustrates the response of different experimental variables and can be used to identify the major interactions between the variables.

(a)



b.

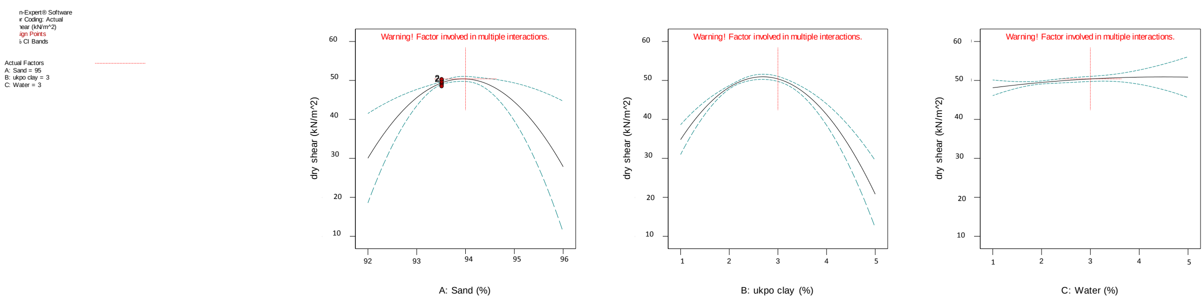


Figure 4.113: 3D surface (a) and single effect plot for the combine effect of Ukpor clay, sand and water (b),carried out at 3% water content.

Figure 4.113: 3D plot and its corresponding single effect plot to show the effect of sand and Ukpor clay on the response at water content of 3%. The graph shows that the maximum dry shear strength of 67.0KN/m^2 at 1% Ukpor clay content and 92% of sand, is in accordance with the model. As dry shear strength increased from 49.8KN/m^2 at 1% Ukpor clay to 67.0KN/m^2 at 5% Ukpor clay. This increase in dry shear strength was as a result of increase in binder content that comes with 3% water content.

Table 4.5a: Fit summary table

Response	**5**	**permeability**	**Transform:**	**None**	
	Sequential	**Lack of Fit**	**Adjusted**	**Predicted**	
Source	**p-value**	**p-value**	**R-Squared**	**R-Squared**	
Linear	0.0326	0.1556	0.3026	-0.1157	
2FI	0.0019	0.6639	0.7162	0.2652	Suggested
Quadratic	0.1363	0.9012	0.7827	0.5094	
Cubic	0.9012		0.6625		Aliased

Table 4.5b: Sequential model sum of squares

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Mean vs Total	4.615E+005	1	4.615E+005			
Linear vs Mean	42.15	3	14.05	3.75	0.0326	
2FI vs Linear	40.15	3	13.38	8.77	0.0019	Suggested
Quadratic vs 2FI	8.16	3	2.72	2.33	0.1363	
Cubic vs Quadratic	2.61	5	0.52	0.29	0.9012	Aliased
Residual	9.07	5	1.81			
Total	4.616E+005	20	23079.00			

Table 4.5c: Lack of fit tests

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Linear	50.91	11	4.63	2.55	0.1556	
2FI	10.76	8	1.35	0.74	0.6639	Suggested
Quadratic	2.61	5	0.52	0.29	0.9012	
Cubic	0.000	0				Aliased
Pure Error	9.07	5	1.81			

4.5d: Model summary statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	1.94	0.4127	0.3026	-0.1157	113.94	
2FI	1.24	0.8058	0.7162	0.2652	75.05	Suggested
Quadratic	1.08	0.8856	0.7827	0.5094	50.10	
Cubic	1.35	0.9112	0.6625		+	Aliased

4.22.9 ANOVA Analysis and Model Fitting

The F-value tests were performed using analysis of variance (ANOVA) to calculate the significance of each type of model. Based on the results of F-value, the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 4.5b, the quadratic vs 2FI and the linear vs mean models have significant F-value of 2.33 and 3.75, respectively while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 8.77 and 0.29, respectively.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. This test measured the adequacy of the different models based on response surface analysis. As shown in Table 4.5c there was a significant difference (F-value = 2.55 and 0.74) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 0.29) for quadratic models.

The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.5b and 4.5c showed that the quadratic model can well describe the green compressive strength of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.8856, 0.7827, 0.5094 and 0.9112, 0.6625 respectively when compared to other models (2FI and linear) as shown on Table 4.5d. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in table 4.5e.

Table 4.5e: ANOVA for response surface 2FI model

Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Model	82.29	6	13.72	8.99	0.0005	significant
A-Sand	*1.01*	*1*	*1.01*	*0.66*	*0.4315*	
B-ukpo clay	*1.31*	*1*	*1.31*	*0.86*	*0.3717*	
C-Water	*0.95*	*1*	*0.95*	*0.62*	*0.4440*	
AB	*0.12*	*1*	*0.12*	*0.081*	*0.7804*	
AC	*0.44*	*1*	*0.44*	*0.29*	*0.6017*	
BC	*22.49*	*1*	*22.49*	*14.74*	*0.0020*	
Residual	19.83	13	1.53			
Lack of Fit	*10.76*	*8*	*1.35*	*0.74*	*0.6639*	*not significant*
Pure Error	*9.07*	*5*	*1.81*			
Cor Total	102.13	19				

Std. Dev.	1.24		R-Squared	0.8058
Mean	151.90		Adj R-Squared	0.7162
C.V. %	0.81		Pred R-Squared	0.2652
PRESS	75.05		Adeq Precision	12.244
-2 Log Likelihood	56.59		BIC	77.56
			AICc	79.92

From the Table 4.5e, it could be seen that the model F-value of 39.97 implies that the model is significant. There is onlya 0.01% chance that an F-value this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicated that model terms are significant.In this case B, AB, BC, A^2, B^2are significant model terms.Values greater than 0.1000 indicate the model terms are not significant.

The independent variables in the specified model and the effect of each variable was evaluated. For this reason and in order to evaluate the adequacy of the selected model several appraisal techniques were used. The coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to weigh the adequacy of the model as used by other researchers (Chen *et al.,* 2010; The "Lack of Fit F-value" of 0.74 implied that the Lack of Fit is not significant relative to the pure error. There is a 66.39% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good because it means the model will be well fitted. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the permeability from River Niger Onitsha beach sand using Ukpor clay. The F-value of the independent variables such as sand, Ukpor clay and water content were estimated as

0.66, 0.86 and 0.62 respectively as shown in Table 4.5e. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.2652 and 0.7162, respectively which illustrated that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimate to the mean value of the observed response is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value of 0.81% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) (Chen et al., 2011). The signal to noise ratio` which is given as the value of the adequacy precision is 12.244. This indicated that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$$Y = +151.90+1.57A-1.03B+0.84C+0.20AB-0.27AC-1.37BC \quad \text{……………………………………(4.9)}$$

In terms of actual values, the model terms are given by the permeability= +64.56333+ 0.83706*sand-5.78073 *Ukpor clay +14.03394 *water + 0.082711*sand *Ukpor clay – 0.11030 *sand *water – 0.96668 *Ukpor clay*water ……………………………(4.10)

Where y = permeability, A = sand, B = Ukpor clay, C = water

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients, while the equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels are to be specified in the original units for each factor.

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the Figure 4.114.

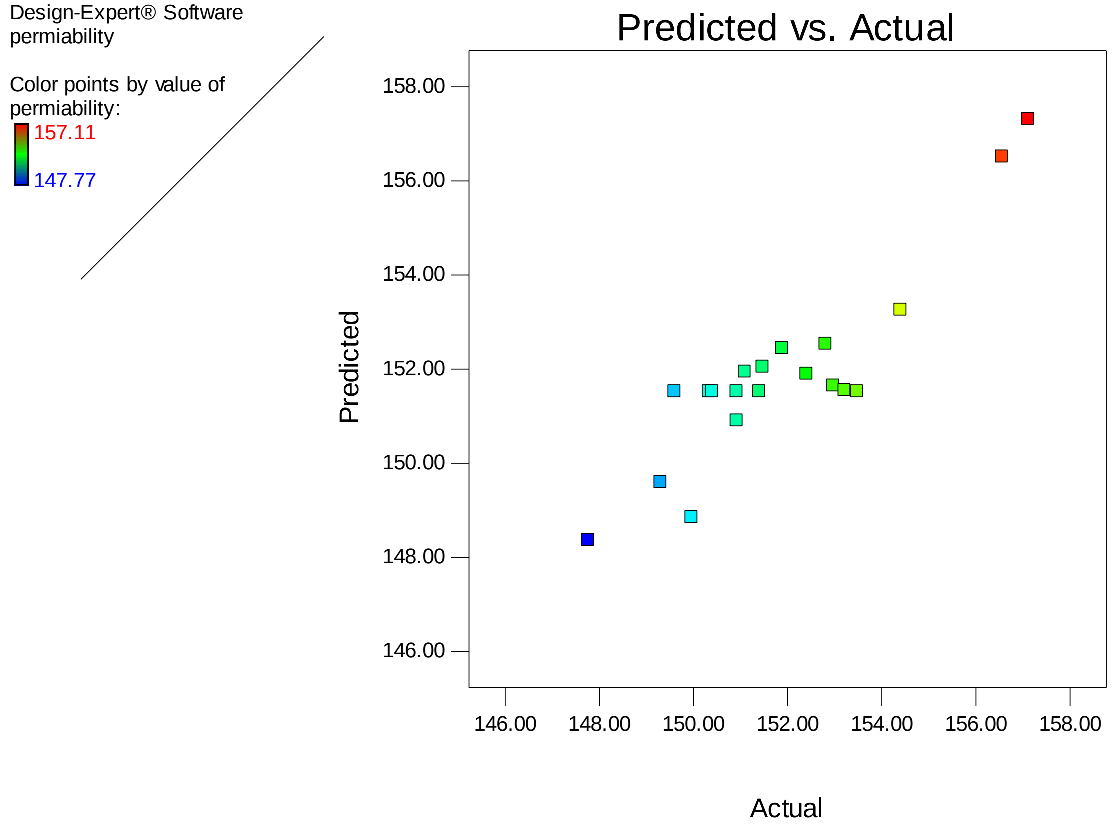


Figure 4.114 Linear correlation between predicted vs. actual values for permeability of River Niger beach sand using Ukpor clay content.

As it can be seen in Figure 4.114, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.115. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with

the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

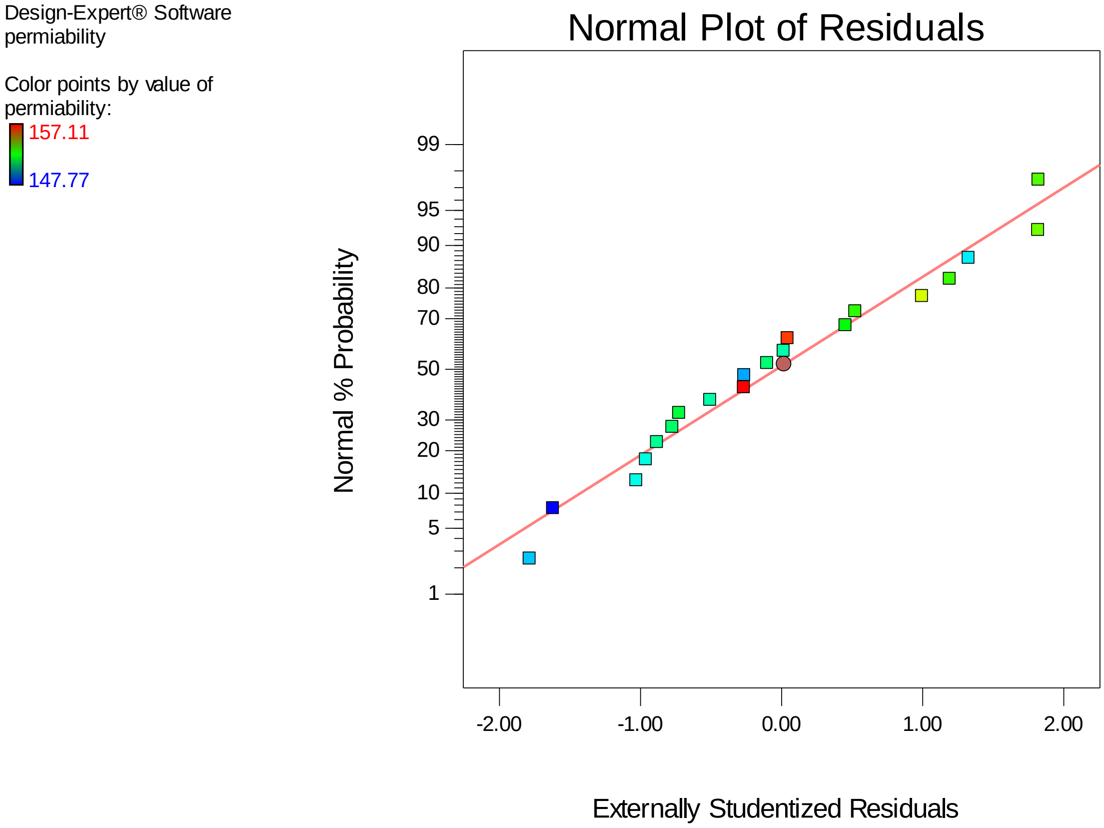
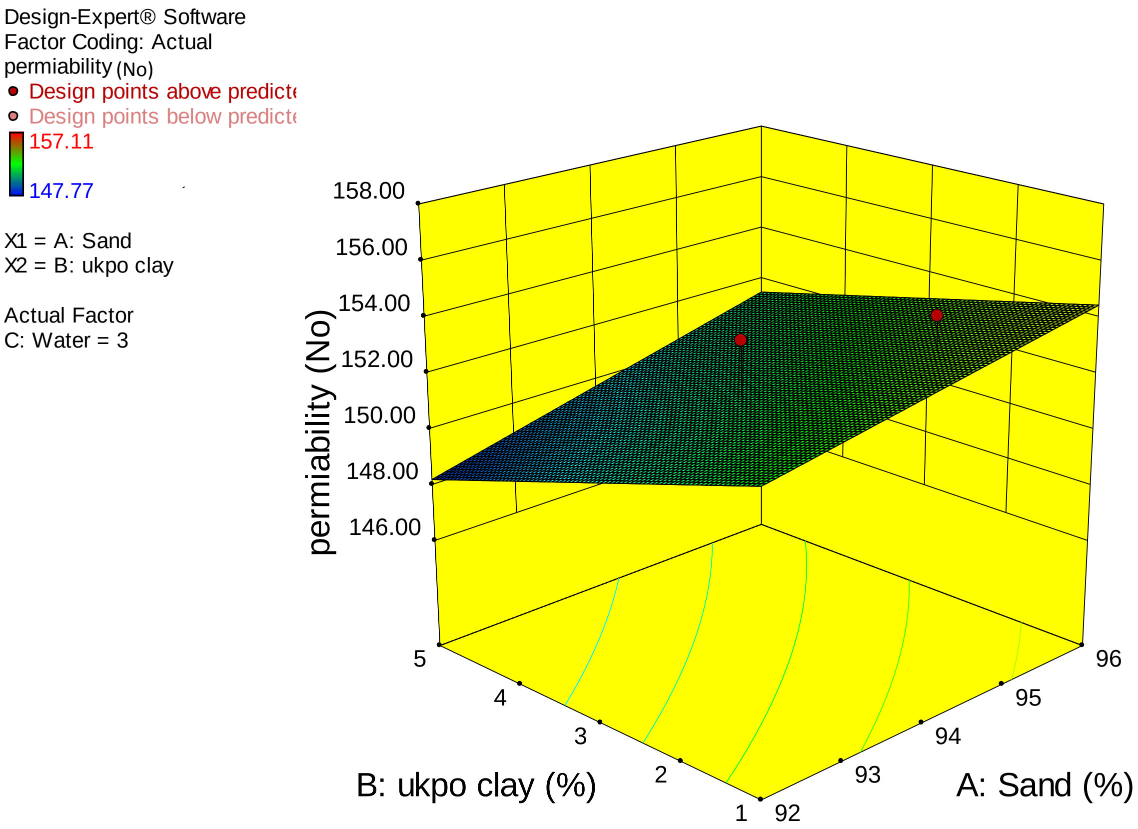


Figure 4.115 Normal probability plot of residuals obtained from the permeability of Ukpor clay sample

4.22.10 3D Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the Ukpor clay and water content. Response surfaces and single effect plots were generated from the quadratic model, as shown in Figure 4.116.

This Figure illustrates the response of different experimental variables and can be used to identify the major interactions between the variables.

(a)



b.

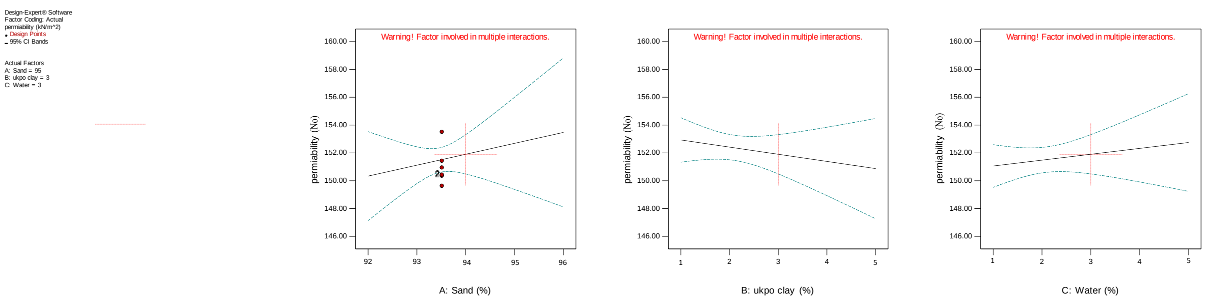


Figure 4.116: 3D surface (a) and single effect plot for the combine effect of Ukpor clay, sand and water (b),carried out at 3% water content.

Figure 4.116: 3D plot and its corresponding single effect plot to show the effect of sand and Ukpor clay on the response at water content of 3%. The graph shows that, it was shown that the maximum permeability value of 156.00 (No) at 5% Ukpor clay content and 92% of sand, is in accordance with the model.

Table 4.6a: Fit summary table

Response	6	Moisture content	Transform:	None	
	Sequential	Lack of Fit	Adjusted	Predicted	
Source	p-value	p-value	R-Squared	R-Squared	
Linear	0.1017	0.3071	0.1856	-0.2318	
2FI	0.7916	0.2256	0.0721	-1.4762	
Quadratic	0.0018	1.0000	0.7151	0.7967	Suggested
Cubic	1.0000		0.4324		Aliased

Table 4.6b: Sequential model sum of squares

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob> F	
Mean vs Total	123.01	1	123.01			
Linear vs Mean	4.23	3	1.41	2.44	0.1017	
2FI vs Linear	0.68	3	0.23	0.35	0.7916	
Quadratic vs 2FI	6.52	3	2.17	10.78	0.0018	Suggested
Cubic vs Quadratic	7.867E-003	5	1.573E-003	3.915E-003	1.0000	Aliased
Residual	2.01	5	0.40			
Total	136.47	20	6.82			

Table 4.6c: Lack of fit tests

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob> F	
Linear	7.22	11	0.66	1.63	0.3071	
2FI	6.53	8	0.82	2.03	0.2256	
Quadratic	7.867E-003	5	1.573E-003	3.915E-003	1.0000	Suggested
Cubic	0.000	0				Aliased
Pure Error	2.01	5	0.40			

Table 4.6d: Model summary statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.76	0.3142	0.1856	-0.2318	16.57	
2FI	0.81	0.3651	0.0721	-1.4762	33.31	
Quadratic	0.45	0.8501	0.7151	0.7967	2.74	Suggested
Cubic	0.63	0.8506	0.4324		+	Aliased

4.22.11 ANOVA Analysis and Model Fitting

The F-value tests were performed using analysis of variance (ANOVA) to calculate the significance of each type of model. Based on the results of F-value, the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 4.6b, the quadratic vs 2FI and the linear vs mean models have significant F-value of 10.78 and 2.44, respectively while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 0.35 and 3.915E-003, respectively.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. This test measured the adequacy of the different models based on response surface analysis. As shown in Table 4.6c there was a significant difference (F-value = 1.63 and 2.03) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 3.915E-003) for quadratic models. The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.6b and 4.6c showed that the quadratic model can well describe the green compressive strength of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.8501, 0.7151, 0.7967 and 0.8506, 0.4324 respectively when compared to other models (2FI and linear) as shown in Table 4.6d. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.6e.

Table 4.6e: ANOVA for response surface quadratic model

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob> F**	
Model	11.44	9	1.27	6.30	0.0041	significant
A-Sand	*0.22*	*1*	*0.22*	*1.09*	*0.3212*	
B-ukpo clay	*1.55*	*1*	*1.55*	*7.67*	*0.0198*	
C-Water	*0.11*	*1*	*0.11*	*0.55*	*0.4767*	
AB	*2.95*	*1*	*2.95*	*14.63*	*0.0033*	
AC	*1.45*	*1*	*1.45*	*7.20*	*0.0229*	
BC	*2.27*	*1*	*2.27*	*11.25*	*0.0073*	
A^2	*2.21*	*1*	*2.21*	*10.97*	*0.0079*	
B^2	*3.40*	*1*	*3.40*	*16.87*	*0.0021*	
C^2	*0.82*	*1*	*0.82*	*4.09*	*0.0708*	
Residual	2.02	10	0.20			
Lack of Fit	*7.867E-003*	*5*	*1.573E-003*	*3.915E-003*	*1.0000*	*not significant*
Pure Error	*2.01*	*5*	*0.40*			
Cor Total	13.45	19				

Std. Dev.	0.45		R-Squared	0.8501
Mean	2.48		Adj R-Squared	0.7151
C.V. %	18.11		Pred R-Squared	0.7967
PRESS	2.74		Adeq Precision	8.684
-2 Log Likelihood	10.88		BIC	40.83
			AICc	55.32

From the Table 4.6e, it could be seen that the F-value of 6.99 implies that the model term is significant. In this case, B, AB, AC, BC, A^2, B^2 are significant model terms. Values greater than 0.100 indicates that the model terms are not significant. The Lack of Fit F value of 0.00 implies that the Lack of Fit is not significant relative to the pure error. There is a 100% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good because it means the model will be well fitted. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the moisture content from River Niger Onitsha beach sand using Ukpor clay. The F-value of the independent variables such as sand, Ukpor clay and water content was estimated as 1.09, 7.67 and 0.55 respectively as shown in Table 4.6e. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.8501 and 0.7151%, respectively which illustrates that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimated mean value of the observed response is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value is18.11%. The signal to noise ratio which is given as the value of the adequacy precision is 8.684. This indicated that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$Y = +1.83 + 1.37A +2.90B + 0.55C+30.65AB +15.29AC + 12.64BC + 18.96A^2 + 10.5B^2 + 2.95C^2$, ………………………………………….(4.11)

In terms of actual values, the model terms are given by the moisture content = +44461.21318–882.58313*sand – 1239.23219 *Ukpor clay – 622.69777 *water + 12.38443 *sand *Ukpor clay +6.17799 *sand *water +8.93716 *Ukpor clay*water + 4.37861*sand^2 + 7.42146 *Ukpor clay^2 + 2.08845 *water^2…………………………….(4.12)

Where y = moisture content, A = sand, B = Ukpor clay, C = water

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the Figure 4.117.

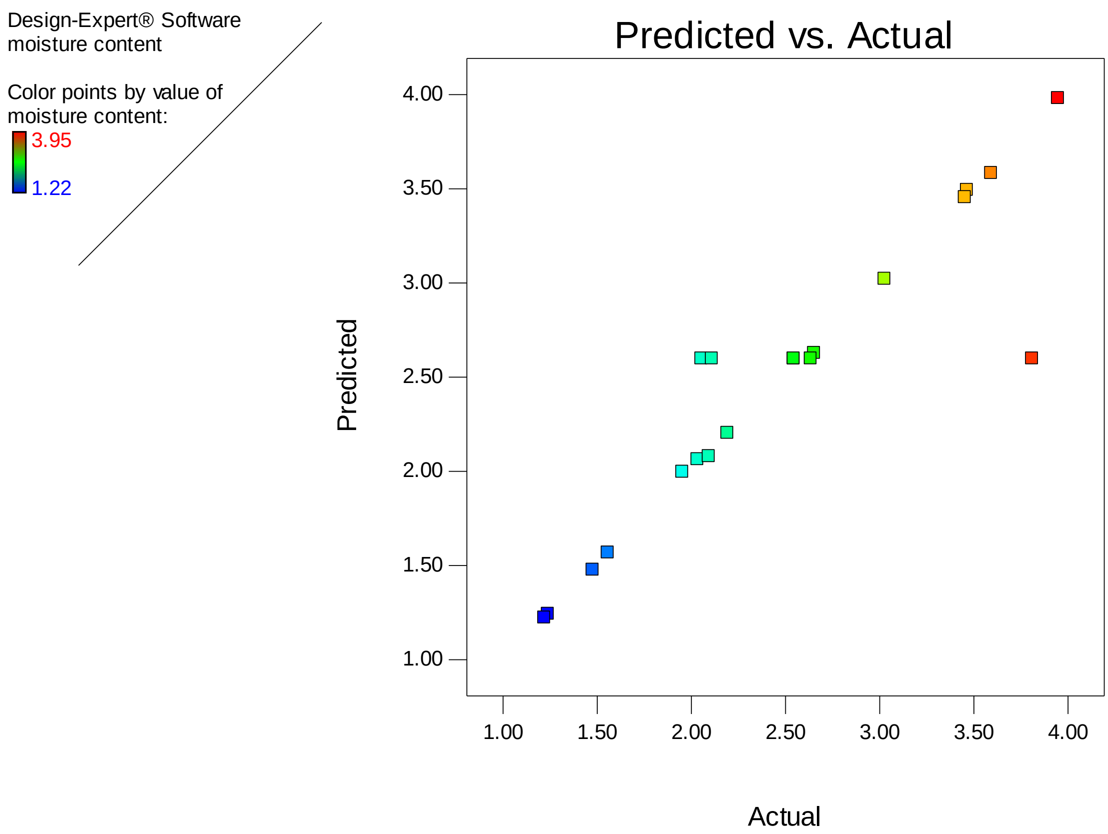


Figure 4.117 Linear correlation between predicted vs. actual values for moisture content of River Niger beach sand using Ukpor clay content.

As it can be seen in Figure 4.117, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.118. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with

the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

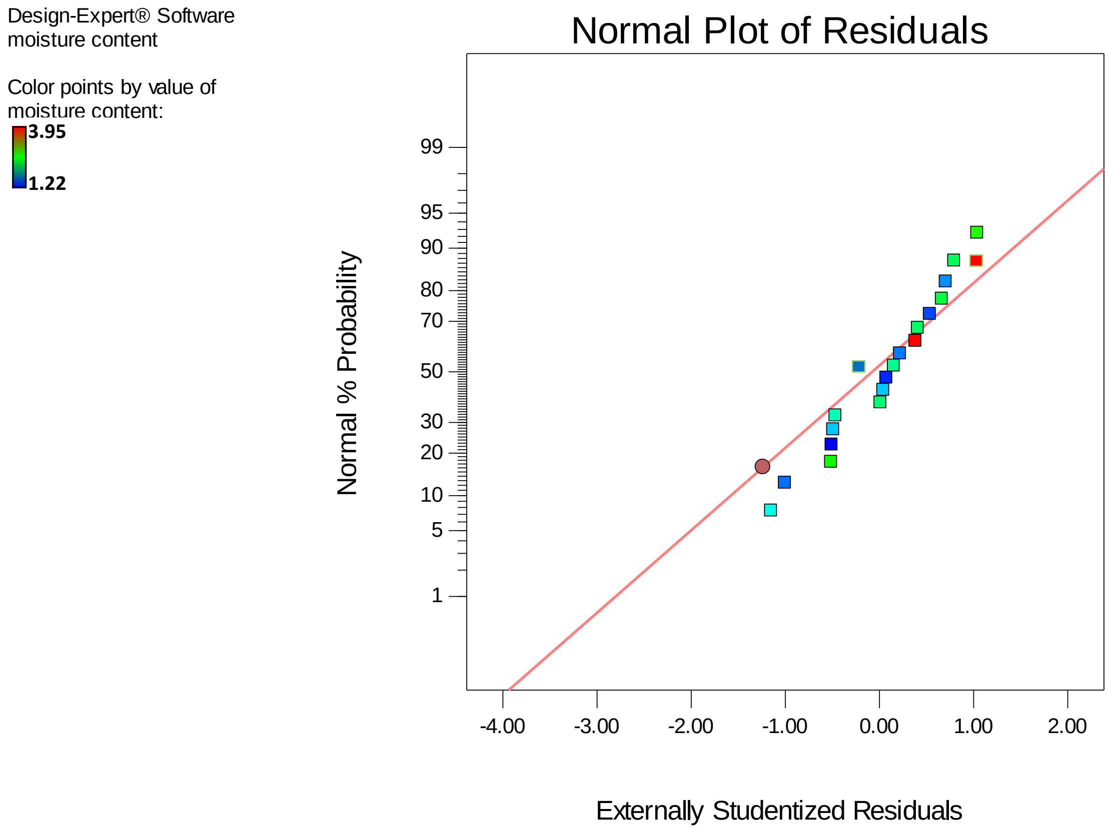
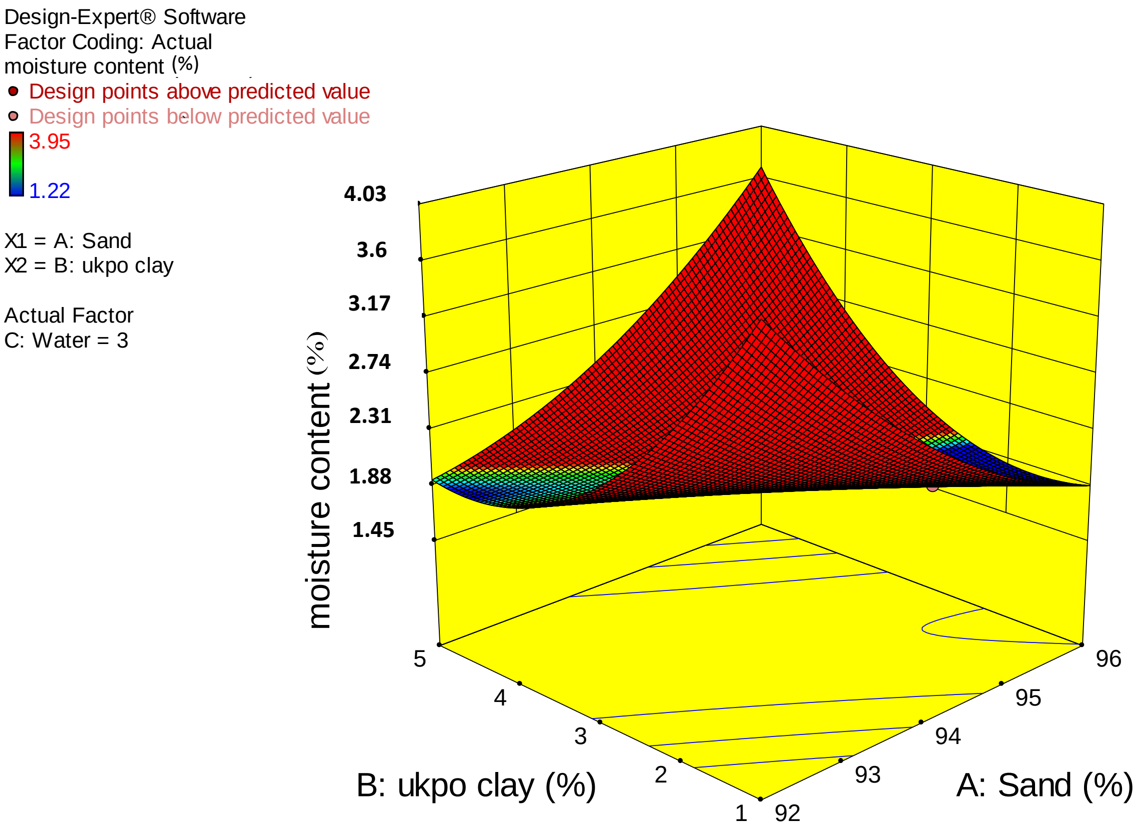


Figure 4.118 Normal probability plot of residuals obtained from the moisture content of Ukpor clay sample

4.22.12 3D Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the Ukpor clay and water content. Response surfaces and single effect plots were generated from the quadratic model, as shown in Figure 4.119.

This Figure illustrates the response of different experimental variables and can be used to identify the major interactions between the variables.

(a)



b.

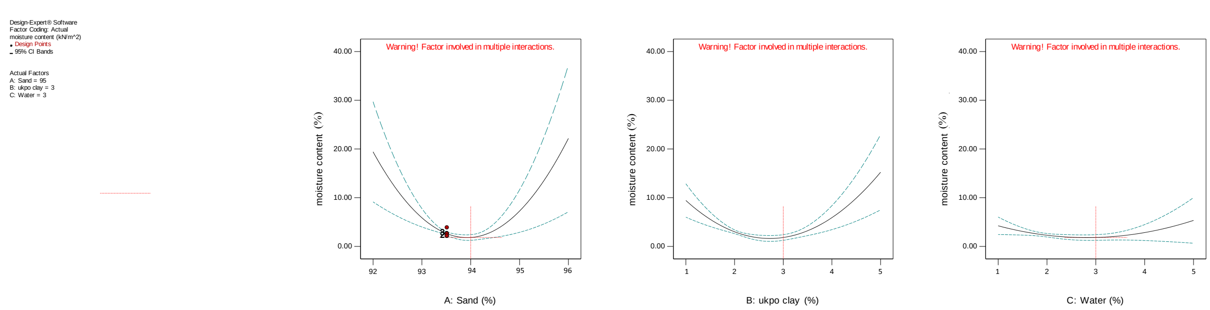


Figure 4.119: 3D surface (a) and single effect plot for the combine effect of Ukpor clay, sand and water (b),carried out at 3% water content.

Figure 4.1119: 3D plot and its corresponding interaction plot to show the effect of sand and Ukpor clay on the response at water content of 3%. The graph shows hat the maximum moisture content of 3.7% at 5% Ukpor clay content and 92% of sand, is in accordance with the model.

Table 4.7a: Fit summary table

Response	7	**Compactibility**	**Transform:**	**None**	
	Sequential	**Lack of Fit**	**Adjusted**	**Predicted**	
Source	**p-value**	**p-value**	**R-Squared**	**R-Squared**	
Linear	0.0153	0.0809	0.3696	0.1681	
2FI	0.0004	0.6043	0.7991	0.4748	
Quadratic	0.0304	1.0000	0.8888	0.9220	Suggested
Cubic	1.0000		0.7780		Aliased

Table 4.7b: Sequential model sum of squares

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Mean vs Total	7629.71	1	7629.71			
Linear vs Mean	241.35	3	80.45	4.71	0.0153	
2FI vs Linear	202.36	3	67.45	12.40	0.0004	
Quadratic vs 2FI	40.59	3	13.53	4.49	0.0304	Suggested
Cubic vs Quadratic	0.063	5	0.013	2.110E-003	1.0000	Aliased
Residual	30.05	5	6.01			
Total	8144.13	20	407.21			

Table 4.7c: Lack of fit tests

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Linear	243.02	11	22.09	3.68	0.0809	
2FI	40.66	8	5.08	0.85	0.6043	
Quadratic	0.063	5	0.013	2.110E-003	1.0000	Suggested
Cubic	0.000	0				Aliased
Pure Error	30.05	5	6.01			

Table 4.7d: Model summary statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	4.13	0.4692	0.3696	0.1681	427.92	
2FI	2.33	0.8626	0.7991	0.4748	270.18	
Quadratic	1.74	0.9415	0.8888	0.9220	40.11	Suggested
Cubic	2.45	0.9416	0.7780		+	Aliased

4.22.13 ANOVA Analysis and Model Fitting

From the Table 4.7b, the quadratic vs 2FI and the linear vs mean models have significant F-value of 4.49 and 4.71 respectively while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 12.40 and 2.110E-003, respectively.

In evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. As shown in Table 4.7c, there was a significant difference (F-value = 3.68 and 0.85) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 2.110E-003) for quadratic models. The significant results of lack of fit for linear and 2FImodels showed that these models are not adequate to use. The results of Tables 4.7b and 4.7c showed that the quadratic model can well describe the compactibility of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.9415, 0.8888, 0.9220 and 0.9416, 0.7780respectively when compared to other models (2FI and linear) as shown on Table 4.7d. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.7e.

Table 4.7e: ANOVA for response surface quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	484.31	9	53.81	17.87	< 0.0001	significant
A-Sand	*8.85*	*1*	*8.85*	*2.94*	*0.1172*	
B-ukpo clay	*8.95*	*1*	*8.95*	*2.97*	*0.1154*	
C-Water	*1.54*	*1*	*1.54*	*0.51*	*0.4904*	
AB	*27.73*	*1*	*27.73*	*9.21*	*0.0126*	
AC	*20.33*	*1*	*20.33*	*6.75*	*0.0266*	
BC	*24.35*	*1*	*24.35*	*8.09*	*0.0174*	
A^2	*24.27*	*1*	*24.27*	*8.06*	*0.0176*	
B^2	*32.18*	*1*	*32.18*	*10.69*	*0.0084*	
C^2	*22.49*	*1*	*22.49*	*7.47*	*0.0211*	
Residual	30.11	10	3.01			
Lack of Fit	*0.063*	*5*	*0.013*	*2.110E-003*	*1.0000*	*not significant*
Pure Error	*30.05*	*5*	*6.01*			
Cor Total	514.42	19				

Std. Dev.	1.74		R-Squared	0.9415
Mean	19.53		Adj R-Squared	0.8888
C.V. %	8.88		Pred R-Squared	0.9220
PRESS	40.11		Adeq Precision	12.609
-2 Log Likelihood	64.94		BIC	94.90
			AICc	109.39

The independent variables in the specified model and the effect of each variable was evaluated. For this reason and in order to evaluate the adequacy of the selected model, several appraisal techniques were used. The coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to weigh the adequacy of the model as used by other researchers (Chen *et al.,* 2010) . It could be seen that the F-value of 17.87 implied that the model term is significant. In this case AB, AC, BC, A^2, B^2, C^2 are significant model terms. Values greater than 0.100 indicate that the model terms are not significant. The Lack of Fit F value of 0.00 implied that the Lack of Fit is not significant relative to the pure error. There is a 100.00% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good because it means the model will be well fitted. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the compactibility from River Niger Onitsha beach sand using Ukpor clay. The F-value of the independent variables such as sand, Ukpor clay and water content were estimated as 2.94, 2.97 and 0.51 respectively as shown in Table 4.7e. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.9415 and 0.8888%, respectively which illustrates that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimate to the mean value of the observed response is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value of 8.88% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) (Chen et al., 2011). The signal to noise ratio which is given as the value of the adequacy precision is 12.609. This indicated that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$Y = +25.44 – 8.73A - 6.79B – 2.07C – 93.95AB – 57.19AC – 41.40BC - 62.80A^2 – 32.28B^2 – 15.42C^2$ ……………………………………….(4.13)

In terms of actual values, the model terms are given by the compactibility = -1.46929E + 005 + 2919.61050*sand+ 3806.25256 *Ukpor clay + 2335.38613 *water – 37.96121 *sand *Ukpor clay – 23.10957 *sand *water – 29.27586*Ukpor clay*water – 14.50048*sand^2 – 22.82546 *Ukpor clay^2 – 10.90699 *water^2……………………………..(4.14)

Where y = compactibility, A = sand, B = Ukpor clay, C = water

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients, while the equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels are to be specified in the original units for each factor.

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the Figure 4.120.

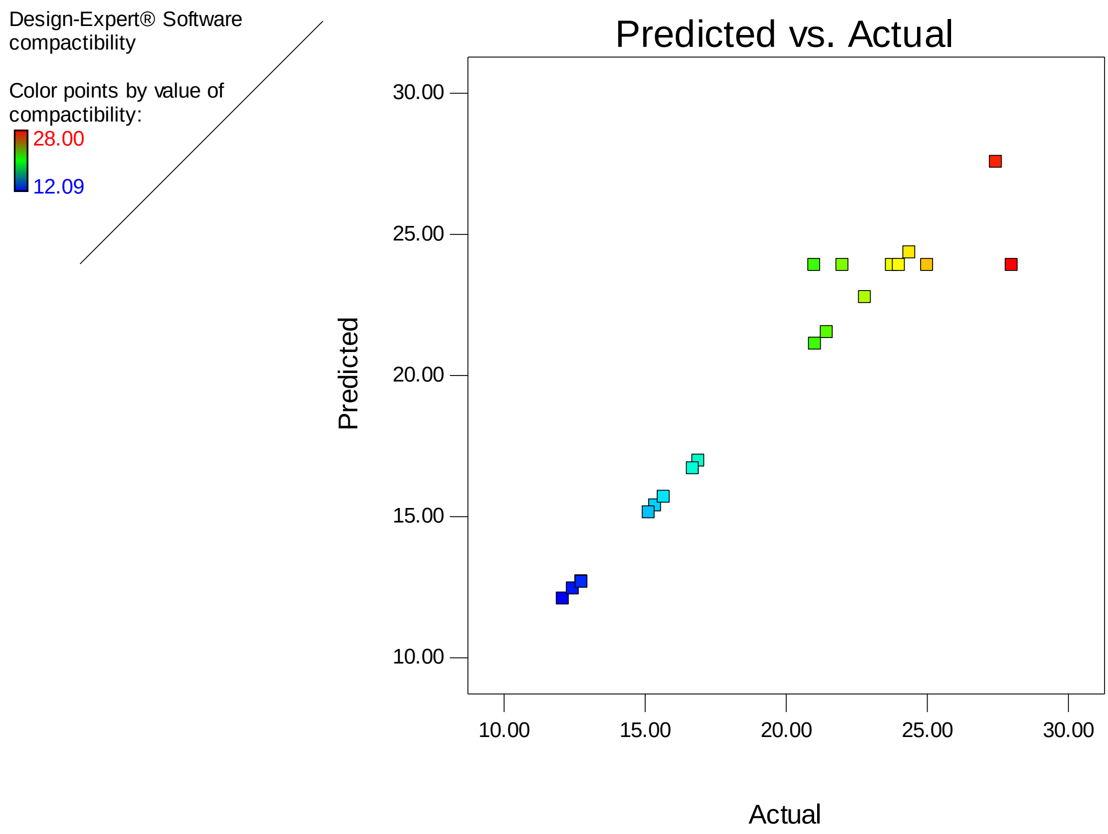


Figure 4.120 Linear correlation between predicted vs. actual values for compactibility of River Niger beach sand using Ukpor clay content.

As it can be seen in Figure 4.120, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.121. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

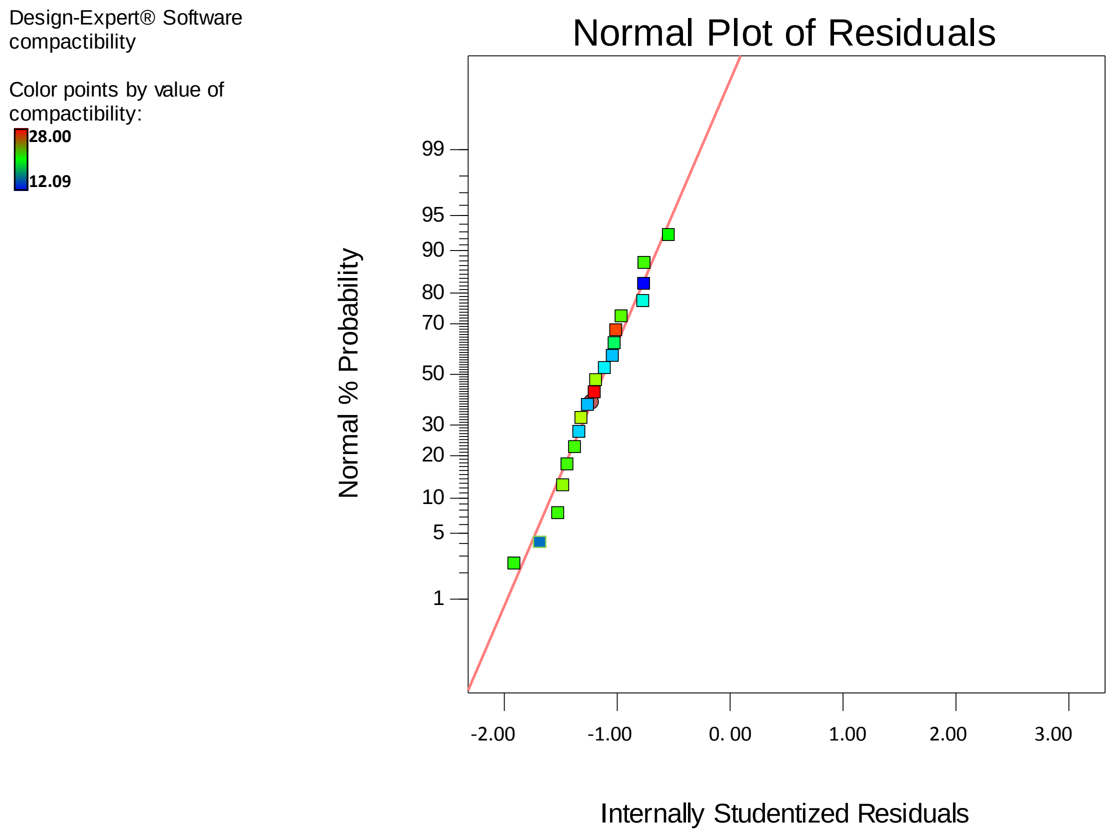
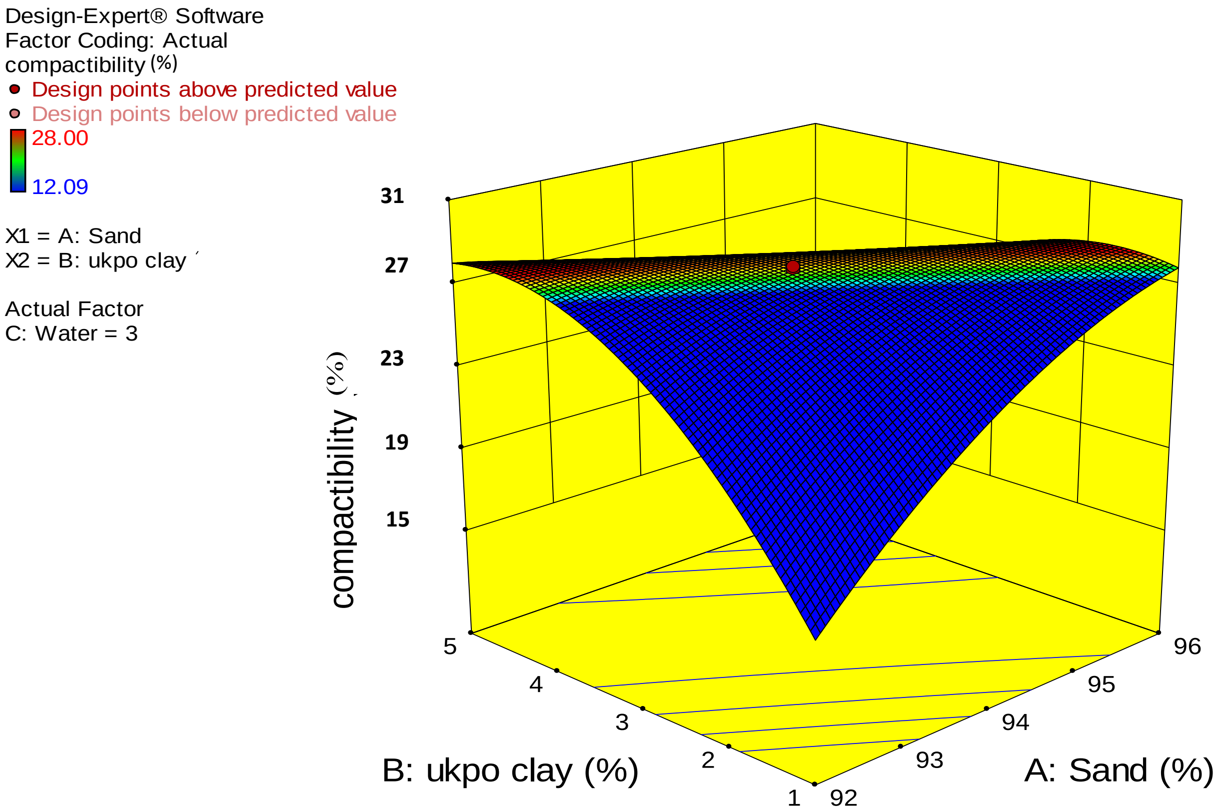


Figure 4.121 Normal probability plot of residuals obtained from the compactibility of Ukpor clay sample

4.22.14 3D Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the Ukpor clay and water content. Response surfaces and interaction plots were generated from the quadratic model, as shown in Figure 4.122. This Figure illustrates the response of different experimental variables and can be used to identify the major interactions between the variables.

(a)



(b)

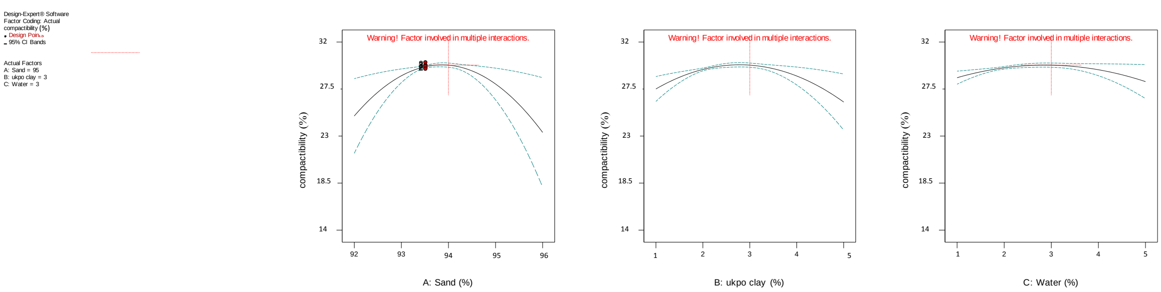


Figure 4.122: 3D surface (a) and single effect plot for the combine effect of Ukpor clay, sand and water (b), carried out at 3% water content.

Figure 4.122: 3D plot and its corresponding single effect plot to show the effect of sand and Ukpor clay on the response at water content of 3%. The graph shows that the maximum compactibility values of 28% at 5% Ukpor clay content and 92% of sand, is in accordance with the model. As compactibility value increased from 22% at 1% Ukpor clay to 28% at 5% Ukpor

clay. This increase in compactibility values was as a result of increase in binder content that comes with 3% water content.

4.23 Experimental Design and Optimization for Foundry Properties of River Niger Beach Sand Using Bentonite as Binder

The result of 20 experimental responses for the River Niger beach sand blended with bentonite and water content using central composite design (CCD) are tabulated in Table 4.8a

Table 4.8a CCD table of experimental factors and responses for optimization of the moulding properties of River Niger beach sand for foundry application.

Std	Run	Factor 1 A sand %	Factor 2 B: Bentonite	Factor C: Water %	Response 1 Green com (kN/m^2)	Response 2 Green Shear (kN/m^2)	Response 3 Dry com (kN/m^2)	Response 4 Dry shear (kN/m^2)	Response 5 Permeability (No)	Response 6 Moisture com kN/m^2	Response 7Compactibility com kN/m^2
11	1	95	1	4	16.1	1.3	207.0	39.4	148.6	2.0	17.5
9	2	91	5	4	14.7	0.8	179.3	46.4	147.0	3.0	22.5
12	3	94	5	1	14.4	0.7	135.2	35.9	154.6	2.2	21.7
2	4	96	2	2	18.8	2.0	175.0	38.2	152.3	2.2	18.1
6	5	97	1	2	15.7	0.7	184.6	36.0	152.4	1.9	15.0
7	6	92	4	4	18.3	1.1	177.2	34.3	153.5	2.3	18.7
10	7	98	1	1	18.1	1.3	155.8	60.1	140.0	4.1	23.7
13	8	95	4	1	18.7	1.7	146.7	66.2	150.8	2.8	28.3
5	9	95	2	3	19.4	2.8	188.7	36.0	149.8	2.2	17.7
1	10	93	3	4	19.1	2.6	189.6	22.4	152.1	2.1	17.4
3	11	94	4	2	20.2	3.3	152.3	47.6	152.4	2.9	24.0
4	12	93	4	3	21.1	3.7	165.9	47.7	152.2	3.1	23.5
8	13	96	3	1	19.6	2.8	152.6	29.4	155.5	2.3	20.4
14	14	94	1	5	18.8	1.9	212.2	67.7	148.2	2.8	27.4
15	15	94	3	3	22.9	5.1	177.3	44.1	150.6	2.8	22.2
16	16	94	3	3	21.4	3.2	177.3	45.1	150.6	2.7	22.8
17	17	94	3	3	23.3	5.2	177.3	43.1	157.0	2.3	22.5
18	18	94	3	3	22.4	4.0	180.2	41.0	150.0	2.6	22.4
19	19	94	3	3	24.4	5.2	171.6	47.0	153.0	2.8	22.5
20	20	94	3	3	22.3	3.9	184.0	42.0	151.0	2.5	24.6

The responses obtained from different experimental runs carried out by combinations of the three variables unique to each of the runs are tabulated on the response column of Table 4.18a above. The three experimental variable interaction gave a total of 20 experimental runs. The responses obtained from various runs are significantly exceptional which implies that each of the factors have substantial effect on the response.

Table 4.8b: Fit summary table

Response	1	Green com strength	Transform:	None	
	Sequential	Lack of Fit	Adjusted	Predicted	
Source	p-value	p-value	R-Squared	R-Squared	
Linear	0.9492	0.0057	-0.1621	-0.7202	
2FI	< 0.0001	0.1623	0.7521	-0.1038	
Quadratic	0.0009	0.9985	0.9333	0.9349	Suggested
Cubic	0.9985		0.8717		Aliased

Table 4.8c: Sequential model sum of squares

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob> F	
Mean vs Total	7593.96	1	7593.96			
Linear vs Mean	3.28	3	1.09	0.12	0.9492	
2FI vs Linear	124.16	3	41.39	20.67	< 0.0001	
Quadratic vs 2FI	20.64	3	6.88	12.77	0.0009	Suggested
Cubic vs Quadratic	0.21	5	0.042	0.040	0.9985	Aliased
Residual	5.18	5	1.04			
Total	7747.42	20	387.37			

Table 4.8d: Lack of fit tests

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob> F	
Linear	145.01	11	13.18	12.72	0.0057	
2FI	20.85	8	2.61	2.52	0.1623	
Quadratic	0.21	5	0.042	0.040	0.9985	Suggested
Cubic	0.000	0				Aliased
Pure Error	5.18	5	1.04			

Table 4.8e: Model summary statistics

	Std.		Adjusted	Predicted		
Source	Dev.	R-Squared	R-Squared	R-Squared	PRESS	
Linear	3.06	0.0214	-0.1621	-0.7202	263.99	
2FI	1.42	0.8304	0.7521	-0.1038	169.40	
Quadratic	0.73	0.9649	0.9333	0.9349	9.98	Suggested
Cubic	1.02	0.9662	0.8717		+	Aliased.

4.23.1 ANOVA Analysis and Model Fitting

The F-value tests were performed using analysis of variance (ANOVA) to calculate the significance of each type of model. Based on the results of F-value, the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 4.8c, the quadratic vs 2FI and the linear vs mean models have significant F-value of 12.77 and 0.12 respectively while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 20.67 and 0.040 respectively.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. This test measured the adequacy of the different models based on response surface analysis. As shown in Table 4.8d there was a significant difference (F-value = 12.72 and 2.52) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 0.040) for quadratic models. The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.8c and 4.8d showed that the quadratic model can well describe the green compressive strength of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.9649, 0.9333, 0.9349 and 0.9662, 0.8717 respectively when compared to other models (2FI and linear) as shown on Table 4.8e. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

The closer the R^2value is to unity, the better the model predicts the response. Adjusted-R^2 is a measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model. The adjusted-R^2decreases as the number of terms in the model increases, if those additional terms don't add value to the model. Predicted-R^2 is a measure of the amount of variation in new data explained by the model.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.8f.

Table 4.8f: ANOVA for response surface quadratic model

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Model	145.17	7	20.74	29.98	< 0.0001	significant
A-Sand	*13.05*	*1*	*13.05*	*18.87*	*0.0010*	
B-Bentonite	*1.52*	*1*	*1.52*	*2.19*	*0.1646*	
C-Water	*14.04*	*1*	*14.04*	*20.30*	*0.0007*	
AB	*15.13*	*1*	*15.13*	*21.87*	*0.0005*	
BC	*11.52*	*1*	*11.52*	*16.66*	*0.0015*	
A^2	*23.79*	*1*	*23.79*	*34.39*	*< 0.0001*	
B^2	*23.92*	*1*	*23.92*	*34.58*	*< 0.0001*	
Residual	8.30	12	0.69			
Lack of Fit	*3.12*	*7*	*0.45*	*0.43*	*0.8491*	*not significant*
Pure Error	*5.18*	*5*	*1.04*			
Cor Total	153.47	19				

Std. Dev.	0.83		R-Squared	0.9459
Mean	19.49		Adj R-Squared	0.9144
C.V. %	4.27		Pred R-Squared	0.7704
PRESS	35.23		Adeq Precision	16.222
-2 Log Likelihood	39.17		BIC	63.14
			AICc	68.26

The independent variables in the specified model and the effect of each variable was evaluated. For this reason and in order to evaluate the adequacy of the selected model, several appraisal techniques were used. The coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to weigh the adequacy of the model as used by other researchers (Chen *et al.,* 2010) . It could be seen that the F-value of 29.98 implies that the model term is significant. Values of prob > F" less than 0.0500 indicate that the model terms are insignificant. In this case A, C, AB, BC, A^2, B^2 are significant model terms. Values greater than 0.100 indicate that the model terms are not significant. The Lack of Fit F value of 0.43 implies that the Lack of Fit is not significant relative to the pure error. There is a 84.91% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good because it means the model would be well fitted. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the green compressive strength from River Niger Onitsha beach sand using bentonite. The F-value of the independent variables such as sand, bentonite and water content were estimated as 18.87, 2.19 and 20.30 respectively as shown in Table 4.8f. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.9459 and 0.9144%, respectively which illustrates that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimate to the mean value of the observed response is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value of 4.27% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) (Chen et al., 2011). The signal to noise ratio which is given as the value of the adequacy precision is 16.222. This indicated that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$$Y = 24.57 + 6.45A + 1.09B + 3.79C - 17.30AB - 5.00BC - 7.42A^2 - 8.89B^2 \qquad (4.14)$$

In terms of actual values, the model terms are given by the green compressive strength = - 7655.32622 + 347.97228*sand + 709.91085 *bentonite+ 13.80309 *water – 6.99135 *sand *bentonite– 3.53756 *bentonite *water – 1.71375 *sand^2– 6.28285*bentonite^2……………………………..(4.15)

Where y = green compressive strength, A = sand, B = bentonite, C = water

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients, while the equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels are to be specified in the original units for each factor.

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the Figure 4.123.

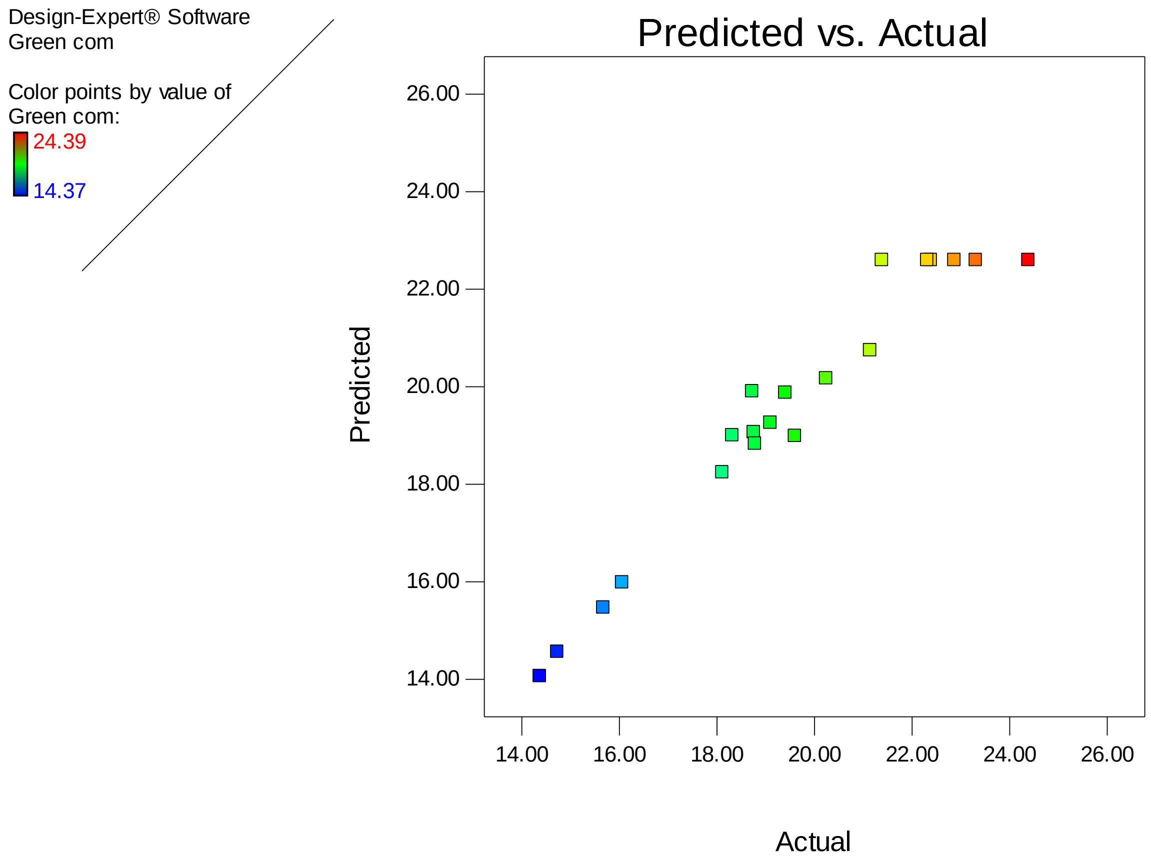


Figure 4.123 Linear correlation between predicted vs. actual values for green compressive strength of River Niger beach sand using bentonite content.

As it can be seen in Figure 4.123, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown in Figure 4.124. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with

the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

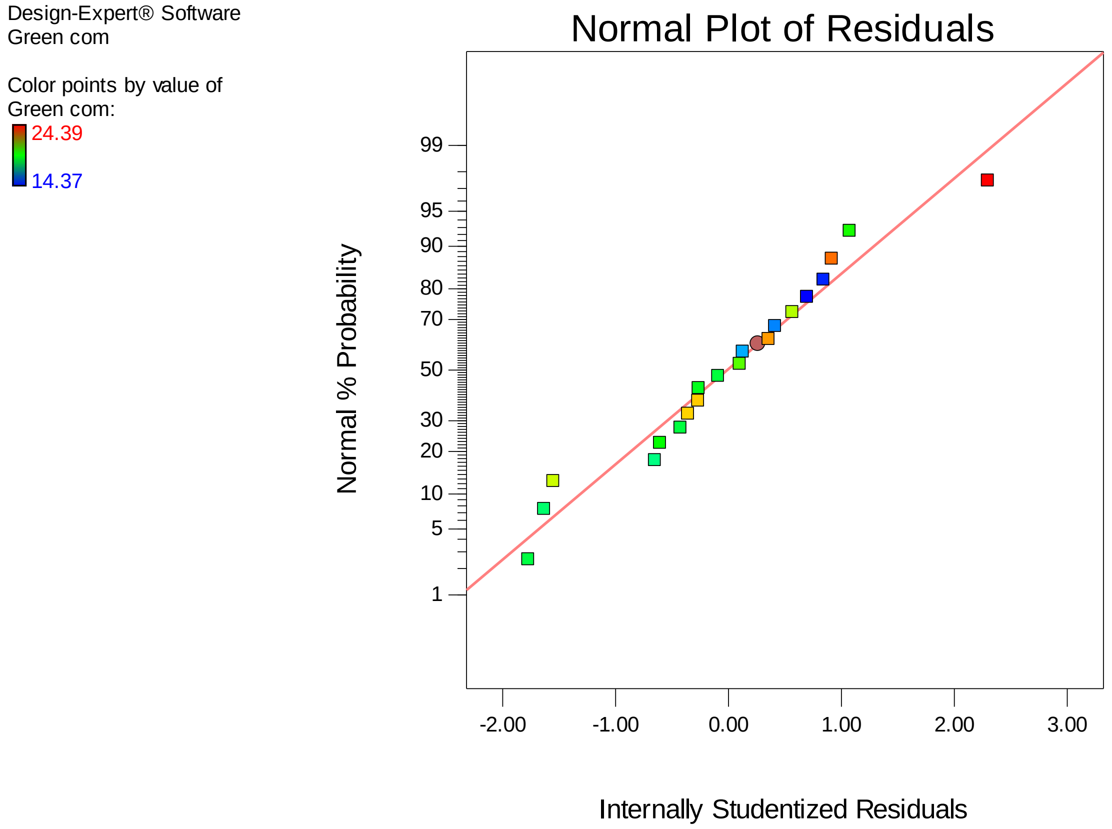
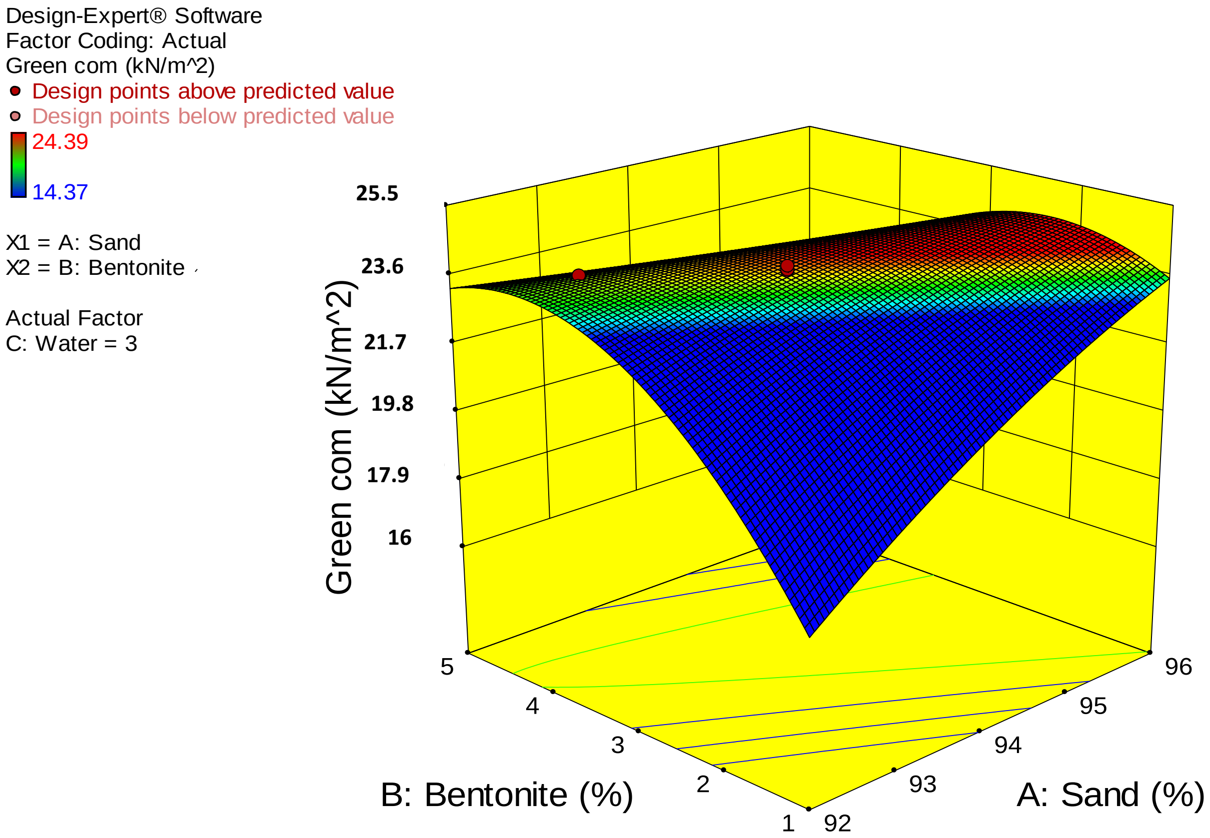


Figure 4.124 Normal probability plot of residuals obtained from the green strength of bentonite sample

4.23.2 3D Surface and Single Effect plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the bentonite and water content. Response surfaces and single effect plots were generated from the quadratic model, as shown in Figure 4.125 below. This Figure illustrates the response of different experimental variables and can be used to identify the major interactions between the variables.

a)



b)

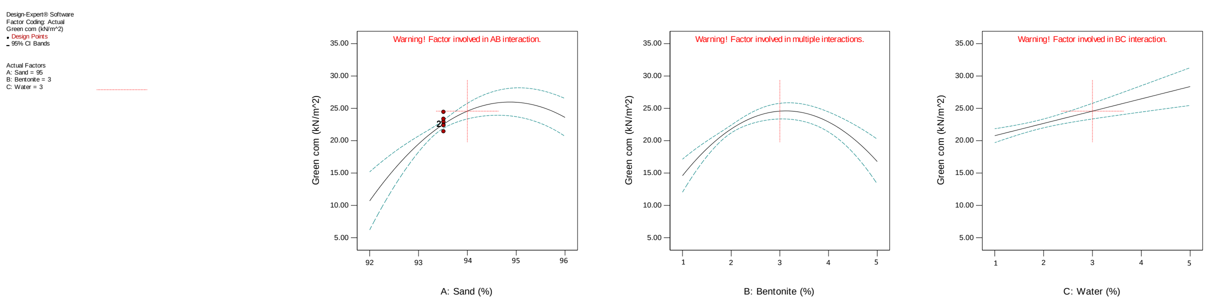


Figure 4.125: 3D surface (a) and single effect plot for the combine effect of bentonite , sand and water (b), carried out at 3% water content.

Figure 4.125: 3D plot and its corresponding single effect plot to show the effect of sand and bentonite on the response at water content of 3%. The graph shows that the maximum green

compressive strength of 24.0KN/m^2 at 5% bentonite content and 92% of sand, is in accordance with the model. As green compressive strength increased from 19.8KN/m^2 at 1% bentonite to 24.0KN/m^2 at 5% bentonite. This increase in green compressive strength was as a result of increase in binder content that comes with 3% water content.

Table 4.9a: Fit summary table

Response	**2**	**Green shear strength**	**Transform:**	**None**	
	Sequential	**Lack of Fit**	**Adjusted**	**Predicted**	
Source	**p-value**	**p-value**	**R-Squared**	**R-Squared**	
Linear	0.9537	0.0506	-0.1637	-0.6876	
2FI	0.0008	0.3736	0.5912	-0.7523	
Quadratic	0.0076	0.9995	0.8307	0.8208	Suggested
Cubic	0.9995		0.6700		Aliased

Table 4.9b: Sequential model sum of squares

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Mean vs Total	142.55	1	142.55			
Linear vs Mean	0.85	3	0.28	0.11	0.9537	
2FI vs Linear	29.70	3	9.90	10.85	0.0008	
Quadratic vs 2FI	8.08	3	2.69	7.13	0.0076	Suggested
Cubic vs Quadratic	0.096	5	0.019	0.026	0.9995	Aliased
Residual	3.68	5	0.74			
Total	184.96	20	9.25			

Table 4.9c: Lack of Fit Tests

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Linear	37.87	11	3.44	4.68	0.0506	
2FI	8.18	8	1.02	1.39	0.3736	
Quadratic	0.096	5	0.019	0.026	0.9995	Suggested
Cubic	0.000	0				Aliased
Pure Error	3.68	5	0.74			

Table 4.9d: Model summary statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	1.61	0.0200	-0.1637	-0.6876	71.56	
2FI	0.96	0.7203	0.5912	-0.7523	74.31	
Quadratic	0.61	0.9109	0.8307	0.8208	7.60	Suggested
Cubic	0.86	0.9132	0.6700		+	Aliased

4.22.3 ANOVA Analysis and Model Fitting

Based on the results of F-value, the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 4.9b, the quadratic vs 2FI and the linear vs mean models have significant F-value of 7.13 and 0.11 respectively, while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 10.85 and 0.026 respectively.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. As shown in Table 4.9c there was a significant difference (F-value = 4.68 and 1.39) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 0.026) for quadratic models. The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.9b and 4.9c showed that the quadratic model can well describe the green shear strength of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.9109, 0.8307, 0.8208 and 0.9132, 0.6700 respectively when compared to other models (2FI and linear) as shown on Table 4.9d. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

The closer the R^2value is to unity, the better the model predicts the response. Adjusted-R^2 is a measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model. The adjusted-R^2decreases as the number of terms in the model increases, if those additional terms don't add value to the model. Predicted-R^2 is a measure of the amount of variation in new data explained by the model.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.9e.

Table 4.9e: ANOVA for response surface quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	38.63	9	4.29	11.36	0.0004	significant
A-Sand	*0.57*	*1*	*0.57*	*1.52*	*0.2463*	
B-Bentonite	*1.52*	*1*	*1.52*	*4.02*	*0.0727*	
C-Water	*0.70*	*1*	*0.70*	*1.86*	*0.2022*	
AB	*2.54*	*1*	*2.54*	*6.71*	*0.0269*	
AC	*2.04*	*1*	*2.04*	*5.39*	*0.0426*	
BC	*2.59*	*1*	*2.59*	*6.85*	*0.0257*	
A^2	*2.32*	*1*	*2.32*	*6.15*	*0.0326*	
B^2	*3.21*	*1*	*3.21*	*8.49*	*0.0155*	
C^2	*2.61*	*1*	*2.61*	*6.90*	*0.0253*	
Residual	3.78	10	0.38			
Lack of Fit	*0.096*	*5*	*0.019*	*0.026*	*0.9995*	*not significant*
Pure Error	*3.68*	*5*	*0.74*			
Cor Total	42.41	19				

Std. Dev.	0.61		R-Squared	0.9109
Mean	2.67		Adj R-Squared	0.8307
C.V. %	23.02		Pred R-Squared	0.8208
PRESS	7.60		Adeq Precision	8.659
-2 Log Likelihood	23.43		BIC	53.39
			AICc	67.87

Several appraisal techniques were used to evaluate the adequacy of the selected model such as the coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to weigh the adequacy of the model as used by other researchers (Chen *et al.,* 2010) . It could be seen that the F-value of 11.36 implies that the model term is significant. In this case AB, AC, BC, A^2, B^2, C^2 are significant model terms. Values greater than 0.100 indicate that the model terms are not significant. The Lack of Fit F value of 0.026 implies that the Lack of Fit is not significant relative to the pure error. There is a 99.95% chance that a Lack of Fit this large could occur due to noise. Non-significant lack of fit is good because it means the model will be well fitted. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the green shear strength from River Niger Onitsha beach sand using bentonite. The F-value of the independent variables such as sand, bentonite and water content was estimated as 1.52, 4.02 and 1.86 respectively as shown in Table 4.9e. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.9109 and 0.8307, respectively which illustrates that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimate to the mean value of the observed response is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value of 23.02% The signal to noise ratio which is given as the value of the adequacy precision is 8.659. This indicated that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$$Y = +4.86 - 2.77A - 3.09B - 1.70C - 29.11AB - 19.46AC - 14.07BC - 20.28A^2 - 10.32B^2 - 5.64C^2 \qquad (4.17)$$

In terms of actual values, the model terms are given by the green shear strength = - 47437.68554 + 942.73933*sand + 1182.60694 *bentonite + 795.48085 *water – 11.76279 *sand *bentonite – 7.86376 *sand *water – 9.95129*bentonite *water – 4.68356 *sand^2- 7.29456 *bentonite^2 – 3.98866 *water^2 ……………………………..(4.18)

Where y = green shear strength, A = sand, B = bentonite, C = water

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the Figure 4.126.

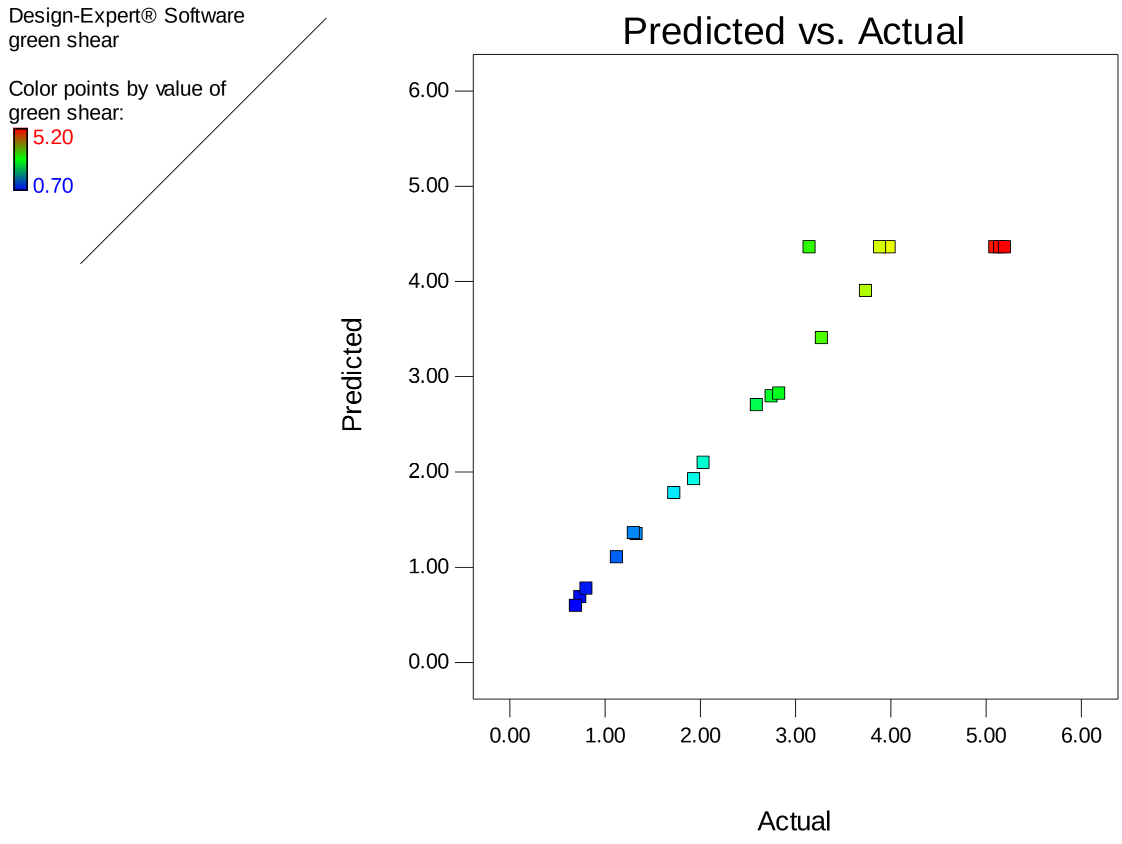


Figure 4.126 Linear correlation between predicted vs. actual values for green shear strength of River Niger beach sand using bentonite content.

As it can be seen in Figure 4.126, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.127. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with

the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

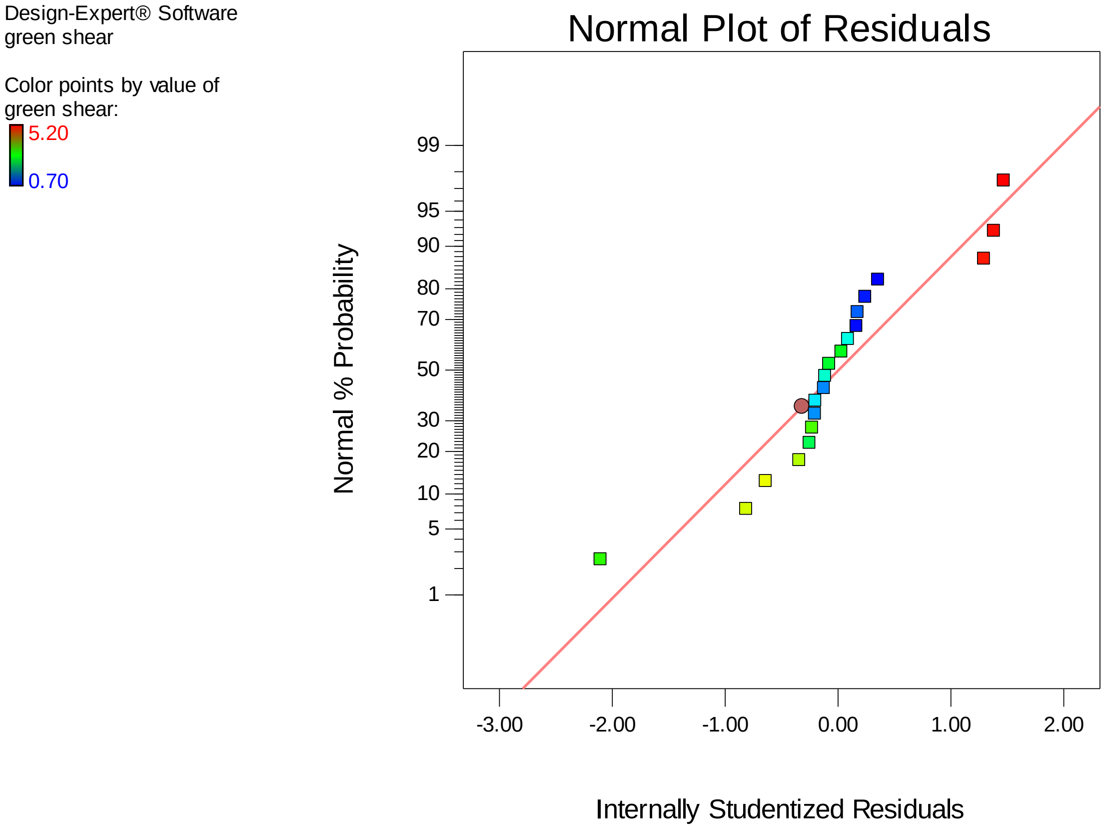
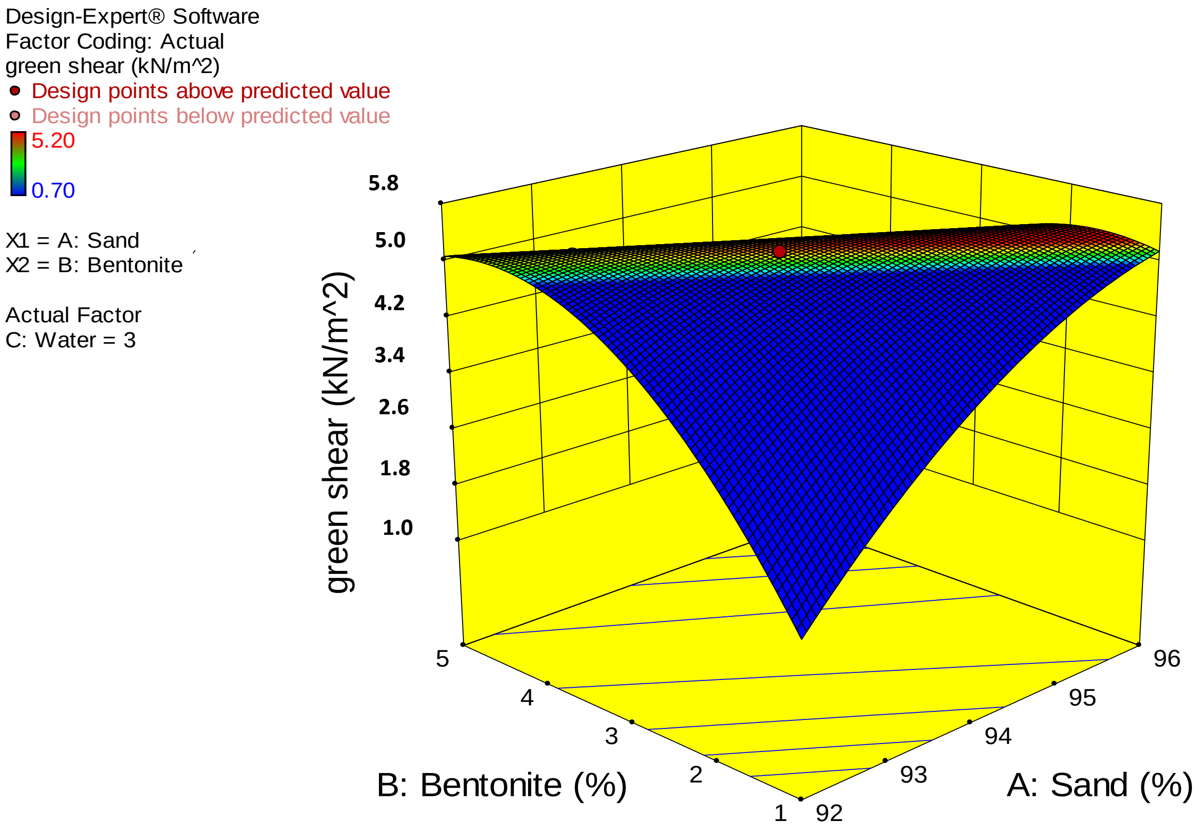


Figure 4.127 Normal probability plot of residuals obtained from the green strength of bentonite sample

4.23.4 3D Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the bentonite and water content. Response surfaces and single effect plots were generated from the quadratic model, as shown in Figure 4.128. This Figure illustrates the response of different experimental

variables and can be used to identify the major interactions between the variables.

(a)



b)

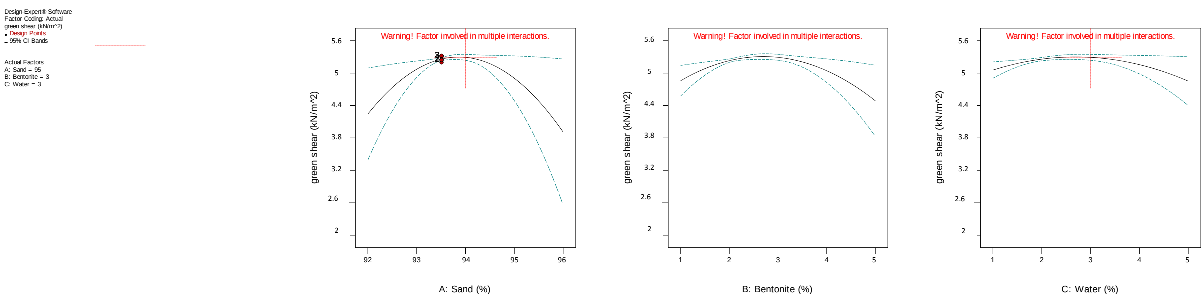


Figure 4.128: 3D surface (a) and single effect plot for the combine effect of bentonite, sand and water (b), carried out at 3% water content.

Figure 4.128: 3D plot and its corresponding single effect plot to show the effect of sand and bentonite on the response at water content of 3%. The graph shows that the maximum green shear strength of 5.1KN/m^2 at 5% bentonite content and 92%

of sand, is in accordance with the model. As green shear strength increased from 2.6KN/m^2 at 1% bentonite to 5.1KN/m^2 at 5% bentonite. This increase in green shear strength was as a result of increase in binder content that comes with 3% water content.

Table 4.10a: Fit summary table

Response	3	Dry com strength	Transform:	None	
	Sequential	Lack of Fit	Adjusted	Predicted	
Source	p-value	p-value	R-Squared	R-Squared	
Linear	< 0.0001	1.0000	0.9854	0.9862	Suggested
2FI	0.9868	1.0000	0.9822	0.9840	
Quadratic	0.9979	1.0000	0.9769	0.9828	
Cubic	1.0000		0.9541		Aliased

Table 4.10b: Sequential model sum of squares

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob> F	
Mean vs Total	6.090E+005	1	6.090E+005			
Linear vs Mean	6822.39	3	2274.13	427.03	< 0.0001	Suggested
2FI vs Linear	0.87	3	0.29	0.045	0.9868	
Quadratic vs 2FI	0.32	3	0.11	0.013	0.9979	
Cubic vs Quadratic	0.60	5	0.12	7.199E-003	1.0000	Aliased
Residual	83.42	5	16.68			
Total	6.159E+005	20	30793.68			

Table 4.10c: Lack of fit tests

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob> F	
Linear	1.79	11	0.16	9.757E-003	1.0000	Suggested
2FI	0.92	8	0.11	6.892E-003	1.0000	
Quadratic	0.60	5	0.12	7.199E-003	1.0000	
Cubic	0.000	0				Aliased
Pure Error	83.42	5	16.68			

Table 4.10d: Model summary statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	2.31	0.9877	0.9854	0.9862	95.53	Suggested
2FI	2.55	0.9878	0.9822	0.9840	110.22	
Quadratic	2.90	0.9878	0.9769	0.9828	119.00	
Cubic	4.08	0.9879	0.9541		+	Aliased

4.23.5 ANOVA Analysis and Model Fitting

As it is shown in Table 4.10b, the quadratic vs 2FI and the linear vs mean models have significant F-value of 0.013 and 427.03 respectively while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 0.045 and 7.199E-003 respectively.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack of fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. As shown in Table 4.10c there was a significant difference (F-value = 9.757E-003 and 6.892E-003) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 7.199E-003) for quadratic models. The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.10b and 4.10c showed that the quadratic model can well describe the dry compressive strength of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.9879, 0.9769, 0.9828 and 0.9879, 0.9541 respectively when compared to other models (2FI and linear) as shown on Table 4.10d. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.10e.

Table 4.10e: ANOVA for response surface quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	6823.58	9	758.18	90.24	< 0.0001	significant
A-Sand	*9.47*	*1*	*9.47*	*1.13*	*0.3133*	
B-Bentonite	*46.14*	*1*	*46.14*	*5.49*	*0.0411*	
C-Water	*16.30*	*1*	*16.30*	*1.94*	*0.1939*	
AB	*0.015*	*1*	*0.015*	*1.763E-003*	*0.9673*	
AC	*3.480E-003*	*1*	*3.480E-003*	*4.141E-004*	*0.9842*	
BC	*0.013*	*1*	*0.013*	*1.508E-003*	*0.9698*	
A^2	*7.512E-003*	*1*	*7.512E-003*	*8.941E-004*	*0.9767*	
B^2	*0.028*	*1*	*0.028*	*3.386E-003*	*0.9547*	
C^2	*0.010*	*1*	*0.010*	*1.229E-003*	*0.9727*	
Residual	84.02	10	8.40			
Lack of Fit	*0.60*	*5*	*0.12*	*7.199E-003*	*1.0000*	*not significant*
Pure Error	*83.42*	*5*	*16.68*			
Cor Total	6907.59	19				

Std. Dev.	2.90		R-Squared	0.9878
Mean	174.49		Adj R-Squared	0.9769
C.V. %	1.66		Pred R-Squared	0.9828
PRESS	119.00		Adeq Precision	37.675
-2 Log Likelihood	85.46		BIC	115.42
			AICc	129.91

The coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to weigh the adequacy of the model as used by other researchers (Chen *et al.,* 2010) . It could be seen that the F-value of 90.24 implies that the model term is significant. In this case, B is a significant model term. Values greater than 0.100 indicates that the model terms are not significant. The Lack of Fit F value of 0.01% implies that the Lack of Fit is not significant relative to the pure error. There is a 100.00% chance that a Lack of Fit this large could occur due to noise. Non-significant lack of fit is good because it means the model will be well fitted. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the dry compressive strength from River Niger Onitsha beach sand using bentonite. The F-value of the independent variables sand, bentonite and water content was estimated as 1.33, 5.49 and 1.94 respectively as shown in Table 4.10e. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.9878 and 0.9769, respectively which illustrates that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimate to the mean value of the observed response is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value of 1.66% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) (Chen et al., 2011). The signal to noise ratio which is given as the value of the adequacy precision is 37.675. This indicated that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$Y = + 175.15 - 11.28A - 17.02B + 8.19C - 2.22AB - 0.80AC - 0.98BC - 1.15A^2 - 0.97B^2 - 0.35C^2$……………………………………….(4.19)

In terms of actual values, the model terms are given by the dry compressive strength = - 2030.89120 + 48.59656*sand + 76.84570 *bentonite+ 41.18449 *water– 0.893 *sand *bentonite – 0.32492*sand *water – 0.69622 *bentonite *water – 0.26637 *sand^2– 0.68688 *bentonite^2 – 0.25091 *water^2……………………………..(4.20)

Where y = dry compressive strength, A = sand, B = bentonite, C = water

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the Figure 4.129.

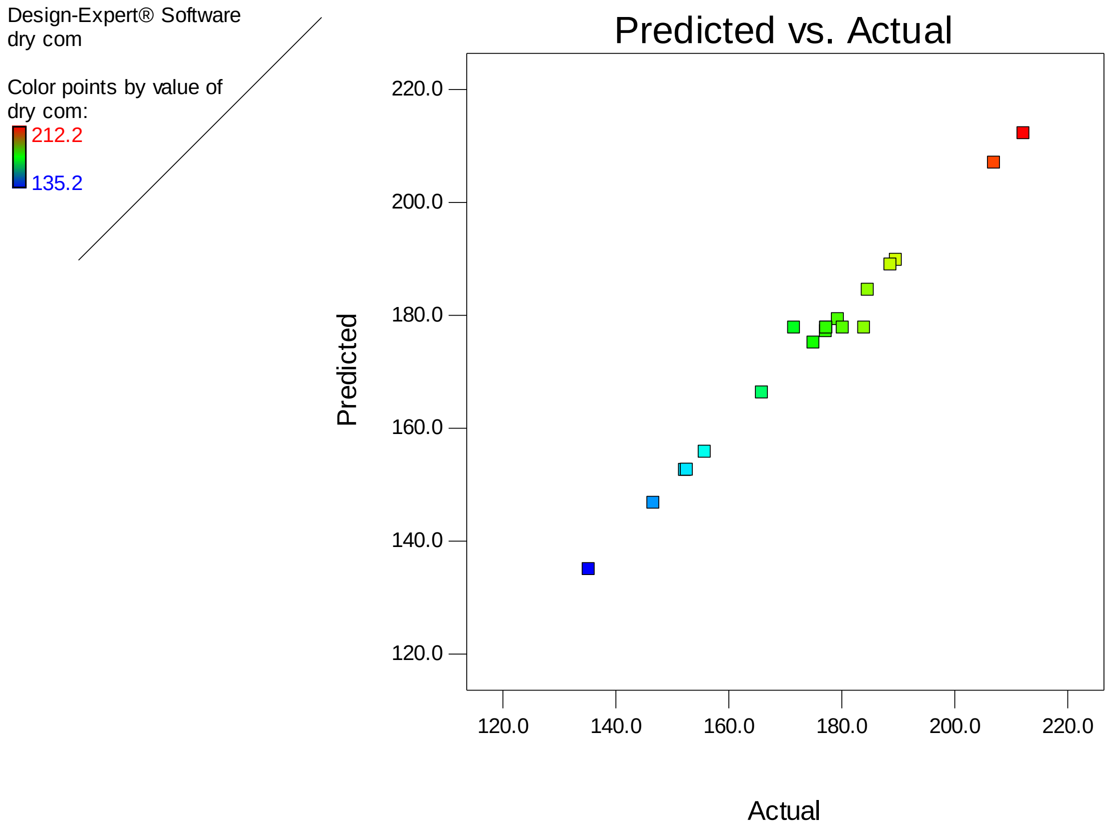


Figure 4.129 Linear correlation between predicted vs. actual values for dry compressive strength of River Niger beach sand using bentonite content.

As it can be seen in Figure 4.129, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.130. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with

the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

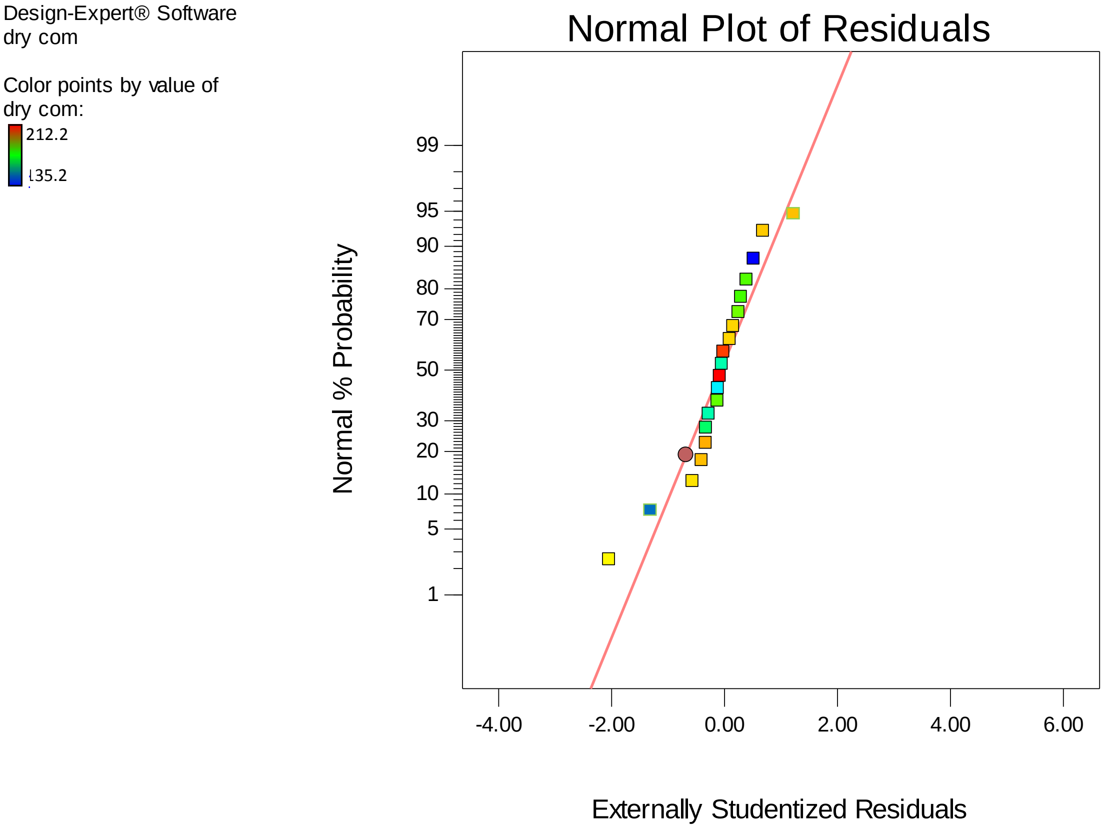
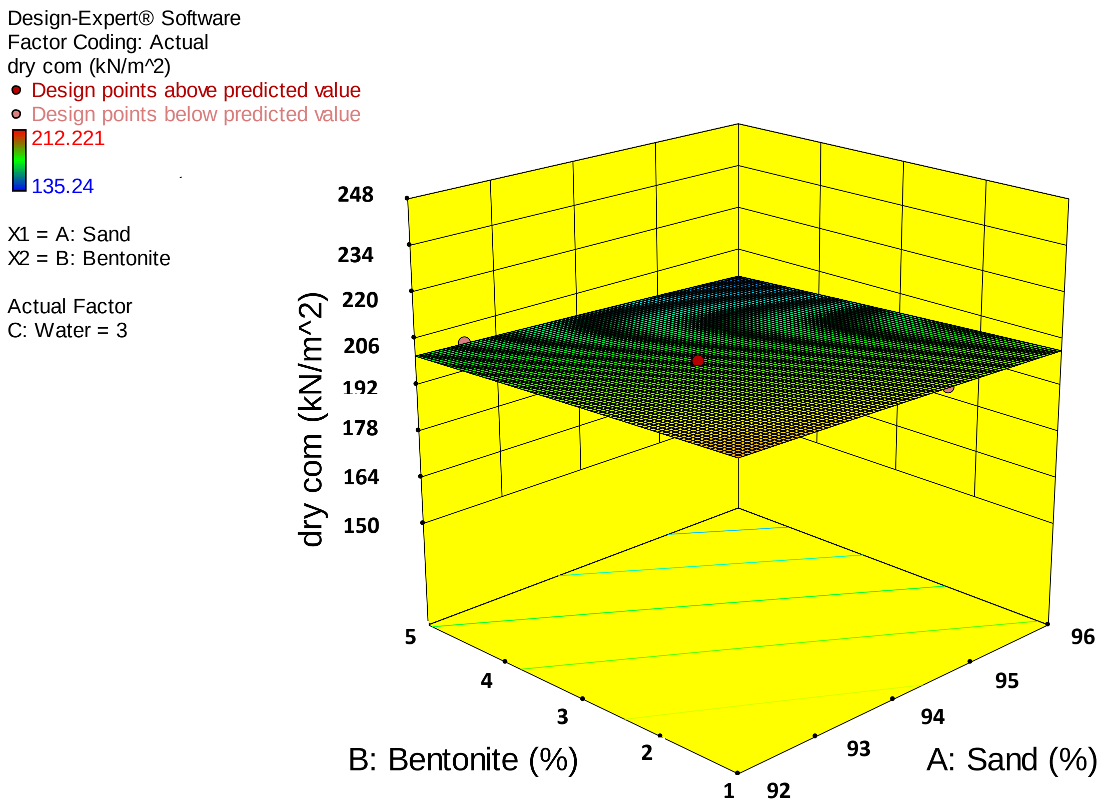


Figure 4.130 Normal probability plot of residuals obtained from the dry compressive strength of bentonite sample

4.23.6 3D Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the bentonite and water content. Response surfaces and single effect plots were generated from the quadratic model, as shown in Figure 4.131. This Figure illustrated that the response of different experimental variables can be used to identify the major interactions between the variables.

(a)



b)

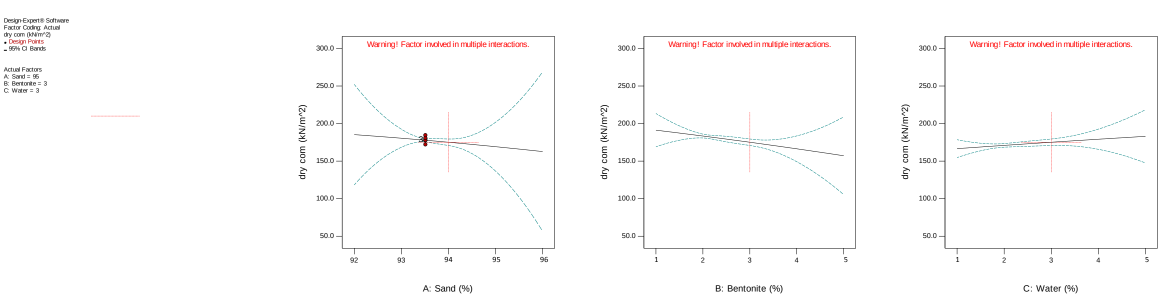


Figure 4.131: 3D surface (a) and single effect plot for the combine effect of bentonite, sand and water (b), carried out at 3% water content.

Figure 4.131: 3D plot and its corresponding single effect plot to show the effect of sand and bentonite on the response at water content of 3%. The graph shows that the maximum dry

compressive strength of 211KN/m^2 at 5% bentonite content and 92% of sand, is in accordance with the model. As dry compressive strength increased from 178KN/m^2 at 1% bentonite to 211KN/m^2 at 5% bentonite. This increase in dry compressive strength was as a result of increase in binder content that comes with 3% water content.

Table 4.11a: Fit summary table

Response	4	Dry shear strength	Transform:	None	
	Sequential	**Lack of Fit**	**Adjusted**	**Predicted**	
Source	**p-value**	**p-value**	**R-Squared**	**R-Squared**	
Linear	0.8605	0.0003	-0.1344	-0.9740	
2FI	0.6040	0.0002	-0.2171	-3.4285	
Quadratic	< 0.0001	0.9845	0.9792	0.9703	Suggested
Cubic	0.9845		0.9625		Aliased

Table 4.11b: Sequential model sum of squares

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Mean vs Total	37818.30	1	37818.30			
Linear vs Mean	106.71	3	35.57	0.25	0.8605	
2FI vs Linear	292.60	3	97.53	0.64	0.6040	
Quadratic vs 2FI	1961.84	3	653.95	249.82	< 0.0001	Suggested
Cubic vs Quadratic	2.62	5	0.52	0.11	0.9845	Aliased
Residual	23.55	5	4.71			
Total	40205.63	20	2010.28			

4.11c: Lack of fit tests

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Linear	2257.06	11	205.19	43.56	0.0003	
2FI	1964.46	8	245.56	52.13	0.0002	
Quadratic	2.62	5	0.52	0.11	0.9845	Suggested
Cubic	0.000	0				Aliased
Pure Error	23.55	5	4.71			

Table 4.11d: Model summary statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	11.94	0.0447	-0.1344	-0.9740	4712.68	
2FI	12.37	0.1673	-0.2171	-3.4285	10572.25	
Quadratic	1.62	0.9890	0.9792	0.9703	70.89	Suggested
Cubic	2.17	0.9901	0.9625		+	Aliased

4.23.7 ANOVA Analysis and Model Fitting

The F-value tests were performed using analysis of variance (ANOVA) to calculate the significance of each type of model. Based on the results of F-value, the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 4.11b, the quadratic vs 2FI and the linear vs mean models have significant F-value of 249.82 and 0.25 respectively while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 0.64 and 0.11 respectively.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. This test measured the adequacy of the different models based on response surface analysis. As shown in Table 4.11c there was a significant difference (F-value = 43.56 and 52.13) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 0.11) for quadratic models. The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.11b and 4.11c showed that the quadratic model can well describe the dry shear strength of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.9890, 0.9792, 0.9703 and 0.9901, 0.9625 respectively when compared to other models (2FI and linear) as shown on Table 4.11d. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

The closer the R^2value is to unity, the better the model predicts the response. Adjusted-$R^2$is a measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model. The adjusted-R^2 decreases as the number of terms in the model increases, if those additional terms don't add value to the model. Predicted-R^2 is a measure of the amount of variation in new data explained by the model.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.11e.

Table 4.11e: ANOVA for response surface quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	2361.15	9	262.35	100.22	< 0.0001	Significant
A-Sand	*246.54*	*1*	*246.54*	*94.18*	*< 0.0001*	
B-Bentonite	*0.59*	*1*	*0.59*	*0.22*	*0.6455*	
C-Water	*336.56*	*1*	*336.56*	*128.57*	*< 0.0001*	
AB	*70.55*	*1*	*70.55*	*26.95*	*0.0004*	
AC	*14.35*	*1*	*14.35*	*5.48*	*0.0412*	
BC	*17.80*	*1*	*17.80*	*6.80*	*0.0261*	
A^2	*3.09*	*1*	*3.09*	*1.18*	*0.3025*	
B^2	*153.20*	*1*	*153.20*	*58.53*	*< 0.0001*	
C^2	*44.66*	*1*	*44.66*	*17.06*	*0.0020*	
Residual	26.18	10	2.62			
Lack of Fit	*2.62*	*5*	*0.52*	*0.11*	*0.9845*	*not significant*
Pure Error	*23.55*	*5*	*4.71*			
Cor Total	2387.33	19				

Std. Dev.	1.62		R-Squared	0.9890
Mean	43.48		Adj R-Squared	0.9792
C.V. %	3.72		Pred R-Squared	0.9703
PRESS	70.89		Adeq Precision	39.883
-2 Log Likelihood	62.14		BIC	92.10
			AICc	106.58

The independent variables in the specified model and the effect of each variable was evaluated. For this reason and in order to evaluate the adequacy of the selected model, several appraisal techniques were used. The coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to weigh the adequacy of the model as used by other researchers (Chen *et al.,* 2010) . It could be seen that the F-value of 100.22 implies that the model term is significant. In this case, A, C, AB, BC, B^2, C^2 is a significant model term. Values greater than 0.100 indicated that the model terms are not significant. The Lack of Fit F value of 0.11% implies that the Lack of Fit is not significant relative to the pure error. There is a 98.45% chance that a Lack of Fit this large could occur due to noise. Non-significant lack of fit is good because it means the model will be well fitted. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the dry shear strength from River Niger Onitsha beach sand using bentonite. The F-value of the independent variables sand, bentonite and water content were estimated as 94.18, 0.22 and 128.57 respectively as shown in Table 4.11e. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.9890and 0.9792, respectively which illustrates that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimate to the mean value of the observed response is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value of 3.72% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) (Chen et al., 2011). The signal to noise ratio which is given as the value of the adequacy precision is 39.883.

This indicated that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$Y = +59.21 + 57.54A + 1.92B + 37.21C – 153.55AB + 51.65AC – 36.91BC – 23.41A^2 – 71.28B^2 + 23.34C^2$……………………………………….(4.21)

In terms of actual values, the model terms are given by the dry shear strength = -63132.88461 + 1172.70973 *sand + 6245.53682 *bentonite– 1961.62179 *water – 62.04432 *sand *bentonite + 20.86986*sand *water – 26.10275 *bentonite *water – 5.40497 *sand^2– 50.40386 *bentonite^2+ 16.50262 *water^2……………………………..(4.22)

Where y = dry shear strength, A = sand, B = bentonite, C = water

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the Figure 4.132.

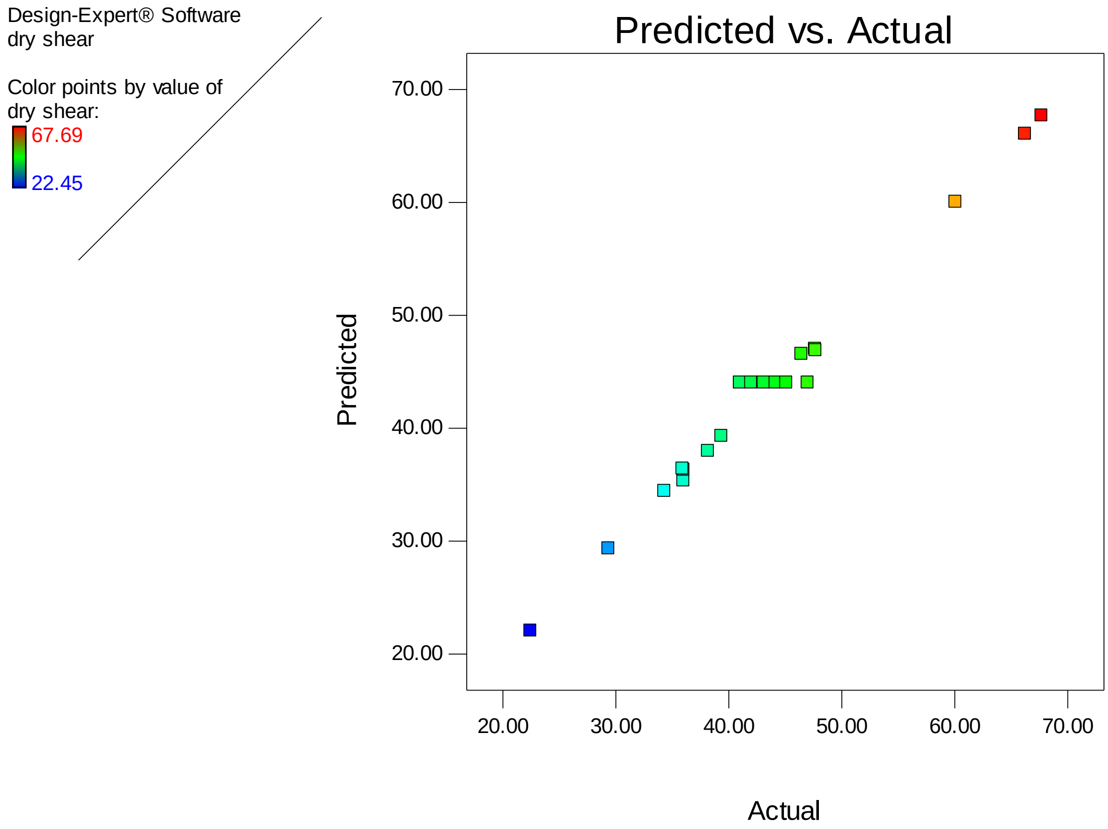


Figure 4.132 Linear correlation between predicted vs. actual values for dry shear strength of River Niger beach sand using bentonite content.

As it can be seen in Figure 4.132, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.133. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with

the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

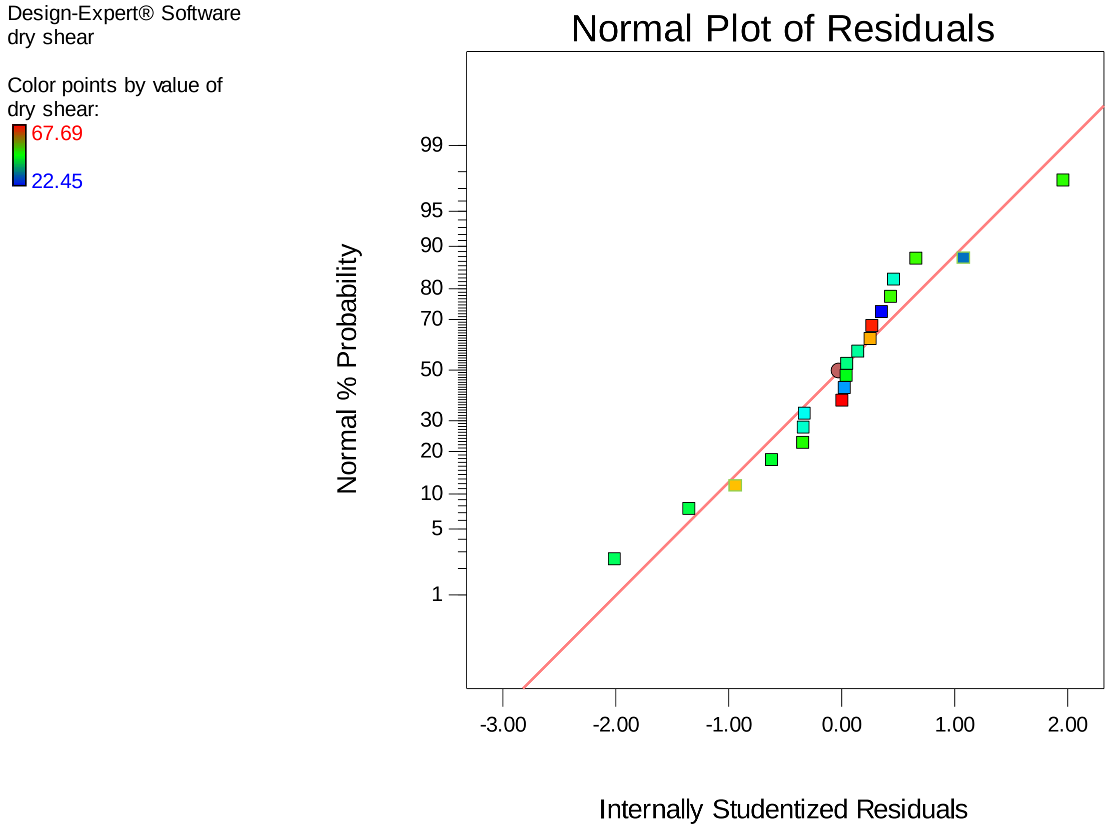
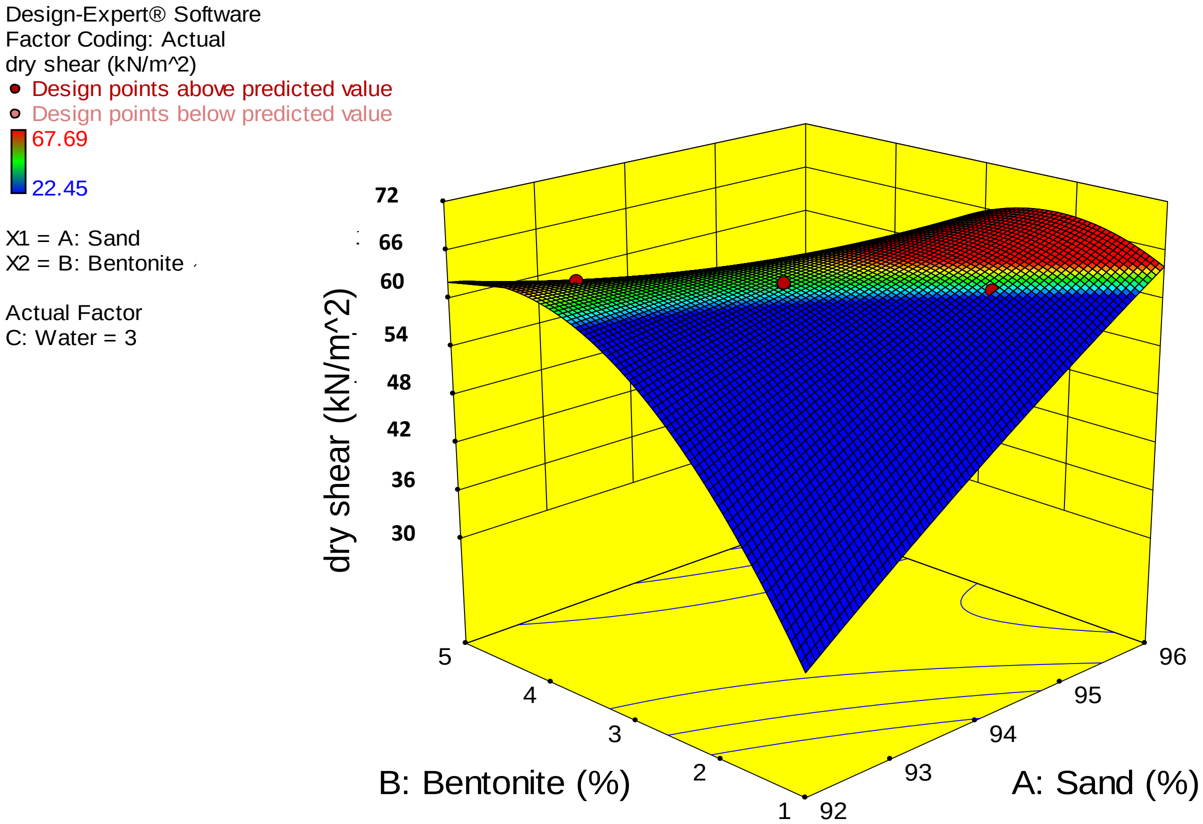


Figure 4.133 Normal probability plot of residuals obtained from the dry shear strength of bentonite sample

4.23.8 3D Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the bentonite and water content. Response surfaces and single effect plots were generated from the quadratic model, as shown in Figure 4.134. This Figure illustrates the response of different experimental

variables and can be used to identify the major interactions between the variables.

(a)



b)

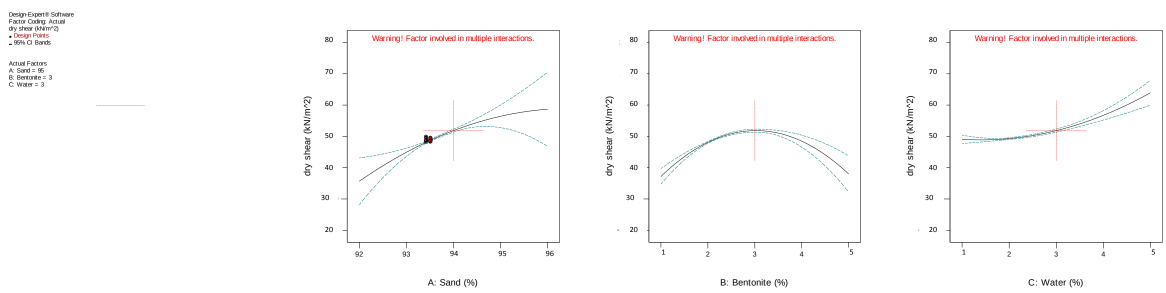


Figure 4.134: 3D surface (a) and single effect plot for the combine effect of bentonite, sand and water (b), carried out at 3% water content.

Figure 4.134: 3D plot and its corresponding single effect plot to show the effect of sand and bentonite on the response at water content of 3%. The graph shows that the maximum dry shear strength of 66.0KN/m^2 at 5% bentonite content and 92% of sand, is in accordance with the model. As dry shear strength increased from 48.0KN/m^2 at 1% bentonite to 66.0KN/m^2 at 5% bentonite. This increase in dry shear strength was as a result of increase in binder content that comes with 3% water content.

Table 4.12a: Fit summary table

Response	**5**	**Permeability**	**Transform:**	**None**	
	Sequential	**Lack of Fit**	**Adjusted**	**Predicted**	
Source	**p-value**	**p-value**	**R-Squared**	**R-Squared**	
Linear	0.2737	0.2247	0.0622	-1.7052	
2FI	0.1557	0.2919	0.2172	-2.9257	
Quadratic	0.0050	0.9925	0.7033	0.6333	Suggested
Cubic	0.9925		0.4507		Aliased

Table 4.12b: Sequential model sum of squares

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Mean vs Total	4.565E+005	1	4.565E+005			
Linear vs Mean	50.74	3	16.91	1.42	0.2737	
2FI vs Linear	61.33	3	20.44	2.06	0.1557	
Quadratic vs 2FI	91.56	3	30.52	8.10	0.0050	Suggested
Cubic vs Quadratic	2.80	5	0.56	0.080	0.9925	Aliased
Residual	34.89	5	6.98			
Total	4.568E+005	20	22837.55			

Table 4.12c: Lack of fit tests

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Linear	155.70	11	14.15	2.03	0.2247	
2FI	94.36	8	11.80	1.69	0.2919	
Quadratic	2.80	5	0.56	0.080	0.9925	Suggested
Cubic	0.000	0				Aliased
Pure Error	34.89	5	6.98			

4.12d: Model summary statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	3.45	0.2103	0.0622	-1.7052	652.82	
2FI	3.15	0.4644	0.2172	-2.9257	947.34	
Quadratic	1.94	0.8438	0.7033	0.6333	88.49	Suggested
Cubic	2.64	0.8554	0.4507		+	Aliased

4.23.9 ANOVA Analysis and Model Fitting

The F-value tests were performed using analysis of variance (ANOVA) to calculate the significance of each type of model. Based on the results of F-value, the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 4.12b, the quadratic vs 2FI and the linear vs mean models have significant F-value of 8.10 and 1.42 respectively while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 2.06 and 0.080 respectively.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. As shown in Table 4.12c there was a significant difference (F-value = 2.03 and 1.69) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 0.080) for quadratic models. The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.12b and 4.12c showed that the quadratic model can well describe the permeability of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.8438, 0.7033, 0.6333 and 0.8554, 0.4507 respectively when compared to other models (2FI and linear) as shown on Table 4.12d. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.12e.

Table 4.12e: ANOVA for response surface quadratic model

	Sum of		Mean	F	p-value	

Source	Squares	df	Square	Value	Prob> F	
Model	203.64	9	22.63	6.00	0.0049	significant
A-Sand	*26.32*	*1*	*26.32*	*6.99*	*0.0246*	
B-Bentonite	*8.91*	*1*	*8.91*	*2.37*	*0.1551*	
C-Water	*25.01*	*1*	*25.01*	*6.64*	*0.0276*	
AB	*5.54*	*1*	*5.54*	*1.47*	*0.2531*	
AC	*13.14*	*1*	*13.14*	*3.49*	*0.0914*	
BC	*6.41*	*1*	*6.41*	*1.70*	*0.2213*	
A^2	*11.91*	*1*	*11.91*	*3.16*	*0.1059*	
B^2	*3.01*	*1*	*3.01*	*0.80*	*0.3921*	
C^2	*11.78*	*1*	*11.78*	*3.13*	*0.1074*	
Residual	37.69	10	3.77			
Lack of Fit	*2.80*	*5*	*0.56*	*0.080*	*0.9925*	*not significant*
Pure Error	*34.89*	*5*	*6.98*			
Cor Total	241.32	19				

Std. Dev.	1.94		R-Squared	0.8438
Mean	151.08		Adj R-Squared	0.7033
C.V. %	1.28		Pred R-Squared	0.6333
PRESS	88.49		Adeq Precision	11.281
-2 Log Likelihood	69.43		BIC	99.39
			AICc	113.87

To evaluate the adequacy of the selected model, the coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to weigh the adequacy of the model. It could be seen that the F-value of 6.00 implied that the model term is significant. In this case, A, B are significant model terms. Values greater than 0.100 indicate that the model terms are not significant. The Lack of Fit F-value of 0.08% implies that the Lack of Fit is not significant relative to the pure error. There is a 99.25% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good because it means the model will be well fitted. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the permeability from River Niger Onitsha beach sand using bentonite. The F-value of the independent variables sand, bentonite and water content were estimated as 6.99, 2.37 and 6.64 respectively as shown in Table 4.12e. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.8438 and 0.7033, respectively which illustrated that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimate to the mean value of the observed response is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value of 1.28% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) (Chen et al., 2011). The signal to noise ratio which is given as the value of the adequacy precision is 11.281. This indicates that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$$Y = + 149.84 - 18.80A - 7.48B - 10.14C - 43.04AB - 49.49AC - 22.15BC - 45.93A^2 - 10.00B^2 - 11.99C^2 \quad \ldots\ldots(4.23)$$

In terms of actual values, the model terms are given by the permeability = -1.04524E + 005 + 207.27735 *sand + 1726.50192 *bentonite+ 1976.24491 *water– 17.39021 *sand *bentonite – 19.96734*sand *water – 15.66471 *bentonite *water – 10.60444 *sand^2– 7.07068 *bentonite^2 – 8.47759 *water^2……………………………..(4.24)

Where y = permeability, A = sand, B = bentonit, C = water

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients, while the equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels are to be specified in the original units for each factor.

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the Figure 4.135.

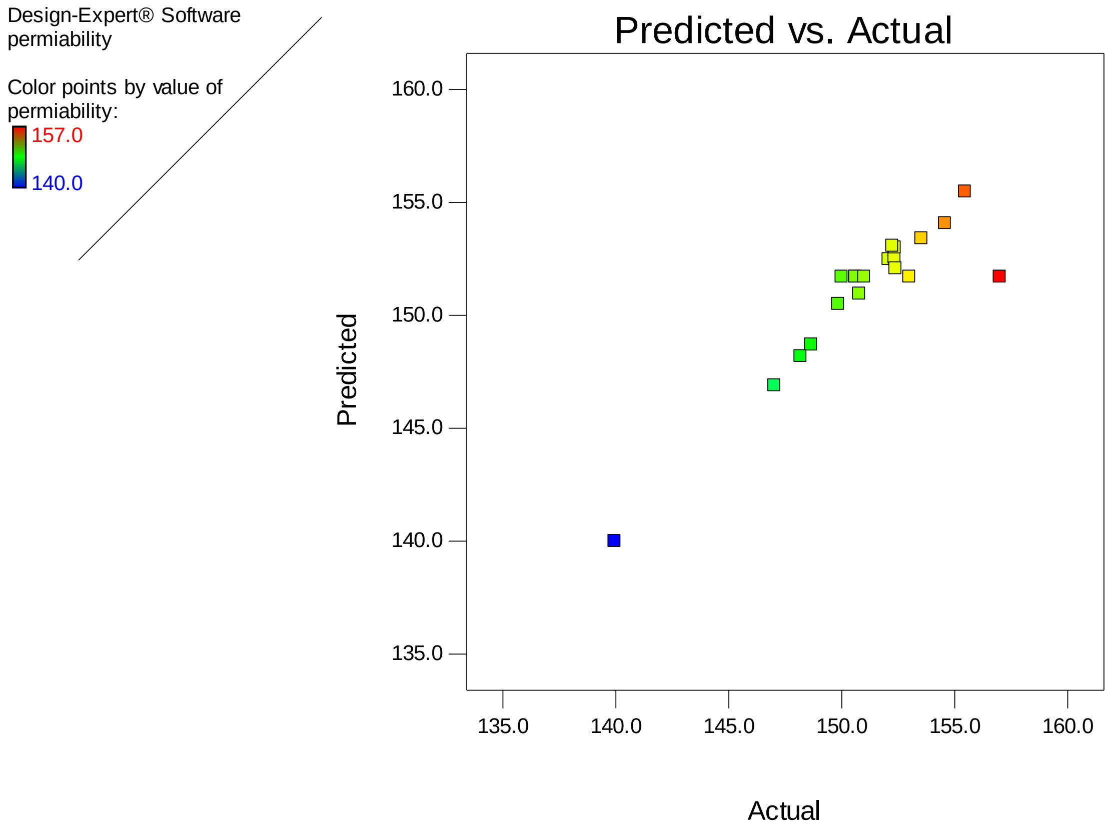


Figure 4.135 Linear correlation between predicted vs. actual values for permeability of River Niger beach sand using bentonite content.

As it can be seen in Figure 4.135, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.136. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with

the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

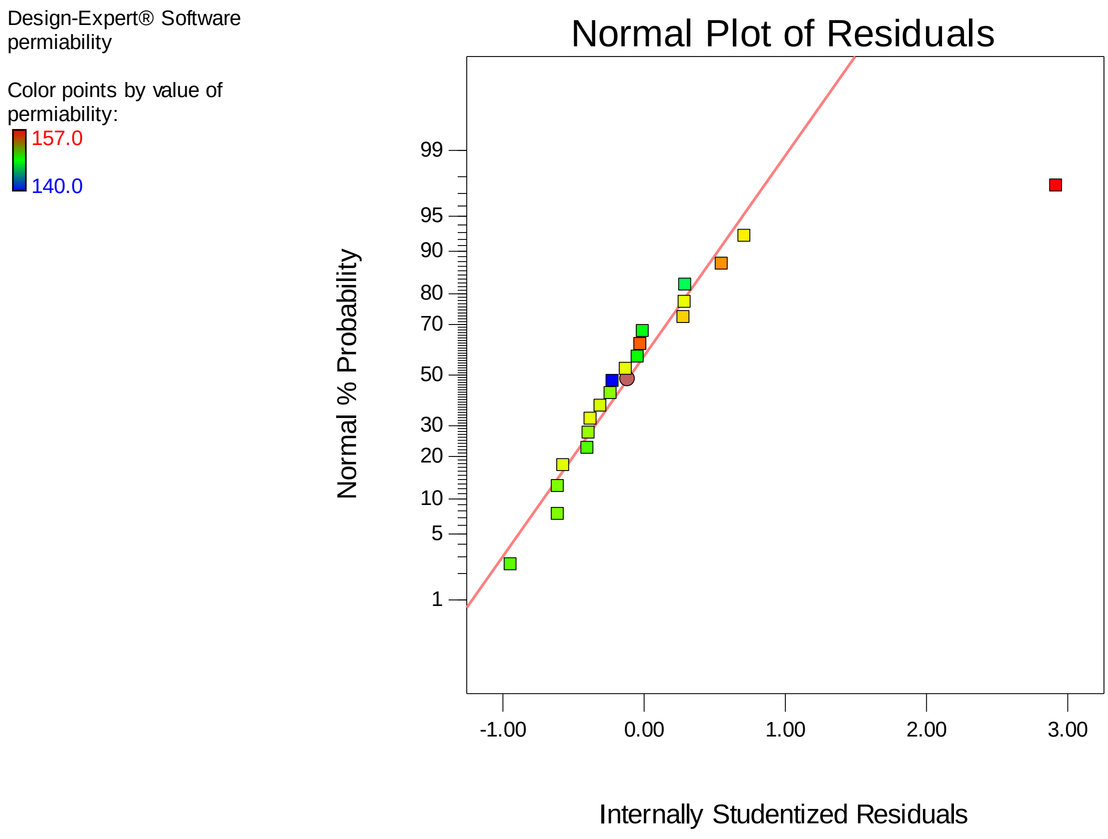
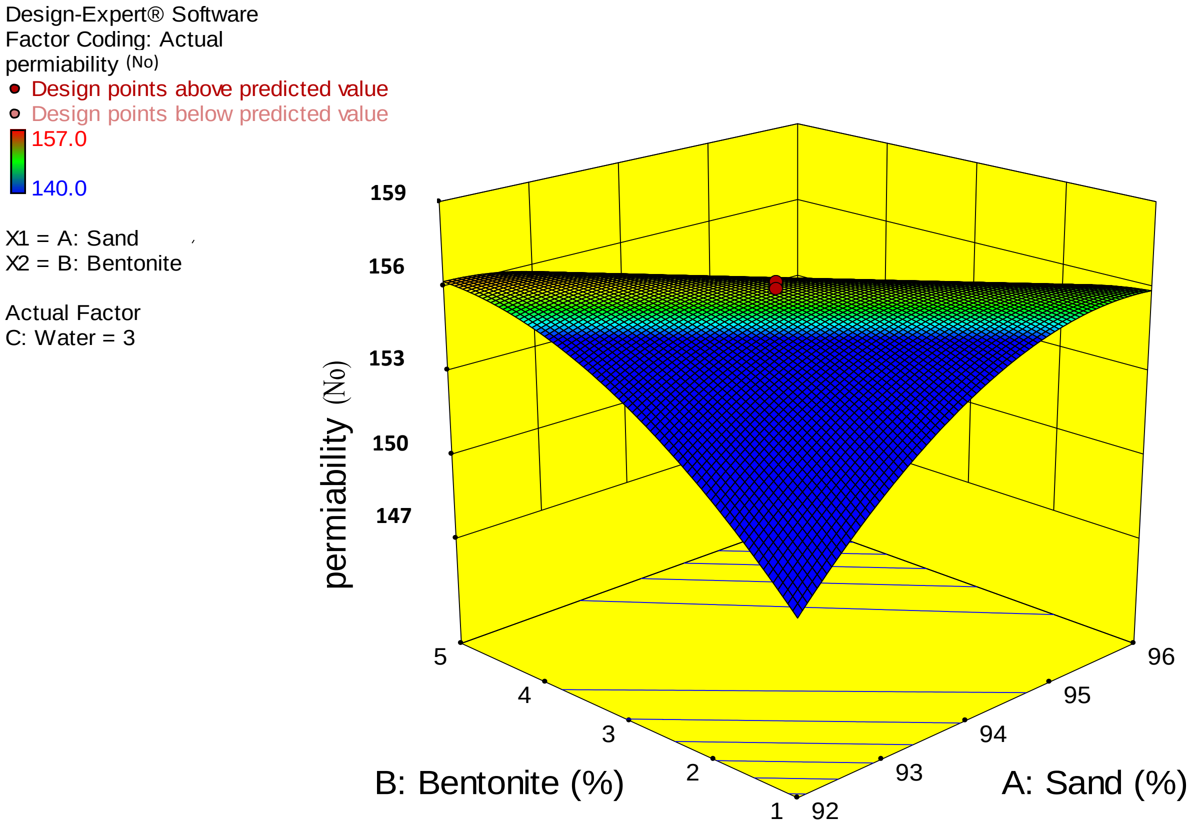


Figure 4.136 Normal probability plot of residuals obtained from the permeability of bentonite sample

4.23.10 Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the bentonite and water content. Response surfaces and single effect plots were generated from the quadratic model, as shown in Figure 4.137. This Figure illustrates the response of different experimental

variables and can be used to identify the major interactions between the variables.

(a)



b)

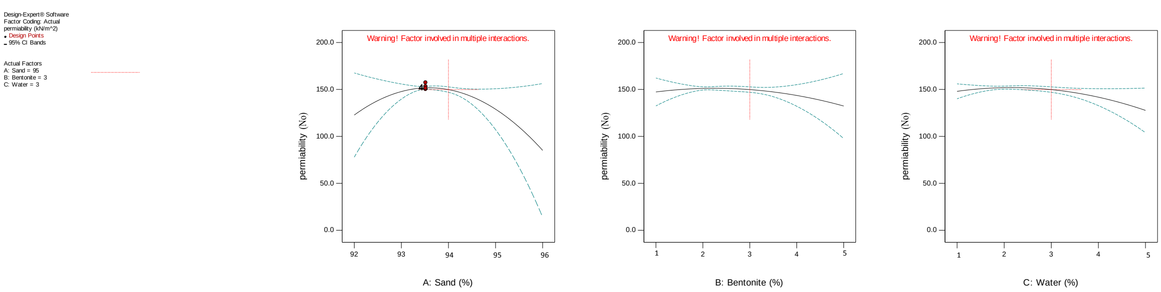


Figure 4.137: 3D surface (a) and single effect plot for the combine effect of bentonite, sand and water (b), carried out at 3% water content.

Figure 4.137: 3D plot and its corresponding single effect plot to show the effect of sand and bentonite on the response at water content of 3%. The graph shows that the maximum permeability values of 156.0 (No) at 5% bentonite content and 92% of sand, is in accordance with the model.

Table 4.13a: Fit summary table

Response	6	Moisture content	Transform:	None	
	Sequential	Lack of Fit	Adjusted	Predicted	
Source	p-value	p-value	R-Squared	R-Squared	
Linear	0.1074	0.0242	0.1794	-1.1870	
2FI	0.5361	0.0189	0.1408	-3.7841	
Quadratic	< 0.0001	0.8790	0.8889	0.7243	Suggested
Cubic	0.8790		0.8323		Aliased

Table 4.13b: Sequential model sum of squares

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob> F	
Mean vs Total	132.47	1	132.47			
Linear vs Mean	1.45	3	0.48	2.38	0.1074	
2FI vs Linear	0.48	3	0.16	0.76	0.5361	
Quadratic vs 2FI	2.48	3	0.83	30.19	< 0.0001	Suggested
Cubic vs Quadratic	0.067	5	0.013	0.32	0.8790	Aliased
Residual	0.21	5	0.041			
Total	137.15	20	6.86			

Table 4.13c: Lack of fit tests

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob> F	
Linear	3.03	11	0.28	6.66	0.0242	
2FI	2.55	8	0.32	7.70	0.0189	
Quadratic	0.067	5	0.013	0.32	0.8790	Suggested
Cubic	0.000	0				Aliased
Pure Error	0.21	5	0.041			

Table 4.13d: Model summary statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.45	0.3090	0.1794	-1.1870	10.25	
2FI	0.46	0.4121	0.1408	-3.7841	22.42	
Quadratic	0.17	0.9416	0.8889	0.7243	1.29	Suggested
Cubic	0.20	0.9559	0.8323		+	Aliased

4.23.11 ANOVA Analysis and Model Fitting

The F-value tests were performed using analysis of variance (ANOVA) to calculate the significance of each type of model. Based on the results of F-value, the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 4.13b, the quadratic vs 2FI and the linear vs mean models have significant F-value of 30.19 and 2.38 respectively while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 0.76 and 0.8790 respectively.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. This test measured the adequacy of the different models based on response surface analysis (Lee *et al.,* 2006). As shown in Table 4.13c there was a significant difference (F-value = 6.66 and 7.70) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 0.32) for quadratic models. The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.13b and 4.13c showed that the quadratic model can well describe the moisture content of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.9416, 0.8889, 0.7243 and 0.9559, 0.8323 respectively when compared to other models (2FI and linear) as shown on Table 4.13d. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

The closer the R^2 value is to unity, the better the model predicts the response. Adjusted-R^2 is a measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model. The adjusted-R^2 decreases as the number of terms in the model increases, if those additional terms don't add value to the model. Predicted-R^2 is a measure of the amount of variation in new data explained by the model.

Based on these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.13e.

Table 4.13e: ANOVA for response surface quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	4.41	9	0.49	17.90	< 0.0001	significant
A-Sand	*0.20*	*1*	*0.20*	*7.42*	*0.0214*	
B-Bentonite	*5.706E-004*	*1*	*5.706E-004*	*0.021*	*0.8881*	
C-Water	*0.19*	*1*	*0.19*	*7.02*	*0.0243*	
AB	*0.17*	*1*	*0.17*	*6.13*	*0.0328*	
AC	*0.013*	*1*	*0.013*	*0.47*	*0.5073*	
BC	*0.11*	*1*	*0.11*	*4.10*	*0.0703*	
A^2	*0.046*	*1*	*0.046*	*1.67*	*0.2257*	
B^2	*0.29*	*1*	*0.29*	*10.51*	*0.0088*	
C^2	*0.010*	*1*	*0.010*	*0.38*	*0.5524*	
Residual	0.27	10	0.027			
Lack of Fit	*0.067*	*5*	*0.013*	*0.32*	*0.8790*	*not significant*
Pure Error	*0.21*	*5*	*0.041*			
Cor Total	4.69	19				

Std. Dev.	0.17		R-Squared	0.9416
Mean	2.57		Adj R-Squared	0.8889
C.V. %	6.43		Pred R-Squared	0.7243
PRESS	1.29		Adeq Precision	18.024
-2 Log Likelihood	-29.06		BIC	0.90
			AICc	15.39

The independent variables in the specified model and the effect of each variable was evaluated. For this reason and in order to evaluate the adequacy of the selected model, several appraisal techniques were used. The coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to weigh the adequacy of the model as used by other researchers (Chen *et al.,* 2010) . It could be seen that the F-value of 17.90 implies that the model term is significant. In this case, A, C, AB, B^2 are significant model terms. Values greater than 0.100 indicate that the model terms are not significant. The Lack of Fit F value of 0.032% implies that the Lack of Fit is not significant relative to the pure error. There is a87.90% chance that a Lack of Fit this large could occur due to noise. Non-significant lack of fit is good because it means the model will be well fitted. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the moisture content from River Niger Onitsha beach sand using bentonite. The F-value of the independent variables sand, bentonite and water content were estimated as 7.42, 0.021 and 7.02 respectively as shown in Table 4.13e. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.9416and 0.8889, respectively which illustrates that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimated mean value of the observed response is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value of 6.43% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) (Chen et al., 2011). The signal to noise ratio which is given as the value of the adequacy precision is 18.024. This indicated that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$Y = +\ 3.24 + 1.65A + 0.060B + 0.89C – 7.49AB – 1.55AC – 2.93BC – 2.84A^2 – 3.09B^2 – 0.36C^2$……………………………………………(4.25)

In terms of actual values, the model terms are given by the moisture content = -7014.83087 + 135.86628*sand + 305.39582 *bentonite+ 67.71912 *water – 3.02660 *sand *bentonite – 0.62690*sand *water – 2.07391 *bentonite *water – 0.65668 *sand^2– 2.18501 *bentonite^2 – 0.25129 *water^2……………………………..(4.26)

Where y = moisture content, A = sand, B = bentonite, C = water

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the Figure 4.138.

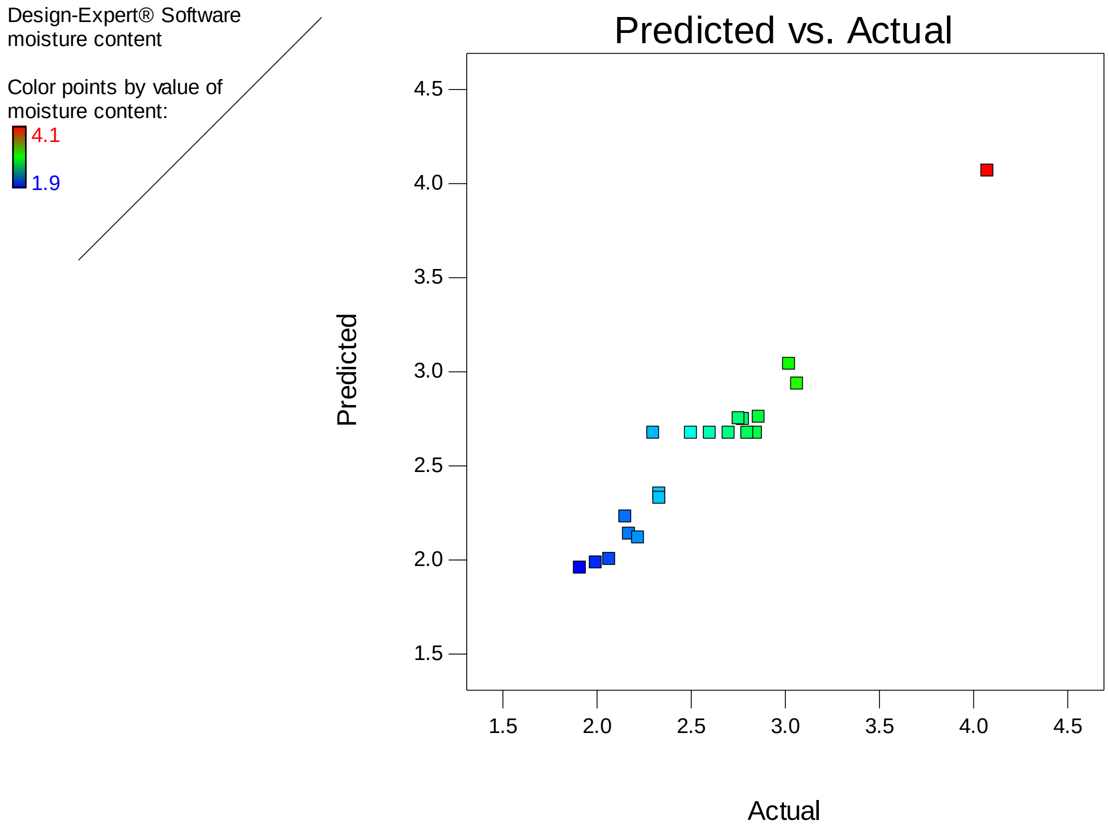


Figure 4.138 Linear correlation between predicted vs. actual values for moisture content of River Niger beach sand using bentonite content.

As it can be seen in Figure 4.138, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. This observation shows that the fractional central composite design (CCD) is well fitted into the model and thus can be used to perform the optimisation operation for the process. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.139. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with

the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

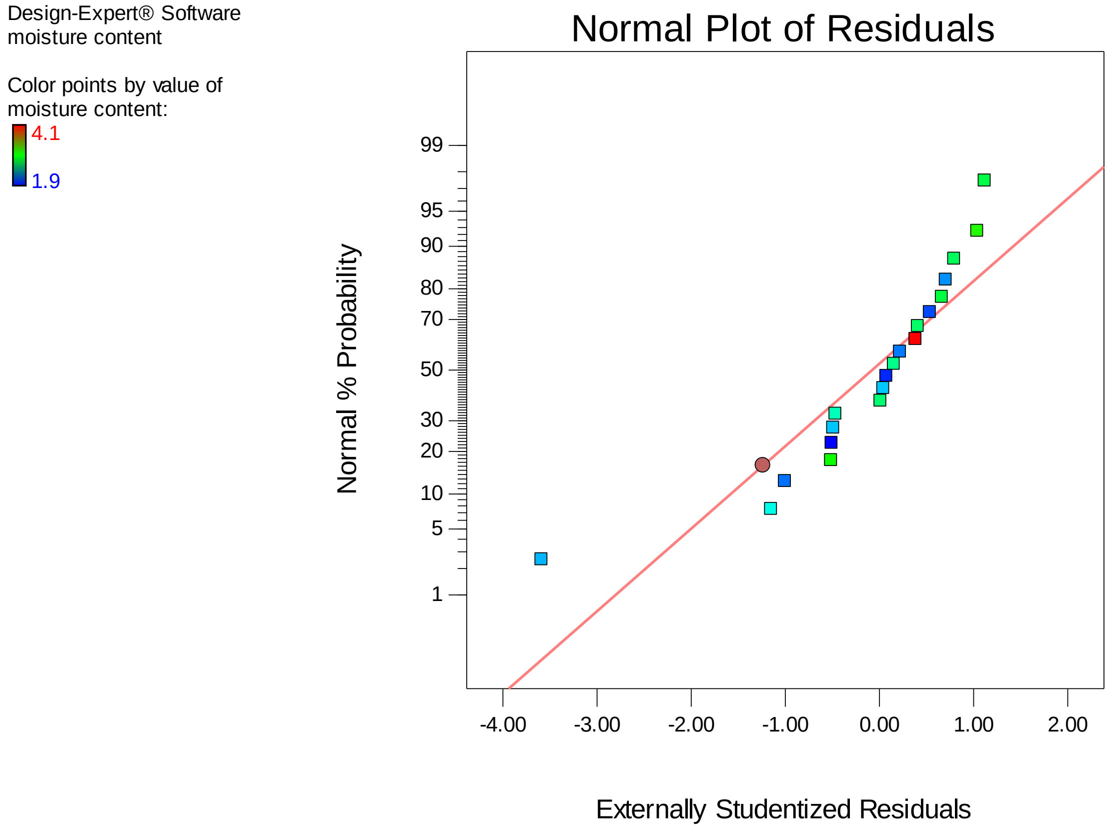
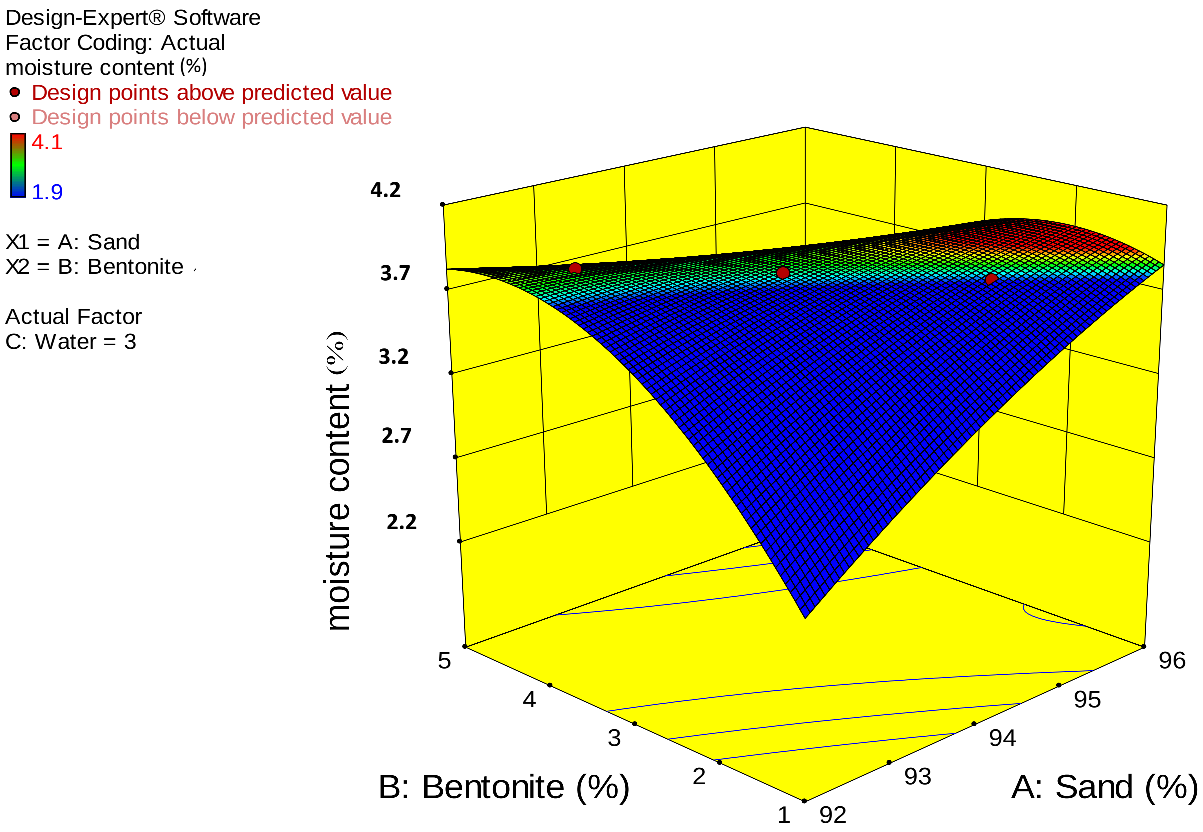


Figure 4.139 Normal probability plot of residuals obtained from the moisture content of bentonite sample

4.23.12 3D Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the bentonite and water content. Response surfaces and single effect plots were generated from the quadratic model, as shown in Figure 4.140. This Figure illustrates the response of different experimental

variables and can be used to identify the major interactions between the variables.

(a)



b)

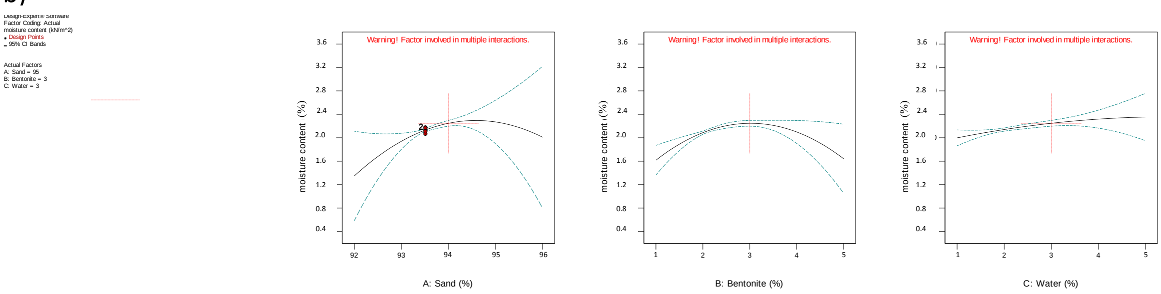


Figure 4.140: 3D surface (a) and single effect plot for the combine effect of bentonite, sand and water. (b), carried out at 3% water content.

Figure 4.140: 3D plot and its corresponding single effect plot to show the effect of sand and bentonite on the response at water

content of 3%. The graph shows that the maximum moisture content of 4.1% at 5% bentonite content and 92% of sand, is in accordance with the model.

Table 4.14a: Fit summary table

Response	7	Compactibility	Transform:	None	
	Sequential	Lack of Fit	Adjusted	Predicted	
Source	p-value	p-value	R-Squared	R-Squared	
Linear	0.3301	0.0020	0.0356	-0.6553	
2FI	0.2400	0.0022	0.1314	-2.4647	
Quadratic	< 0.0001	0.9969	0.9639	0.9614	Suggested
Cubic	0.9969		0.9316		Aliased

Table 4.14b: Sequential model sum of squares

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob> F	
Mean vs Total	9366.67	1	9366.67			
Linear vs Mean	41.61	3	13.87	1.23	0.3301	
2FI vs Linear	48.25	3	16.08	1.59	0.2400	
Quadratic vs 2FI	127.43	3	42.48	100.98	< 0.0001	Suggested
Cubic vs Quadratic	0.22	5	0.043	0.054	0.9969	Aliased
Residual	3.99	5	0.80			
Total	9588.15	20	479.41			

4.14c: Lack of fit tests

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob> F	
Linear	175.89	11	15.99	20.04	0.0020	
2FI	127.64	8	15.96	20.00	0.0022	
Quadratic	0.22	5	0.043	0.054	0.9969	Suggested
Cubic	0.000	0				Aliased
Pure Error	3.99	5	0.80			

4.14d: Model summary statistics

	Std.		Adjusted	Predicted		
Source	Dev.	R-Squared	R-Squared	R-Squared	PRESS	
Linear	3.35	0.1879	0.0356	-0.6553	366.63	
2FI	3.18	0.4057	0.1314	-2.4647	767.39	
Quadratic	0.65	0.9810	0.9639	0.9614	8.56	Suggested
Cubic	0.89	0.9820	0.9316		+	Aliased

4.23.13 ANOVA Analysis and Model Fitting

From the results of F-value, the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 4.14b, the quadratic vs 2FI and the linear vs mean models have significant F-value of 100.98 and 1.23 respectively while the other models (the 2FI vs linear and cubic vs quadratic models) were not significant with F-values of 1.59 and 0.054 respectively.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an F-test of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. This test measured the adequacy of the different models based on response surface analysis. As shown in table 4.14c there was a significant difference (F-value = 20.04 and 20.00) lack of fit for Linear and 2FI models. However, the test was not significant (F-value = 0.054) for quadratic models. The significant results of lack of fit for linear and 2FI models showed that these models are not adequate to use. The results of Tables 4.14b and 4.14c showed that the quadratic model can well describe the compactibility of River Niger beach sand sample. Apart from the F-value and the lack of fit, the R-squared, adjusted R-squared and the predicted R-squared values for the quadratic and cubic models showed a high value of 0.9810, 0.9639, 0.9614 and 0.9820, 0.9316 respectively w hen compared to other models (2FI and linear) as shown on Table 4.14d. The measure of how efficient the variability in the actual response values can be explained by the experimental variables and their interactions is given by the R-Squared value.

From these results, the effect of each parameter was evaluated using quadratic model as shown in Table 4.14e.

Table 4.14e: ANOVA for response surface quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	217.28	9	24.14	57.39	< 0.0001	significant
A-Sand	*3.97*	*1*	*3.97*	*9.44*	*0.0118*	
B-Bentonite	*1.39*	*1*	*1.39*	*3.31*	*0.0987*	
C-Water	*6.99*	*1*	*6.99*	*16.61*	*0.0022*	
AB	*13.05*	*1*	*13.05*	*31.02*	*0.0002*	
AC	*0.76*	*1*	*0.76*	*1.80*	*0.2091*	
BC	*7.89*	*1*	*7.89*	*18.76*	*0.0015*	
A^2	*4.44*	*1*	*4.44*	*10.55*	*0.0088*	
B^2	*22.23*	*1*	*22.23*	*52.84*	*< 0.0001*	
C^2	*0.033*	*1*	*0.033*	*0.080*	*0.7837*	
Residual	4.21	10	0.42			
Lack of Fit	*0.22*	*5*	*0.043*	*0.054*	*0.9969*	*not significant*
Pure Error	*3.99*	*5*	*0.80*			
Cor Total	221.49	19				

Std. Dev.	0.65		R-Squared	0.9810
Mean	21.64		Adj R-Squared	0.9639
C.V. %	3.00		Pred R-Squared	0.9614
PRESS	8.56		Adeq Precision	29.384
-2 Log Likelihood	25.58		BIC	55.53
			AICc	70.02

The independent variables in the specified model and the effect of each variable was evaluated. For this reason and in order to evaluate the adequacy of the selected model, several appraisal techniques were used. The coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to weigh the adequacy of the model as used by other researchers (Chen *et al.,* 2010) . It could be seen that the F-value of 57.39 implies that the model term is significant. In this case, A, C, AB, BC, A^2, B^2 are significant model terms. Values greater than 0.100 indicate that the model terms are not significant. The Lack of Fit F value of 0.05% implies that the Lack of Fit is not significant relative to the pure error. There is a 99.69% chance that a Lack of Fit this large could occur due to noise. Non-significant lack of fit is good because it means the model will be well fitted. Since many insignificant model terms have been reduced, the improved model can be used to predict effectively, the responses of the compactibility from River Niger Onitsha beach sand using bentonite. The F-value of the independent variables sand, bentonite and water content were estimated as 9.44, 3.31 and 16.61 respectively as shown in Table 4.14e. Showing that the effect of most independent variable on the dependent variable was significantly high. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.9810and 0.9639, respectively which illustrates that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well (Chen *et al.,* 2011). The CV called coefficient of variation which is defined as the ratio of the standard deviation of estimate to the mean value of the observed response, is independent of the unit. It is also a measure of reproducibility and repeatability of the models (Chen *et al.,* 2010; Chen *et al.,* 2011). The calculations indicated the CV value of 3.00% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) (Chen et al., 2011). The signal to noise ratio which is given as the value of the adequacy precision is 29.384. This indicated that an adequate relationship of signal to noise ratio exists.

The selected model in terms of the coded and the actual values are given in the equations:

$Y = + 26.10 + 7.30A - 2.96B + 5.36C - 66.04AB - 11.87AC - 24.58BC - 28.04A^2 - 27.15B^2 - 0.64C^2$……………………………………………(4.27)

In terms of actual values, the model terms are given by the compactibility = -67381.78108 + 1321.49287 *sand + 2686.42539 *bentonite+ 512.56823 *water – 26.68342 *sand *bentonite – 4.79592*sand *water – 17.37869 *bentonite *water – 6.47379 $*sand^2$ – 19.19914 $*bentonite^2$ – 0.45166 $*water^2$……………………………..(4.28)

Where y = compactibility, A = sand, B = bentonite, C = water

The response values obtained by inserting the independent values are the predicted values of the model. These values are compared to the actual and experimental values. The result of this comparison is shown in the Figure 4.141.

a)

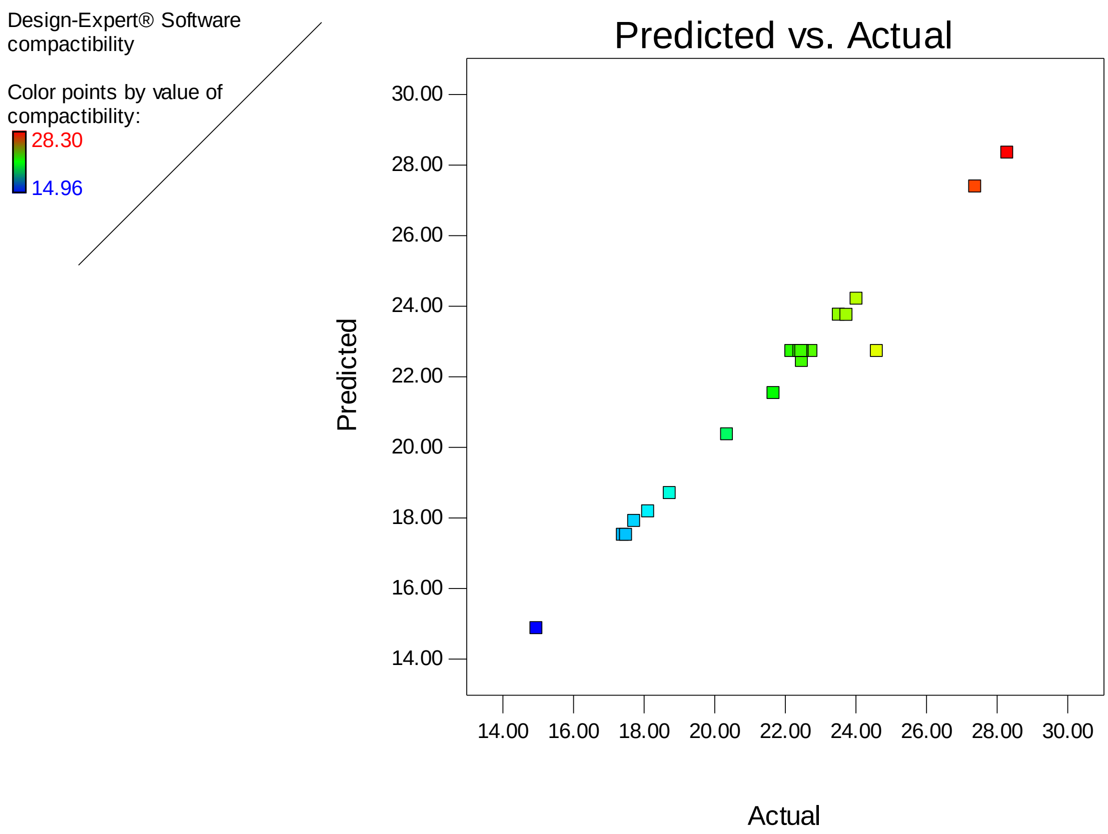


Figure 4.141 Linear correlation between predicted vs. actual values for compactibility of River Niger beach sand using bentonite content.

From the Figure 4.141, the actual values were distributed relatively near to the predicted value line. Showing that there is a good correlation between the actual and the predicted values. The diagnostics analysis which is completed by normal probability plots of residuals for investigations are shown on Figure 4.142. From the diagram it could be concluded that the residuals followed a normal distribution pattern. The points of the normal distributions are seen to be mostly interlocked with the straight line with a few points lying outside the diagonal line in a moderately scattered manner.

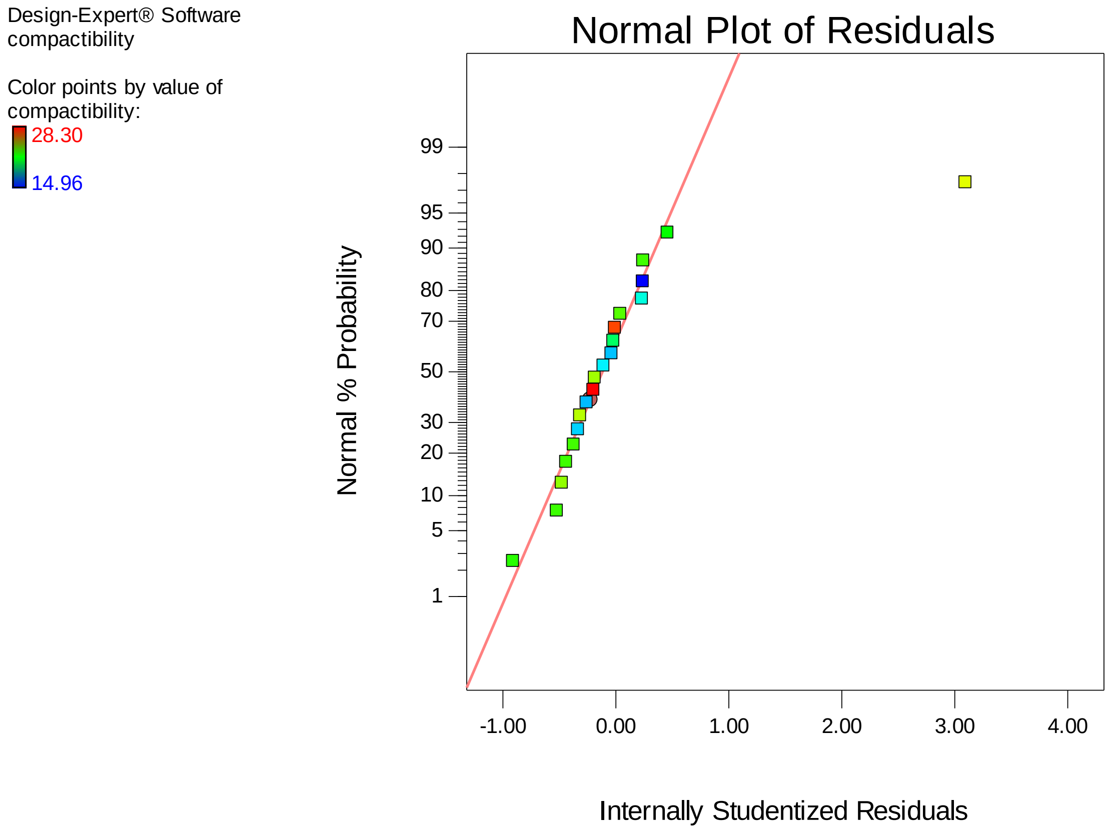
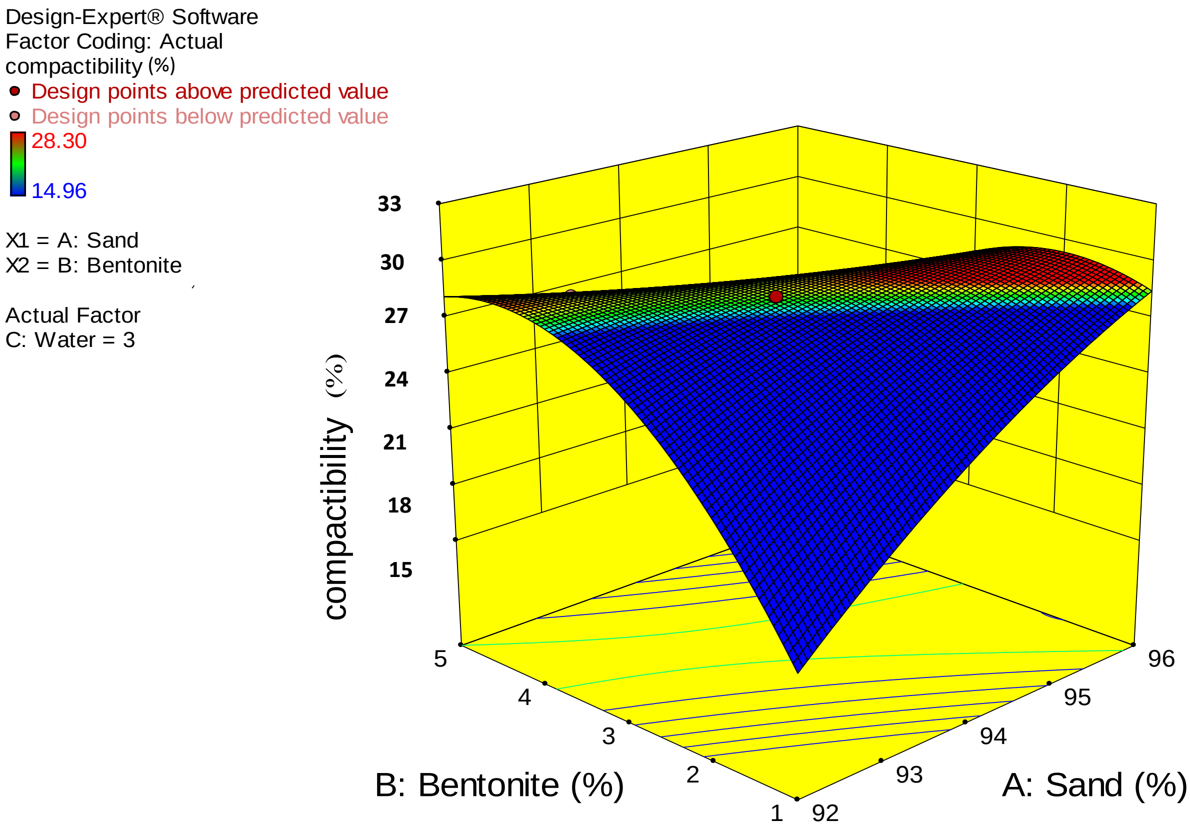


Figure 4.142 Normal probability plot of residuals obtained from the compactibility of bentonite sample

4.23.14 3D Surface and Single Effect Plots In order to visualize the relationship between the experimental variables and the response, and to study individual and interaction effects of the three factors consisting of the sand, the bentonite and water content. Response surfaces and single effect plots were generated from the quadratic model, as shown in Figure 4.143. This Figure illustrated the response of different experimental variables and can be used to identify the major interactions between the variables.

a)



b)

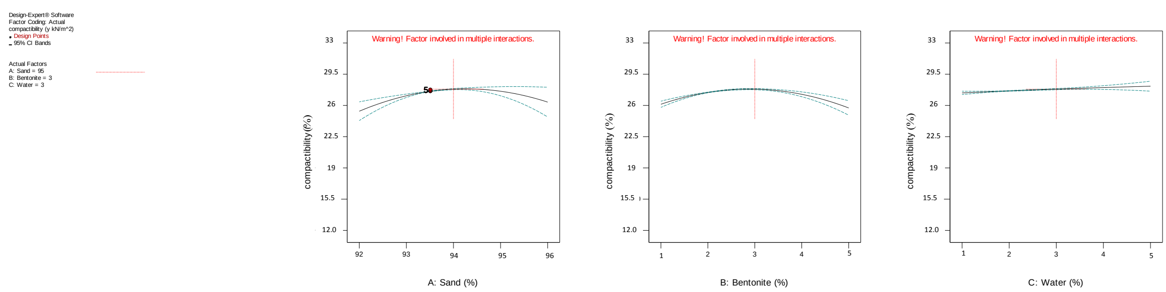


Figure 4.143: 3D surface (a) and single effect plot for the combine effect of bentonite, sand and water (b),carried out at 3% water content.

Figure 4.143: 3D plot and its corresponding single effect plot to show the effect of sand and bentonite on the response at water content of 3%, the graph shows that the maximum compactibility of $28KN/m^2$ at 5% bentonite content and 92% of sand is in accordance with the model. As bentonite content increased from 2% to 5% at 92% of sand, the green compressive

strength increased from 22KN/m^2 to 28KN/m^2. This linear relationship is as a result of increase in binder content that comes with 3% water content.

4.24 Process Optimization

Process optimization was done by using numerical optimization technique which is a feature of central composite design in the design expert software. A combination of factors that concurrently satisfy the requirements placed on each of the independent and dependant variables was performed and a goal was set on each of the variable. The constraints and set objectives for Ukpor clay and bentonite are tabulated on Tables 4.15a and 4.15b

Table 4.15a Constraints and set objectives for Ukpor clay

Constraints						
		Lower	**Upper**	**Lower**	**Upper**	
Name	**Goal**	**Limit**	**Limit**	**Weight**	**Weight**	**Importance**
A:Sand	is in range	92.4189	96.5811	1	1	3
B:Ukpor clay	is in range	1.81079	5.00	1	1	3
C:Water	is in range	1.81079	4.18921	1	1	3
Green com	maximize	14.3739	24.3873	1	1	3
green shear	maximize	0.696545	5.20	1	1	3
dry com	maximize	135.24	212.221	1	1	3
dry shear	maximize	22.4478	67.6936	1	1	3
permeability	maximize	139.951	157	1	1	3
moisture content	minimize	1.91012	4.07454	1	1	3
compactibility	is in range	14.9574	28.2962	1	1	3

Table 4.15b Constraints and set objectives for bentonite

Constraints						
		Lower	**Upper**	**Lower**	**Upper**	
Name	**Goal**	**Limit**	**Limit**	**Weight**	**Weight**	**Importance**
A:Sand	is in range	92.4189	96.5811	1	1	3
B:Bentonite	is in range	1.81079	5.00	1	1	3
C:Water	is in range	1.81079	4.18921	1	1	3
Green com	maximize	14.3739	24.3873	1	1	3
green shear	maximize	0.696545	5.2	1	1	3
dry com	maximize	135.24	212.221	1	1	3
dry shear	maximize	22.4478	67.6936	1	1	3
permeability	maximize	139.951	157	1	1	3
moisture content	minimize	1.91012	4.07454	1	1	3
compactibility	is in range	14.9574	28.2962	1	1	3

Based on these, the software predicted optimum reaction conditions with a desirability of 0.7, tabulated on Tables 4.15c and 4.15d for Ukpor and bentonite samples respectively.

Table 4.15c Showing values for optimum reaction conditions for Ukpor clay sample

Solutions												
Number	**Sand**	**Ukpor clay**	**Water**	**Green com strength**	**Green shear strength**	**Dry strength**	**Dry shear strength**	**Permeability**	**Moisture content**	**Compactibility**	**Desirability**	
1	94.372	2.344	3.620	23.667	4.782	210.348	62.284	149.862	3.155	26.733	0.711	Selected
2	94.366	2.345	3.627	23.666	4.776	210.408	62.316	149.858	3.155	26.743	0.711	
3	94.376	2.346	3.612	23.679	4.790	210.228	62.258	149.870	3.156	26.729	0.711	
4	94.394	2.343	3.592	23.688	4.808	210.040	62.217	149.879	3.158	26.712	0.710	

Table 4.15d Showing values for optimum reaction conditions for bentonite sample

Solutions												
Number	**Sand**	**Bentonite**	**Water**	**Green com strength**	**Green shear strength**	**Dry strength**	**Dry shear strength**	**Permeability**	**Moisture content**	**Compactibility**	**Desirability**	
1	94.371	2.343	3.621	23.669	4.782	210.359	62.315	149.859	3.156	26.740	0.711	Selected
2	94.378	2.343	3.612	23.670	4.788	210.268	62.244	149.868	3.155	26.722	0.711	
3	94.361	2.348	3.631	23.674	4.775	210.413	62.370	149.854	3.157	26.761	0.710	

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

This work has been able to characterize and produce River Niger Onitsha Beach foundry sand using bentonite and Ukpor clay as binders.

The mechanical sieve analysis showed that the River Niger Onitsha beach sand has an average grain fineness number of 82, which is within the acceptable range of 40 to 330 average grain fineness recommended for foundry application.

The X-ray florescence analysis showed that the River Niger Onitsha beach sand is composed predominantly of silica (94.49%) which is below the range that is recommended for steel and other heavy metals foundry. The X-ray diffraction analysis showed that the River Niger Onitsha beach sand consist of quartz, feldspar, antigorite, muscovite and albite as the predominant minerals with hopeite and orthoclase as minor minerals, while Ukpor clay deposit has anhydrodite, trscottite, parangonite and riebekite as the predominant minerals with gibbsite and haematite as minor minerals.

The foundry properties results showed that sand mix with 5% bentonite and 3.80% moisture content produced the best moulding mixture followed by 5% Ukpor clay and 3.55% moisture content. The properties compared favorably with the proportion of the moulding sand currently used in foundry for casting non ferrous metals and alloys.

5.1 Conclusions

From the results of the analysis presented, the following conclusions were drawn

1. The mechanical sieve analysis result revealed that the grain of the sand was sub-angular and it has a well-defined grading with 70.85(%) percent concentration of the sand grains retained by the three adjacent sieves of 0.18mm, 0.125mm and 0.09mm
2. Moisture has a very strong influence on the foundry properties of River Niger Onitsha beach sand.
3. The chemical analysis showed that the River Niger Onitsha beach sand is composed predominantly of silica (94.49%), but not in the range that could be used for steel and other heavy metals foundry. The analysis also indicated that Ukpor clay has Al_2O_3, SiO_2 and TiO_2 as the major components with 22.1%, 70.3% and 4.022% respectively, while bentonite sample has Al_2O_3 (24.60%), SiO_2 (64.10%) as its major constituents.
4. The result of the mechanical properties analysis of the sand was compared to the existing foundry standard and it was found to be very suitable for non ferrous alloy castings at about 3% to 5% of bentonite and Ukpor clay and with about 3.11% to 4.0% moisture content for both binders.

5. The sand mix with 5% bentonite and 3.80% moisture content was the best mixture followed by 5% Ukpor clay and 3.55% moisture content. The properties compared favourably with the proportion of the moulding sand currently used in foundries for the casting of aluminium alloys.

5.2 Contribution to Knowledge

1. The River Niger mixture with moisture content of 3.11% to 4.0%, produced a quality casting of aluminium using aluminium copper alloy.
2. The grain fineness number (G.F.N.) was found to be 82 AFS with fusion points of 1390^{o}C, 1464^{0}C and 1480^{0}C for pure silica sand, when mixed with 5% bentonite and 5% Ukpor clay each with constant 5% of water for both binders.This means that the River Niger sand would be suitable for casting metals and alloys with melting point lower than1390^{0}C
3. For the maximum dry-compressive strength, the moisture content should be 4% for the both binders.

5.3 Recommendations

For effective and efficient utilization of solid minerals in Nigeria, the following recommendations are made.

1. Further research aimed at determining the binding properties of cassava starch as a moulding material is suggested.
2. This work is recommended for foundry casters for use in preparing mould for casting of non ferrous alloys for possible replacement of the imported synthetic sand.

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APPENDIX

Table 4.16aMechanical sieve analysis values of River Niger Onitsha beach sand

Sieve Serial No	Aperture size in (mm)	Sand Retained on each sieve(g)	Percentage of sand retained	Cummulative% retained
1	1.00	9.8	0.98	0.98
2	0.71	10.5	1.05	2.03
3	0.50	40.2	4.02	6.05
4	0.355	95.2	9.52	15.57
5	0.25	44.7	4.47	20.04
6	0.18	340.5	34.05	54.09
7	0.125	205	20.50	74.59
8	0.09	163	16.30	90.89
9	0.063	55.0	5.50	96.39
10	Pan (-63)	36.1	3.61	100
11		1000	100	

Table 4.16b Parameters of River Niger Onitsha beach sand and AFS fineness number

Sieve Serial No	Apperture size in (mm)	Sand Retained on each sieve(g)	Percentage of sand retained	Multiplier	Product
1	1.00	9.8	0.98	9	8.82
2	0.71	10.5	1.05	15	15.75
3	0.50	40.2	4.02	25	100.50
4	0.355	95.2	9.52	35	333.20
5	0.25	44.7	4.47	45	201.15
6	0.18	340.5	34.05	60	2043
7	0.125	205	20.50	81	1660.5
8	0.09	163	16.30	118	1923.4
9	0.063	55.0	5.50	164	902
10	Pan (-63)	36.1	3.61	275	992.75
11		1000	100		8181.07

$$A.F.S.\, grain\ fineness\ number = 82$$

Table 4.16c Sieve analysis of Yola natural sand

S/ No	ISO Aperture (microns)	Sieve No	Weight Retained (g)	Weight Retained (%)	Cumulative Weight	Product
1.	1400	14	1.80	1.80	1.80	0.00
2.	1000	18	3.00	3.00	4.80	42.00
3.	710	25	4.10	4.10	7.90	73.30
4.	500	35	4.50	4.50	11.40	112.50
5.	355	45	7.00	7.00	18.40	245.00
6.	250	60	17.00	17.00	35.40	765.00
7.	180	80	18.50	18.50	53.90	1110.00
8.	125	120	17.40	17.40	71.30	1392.00
9.	90	170	8.20	8.20	79.50	984.00
10.	63	230	2.90	2.90	82.40	493.00
11.	-63	-230	15.60	15.60	100.00	3588.00
12.						∑8805.30

Source: Paul A. I. et al. (2011)

4.17a Chemical analysis of River Niger Onitsha beach sand

Compound	SiO_2	K_2O	CaO	TiO_2	V_2O_5	MnO	Fe_2O_3	NiO	CuO	Ag_2O	BaO	Nd_2O_3	OSO_4	Au	HgO
Conc. Unit (%)	94.49	1.30	0.475	0.341	0.012	0.027	1.675	0.0058	0.001	0.904	0.052	0.049	0.14	0.23	0.30

Table 4.17b Chemical composition of some foundry Sands

Constituent	Chelford	Warri River sand (%)	Ethiope River sand (%)	Ughelli River sand (%)	Lagos Bar Beach sand (%)
SiO_2	97.91	96.18	98.12	97.01	53.16
Al_2O_3	1.13	2.76	0.91	1.96	19.40
Fe_2O_3	0.50	0.06	0.16	0.13	4.70
CaO	-	-	-	-	2.66
MgO	-	-	-	-	2.08
K_2O	0.25	-	-	-	-
Loss on ignition	0.21	1.00	0.72	0.90	18.00
Total	100.00	100.00	100.00	100.00	100.00

Source: (Dietert .1954)

Table 4.17c Chemical analysis of Ukpor clay

Compound	Al_2O_3	SiO_2	SO_3	K_2O	CaO	Sc_2O_3	TiO_2	V_2O_5	Cr_2O_3	MnO	Fe_2O_3	CuO	Ga_2O_3
Conc. Unit (%)	22.1	70.3	0.100	0.038	0.126	0.000	4.022	0.164	0.013	0.034	2.113	0.0088	0.014
Compound	Ag_2O	Eu_2O	Re_2O_7	HgO									
Conc. Unitn(%)	0.762	0.047	0.068	0.07									

Table 4.17d Chemical analysis of bentonite sample

Compound	Al_2O_3	SiO_2	SO_3	K_2O	CaO	TiO_2	V_2O_5	MnO	Fe_2O_3	CuO	ZnO	Ga_2O_3
Conc. Unit (%)	24.60	64.10	0.704	0.449	1.39	0.198	0.015	0.003	6.94	0.015	0.005	0.015
Compound	Ag_2O	BaO	Eu_2O	Re_2O_7	WO_3	IrO_2						
Conc. Unit (%)	1.05	0.082	0.11	0.075	0.065	0.12						

Table 4.18a X-Ray diffraction peak database for River Niger Sand

a) Strongest 3 peaks

No.	Peak no.	2Thelta (deg)	d (A)	I/I1	FWHM (deg)	Intensity (Counts)	Integrated Int (counts)
1	5	24.0248	3.70117	100	0.19900	207	2333
2	3	18.2689	4.85223	28	0.18900	58	603
3	14	47.4844	1.91321	10	0.19000	21	226

b) X-Ray diffraction data list of River Niger Onitsha sand.

Peak no.	2Thelta (deg)	d (A)	I/I1	FWHM (deg)	Intensity (Counts)	Integrated Int (counts)
1	10.6547	8.29654	3	0.24000	6	114
2	17.3618	5.10365	3	0.14500	6	68
3	18.2689	4.85223	28	0.18900	58	603
4	20.6176	4.30447	4	0.11330	8	53
5	24.0248	3.70117	100	0.19900	207	2333
6	33.7990	2.64987	5	0.08000	10	75
7	34.0188	2.63325	4	0.09340	9	66
8	36.6364	2.45089	3	0.12000	6	37
9	36.8363	2.43805	5	0.20000	11	125
10	37.5207	2.39513	3	0.11000	6	36
11	37.7176	2.38308	5	0.11600	11	78
12	39.7940	2.26339	6	0.13000	12	97
13	43.1501	2.09480	4	0.18330	8	105
14	47.4844	1.91321	10	0.19000	21	226
15	52.2672	1.74883	3	0.22000	7	83
16	57.3003	1.60660	10	0.21000	21	271
17	57.5552	1.60009	3	0.06000	6	19

Table 4.18b X-Ray diffraction peak data list for Ukpor clay deposit

a) Strongest 3 peaks

No.	Peak no.	2Thelta (deg)	d (A)	I/I1	FWHM (deg)	Intensity (Counts)	Integrated Int (counts)
1	3	24.1227	3.68637	100	0.18220	442	4174
2	1	18.3535	4.83005	31	0.15480	137	1248
3	11	57.4312	1.60325	16	0.13860	71	578

b) X-Ray diffraction data list of Ukpor clay

Peak no.	2Thelta (deg)	D (A)	I/I1	FWHM (deg)	Intensity (Counts)	Integrated Int (counts)
1.	18.3535	4.83005	31	0.15480	137	1248
2.	23.8333	3.73047	5	0.12000	20	269
3.	24.1227	3.68637	100	0.18220	442	4174
4.	33.9897	2.63543	7	0.18830	29	317
5.	36.9400	2.43144	12	0.11770	55	381
6.	37.7485	2.38120	6	0.12600	25	180
7.	39.9175	2.25667	9	0.12730	41	292
8.	43.2617	2.08966	4	0.16000	18	163
9.	47.6000	1.90883	14	0.13400	61	483
10.	52.3347	1.74673	5	0.17500	23	237
11.	57.4312	1.60325	16	0.13860	71	578

Table 4.19a Foundry properties results of River Niger sand at 1% bentonite constant and varying percentages of water

Sand %	Bentonite %	Water %	Green Compression (KN/M2)	Green Shear (KN/M2	Dry-Compression (KN/M2)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
99	1	0	-	-	-	-	151.00	1.04	8.00
98	1	1	-	-	-	-	153.00	1.48	12.15
97	1	2	13.30	1.01	134.00	25.00	154.00	2.40	16.20
96	1	3	14.35	1.30	140.00	30.00	156.00	2.60	21.18
95	1	4	14.20	1.25	151.00	40.00	150.00	3.60	18.50
94	1	5	13.50	1.01	162.00	48.00	145.00	4.12	16.30

Table 4.19b Foundry properties of River Niger Onitsha beach sand at 2% bentonite constant and varying percentages of water

Sand %	Bentonite %	Water %	Green Compression (KN/M2)	Green Shear (KN/M2	Dry-Compression (KN/M2)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
98	2	0	-	-	-	-	150.00	1.11	8.60
97	2	1	16.00	1.01	148.20	35.00	152.00	1.40	15.15
96	2	2	17.35	1.06	159.00	40.00	154.10	2.30	20.48
95	2	3	18.48	1.54	168.00	42.00	155.00	2.60	22.50
94	2	4	18.40	1.52	174.00	49.00	148.10	3.50.0	19.50
93	2	5	17.10	1.50	184.00	54.00	144.00	4.10	17.40

Table 4.19c Foundry properties of River Niger Onitsha sand using 3% bentonite constant and varying percentages of water

Sand %	Bentonite %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
97	3	0	-	-	-	-	150.00	1.0	8.90
96	3	1	16.08	3.12	164.08	37.00	152.10	1.31	18.11
95	3	2	20.00	3.15	175.00	42.0	153.00	2.30	23.50
94	3	3	21.76	3.85	184.00	48.0	154.00	2.50	25.30
93	3	4	21.76	3.89	196.00	53.0	146.94	3.20	24.21
92	3	5	21.00	3.99	201.00	57.00	140.00	4.0	23.00

Table 4.19d Foundry properties results of River Niger Onitsha beach sand using 4% bentonite constant and varying percentages of water

Sand %	Bentonite %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
96	4	0	-	-	-	-	148.00	1.01	9.10
95	4	1	16.08	4.00	170.75	53.0	150.00	1.30	18.60
94	4	2	23.05	5.07	185.00	58.0	152.00	2.11	24.20
93	4	3	25.70	5.10	194.00	64.0	151.00	2.50	27.10
92	4	4	25.80	5.20	210.00	68.0	146.90	3.11	27.10
91	4	5	25.72	5.15	213.00	74.0	140.00	4.0	25.05

Table 4.19e Foundry properties results of River Niger Onitsha silica sand using 5% bentonite constant and varying percentages of water

Sand %	Bentonite %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
95	5	0	-	-	-	-	145.50	1.02	10.00
94	5	1	15.90	4.06	182.00	54.0	146.23	1.30	18.40
93	5	2	23.10	5.07	190.00	60.0	146.40	1.80	25.10
92	5	3	27.88	6.48	212.00	66.0	146.50	2.00	28.10
91	5	4	28.00	6.80	217.00	73.0	146.64	3.11	30.50
90	5	5	31.65	7.09	224.00	76.0	141.15	3.80	30.80

Table 4.19f Foundry properties results of River Niger silica sand using 1% of water constant and varying percentages of bentonite

Sand %	Bentonite %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
99	0	1	-	-	-	-	153.01	1.5	8.00
98	1	1	-	-	-	-	153.00	1.48	12.15
97	2	1	16.00	1.01	148.20	35.00	152.10	1.40	15.15
96	3	1	16.08	3.12	164.08	37.00	152.00	1.31	18.11
95	4	1	16.08	4.00	170.75	53.00	150.00	1.30	18.60
94	5	1	15.90	4.06	182.00	54.00	146.24	1.30	18.40

Table 4.19g Foundry properties results of River Niger silica sand using 2% of water constant and varying percentages of bentonite

Sand %	Bentonite %	Water %	Green Compression (KN/M²)	Green Shear (KN/M²	Dry-Compression (KN/M²)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
98	0	2	-	-	-	-	156.94	2.50	8.53
97	1	2	13.30	1.01	134.00	25.00	154.50	2.40	16.20
96	2	2	17.35	1.07	159.00	40.00	154.00	2.30	20.48
95	3	2	20.00	3.15	175.00	42.00	153.60	2.30	23.50
94	4	2	23.05	5.07	185.00	58.00	152.00	2.11	24.20
93	5	2	23.10	5.07	189.00	60.00	146.70	1.80	25.10

Table 4.19h Foundry properties result of River Niger Onitsha silica sand using 3% of water constant and varying percentages of bentonite

Sand %	Bentonite %	Water %	Green Compression (KN/M²)	Green Shear (KN/M²	Dry-Compression (KN/M²)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
97	0	3	-	-	-	-	158.00	2.62	10.00
96	1	3	14.35	1.30	140.00	30.00	156.00	2.61	21.18
95	2	3	18.48	1.54	168.00	42.00	155.00	2.60	22.50
94	3	3	21.76	3.85	184.00	48.00	154.00	2.51	25.31
93	4	3	25.70	5.10	194.00	64.0	151.00	2.50	27.10
92	5	3	27.88	6.48	212.00	66.00	146.50	2.00	28.11

Table 4.19i Foundry properties result of River Niger silica sand, using 4% of water constant and varying percentages of bentonite

Sand %	Bentonite %	Water %	Green Compression (KN/M²)	Green Shear (KN/M²	Dry-Compression (KN/M²)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
96	0	4	-	-	-		156.00	4.0	10.00
95	1	4	14.20	1.25	151.00	40.00	150.00	3.60	18.50
94	2	4	18.40	1.52	174.00	49.00	148.00	3.50	19.50
93	3	4	21.76	3.89	196.00	53.00	146.94	3.20	24.21
92	4	4	25.80	5.20	210.00	68.00	146.90	3.11	27.10
91	5	4	28.00	6.80	217.00	73.00	146.64	3.11	30.60

Table 4.19j Foundry properties result of River Niger silica sand, using 5% of water constant and varying percentages of bentonite

Sand %	Bentonite %	Water %	Green Compression (KN/M²)	Green Shear (KN/M²	Dry-Compression (KN/M²)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
95	0	5	-	-			154.00	5.11	10.10
94	1	5	13.50	1.01	162.00	48.00	145.00	4.12	16.30
93	2	5	17.00	1.50	184.00	54.00	144.00	4.10	17.40
92	3	5	21.00	3.99	201.00	57.00	140.50	4.00	23.00
91	4	5	26.76	5.15	213.00	74.00	140.30	4.00	25.15
90	5	5	31.65	7.09	224.00	76.00	140.15	3.80	25.05

Table 4.20a Foundry properties result of River Niger silica sand, using 1% Ukpor clay and varying percentages of water.

Sand %	Ukpor Clay %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
99	1	0	-	-	-	-	150.00	1.01	8.00
98	1	1	-	-	-	-	153.00	1.50	12.00
97	1	2	12.40	1.38	125	23.00	156.20	2.41	12.10
96	1	3	12.50	1.43	134	28.00	156.00	2.51	13.40
95	1	4	12.41	1.40	150	31.00	154.00	3.35	13.10
94	1	5	12.20	1.37	150	40.00	150.00	4.10	13.00

Table 4.20b Foundry properties result of River Niger silica sand, using 2% Ukpor clay and varying percentages of water.

Sand %	Ukpor Clay %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
98	2	0	-	-	-	-	148.00	1.05	8.41
97	2	1	15.49	2.01	140.00	25.00	152.00	1.50	13.51
96	2	2	15.48	2.20	152.00	29.00	156.00	2.30	15.20
95	2	3	15.31	2.21	165.00	33.00	155.10	2.51	17.50
94	2	4	15.30	2.20	175.00	41.00	153.00	3.25	17.40
93	2	5	15.20	2.00	183.00	41.00	148.00	4.05	17.10

Table 4.20c Foundry properties result of River Niger silica sand, using 3% Ukpor clay and varying percentages of water.

Sand %	Ukpor Clay %	Water %	Green Compression (KN/M²)	Green Shear (KN/M²	Dry-Compression (KN/M²)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
97	3	0	-	-	-	-	148.00	1.0	8.30
96	3	1	17.30	2.20	150.00	30.10	150.00	1.30	15.40
95	3	2	17.28	2.40	172.00	37.00	153.00	2.02	21.15
94	3	3	17.25	2.64	190.00	42.00	153.62	2.02	23.09
93	3	4	17.25	2.81	196.00	50.00	150.10	3.20	24.00
92	3	5	16.51	3.30	201.00	51.00	147.80	3.80	22.50

Table 4.20d Foundry properties result of River Niger silica sand, using 4% Ukpor clay and varying percentages of water.

Sand %	Ukpor Clay %	Water %	Green Compression (KN/M²)	Green Shear (KN/M²	Dry-Compression (KN/M²)	Dry Shear	Permeability (No)	Moisture content %	Compactibility %
96	4	0	-	-	-	-	145.00	1.00	8.50
95	4	1	15.50	3.00	165.00	42.00	148.00	1.11	15.10
94	4	2	19.80	3.91	180.00	45.00	151.00	1.34	22.20
93	4	3	21.69	4.01	201.00	51.00	150.50	1.51	25.10
92	4	4	21.44	4.00	206.00	57.00	150.00	3.00	25.00
91	4	5	20.30	3.85	210.00	60.00	147.00	3.55	24.01

Table 4.20e Foundry properties result of River Niger silica sand, using 5% Ukpor clay and varying percentages of water.

Sand %	Ukpor Clay %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2)	Dry-Compression (KN/M^2)	Dry Shear (KN/M^2)	Permeability (No)	Moisture content %	Compactibility %
95	5	0	-	-	-	-	145.00	1.10	8.00
94	5	1	15.30	2.80	180.00	50.00	145.14	1.01	15.50
93	5	2	21.90	4.00	189.00	57.00	146.00	1.30	21.30
92	5	3	23.40	4.00	203.00	61.00	148.40	1.41	25.20
91	5	4	23.48	4.91	215.00	61.00	148.55	2.94	27.40
90	5	5	23.25	4.90	220.00	65.00	143.00	3.55	27.00

Table 4.20f Foundry properties result of River Niger silica sand, using 1% water constant and varying percentages of Ukpor clay

Sand %	Ukpor Clay %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2)	Dry-Compression (KN/M^2)	Dry Shear (KN/M^2)	Permeability (No)	Moisture content %	Compactibility %
99	0	1	-	-	-	-	153.09	1.51	8.00
98	1	1	-	-	-	-	153.00	1.50	12.00
97	2	1	15.49	2.01	140.00	25.00	152.00	1.50	13.51
96	3	1	17.30	2.20	150.00	30.10	150.00	1.30	15.40
95	4	1	15.50	3.00	165.00	42.00	148.00	1.11	15.10
94	5	1	15.30	2.80	180.00	50.00	145.00	1.01	15.50

Table 4.20g Foundry properties result of River Niger silica sand, using 2% water constant and varying percentages of Ukpor clay

Sand %	Ukpor Clay %	Water %	Green Compression (KN/M²)	Green Shear (KN/M²	Dry-Compression (KN/M²)	Dry Shear (KN/M²)	Permeability (No)	Moisture content %	Compactibility %
98	0	2	-	-	-	-	156.94	2.50	8.53
97	1	2	12.40	1.38	125.00	23.00	156.30	2.41	12.10
96	2	2	15.48	2.20	152.00	29.00	156.10	2.30	15.20
95	3	2	17.28	2.40	172.00	37.00	153.00	2.02	21.15
94	4	2	19.80	3.91	180.00	45.00	150.00	1.34	22.20
93	5	2	21.90	4.00	189.00	57.00	146.00	1.30	21.30

Table 4.20h Foundry properties result of River Niger silica sand, using 3% water constant and varying percentages of Ukpor clay

Sand %	Ukpor Clay %	Water %	Green Compression (KN/M²)	Green Shear (KN/M²	Dry-Compression (KN/M²)	Dry Shear (KN/M²)	Permeability (No)	Moisture content %	Compactibility %
97	0	3	-	-	-	-	158.00	2.62	10.00
96	1	3	12.50	1.43	134.00	28.00	156.00	2.51	13.40
95	2	3	15.31	1.50	165.00	33.00	155.00	2.51	17.50
94	3	3	17.25	2.64	190.00	42.00	153.60	2.02	23.09
93	4	3	21.69	4.00	201.00	51.00	150.00	1.51	25.10
92	5	3	23.50	4.00	203.00	61.00	148.00	1.41	25.20

Table 4.20i Foundry properties result of River Niger silica sand, using 4% water constant and varying percentages of Ukpor clay

Sand %	Ukpor Clay %	Water %	Green Compression (KN/M2)	Green Shear (KN/M2	Dry-Compression (KN/M2)	Dry Shear (KN/M2)	Permeability (No)	Moisture content %	Compactibility %
96	0	4	-	-	-	-	156.00	4.0	10.00
95	1	4	12.41	1.40	150.00	31.00	154.20	3.35	13.10
94	2	4	15.30	2.20	175.00	41.00	153.00	3.25	17.40
93	3	4	17.25	2.81	196.00	50.00	150.30	3.20	24.00
92	4	4	21.44	4.00	206.00	57.00	150.00	3.00	25.00
91	5	4	23.48	4.91	215.00	61.00	148.45	2.94	27.30

Table 4.20j Foundry properties result of River Niger silica sand, using 5% water constant and varying percentages of Ukpor clay

Sand %	Ukpor Clay %	Water %	Green Compression (KN/M2)	Green Shear (KN/M2	Dry-Compression (KN/M2)	Dry Shear (KN/M2)	Permeability (No)	Moisture content %	Compactibility %
95	0	5	-	-	-	-	154.00	5.10	10.10
94	1	5	12.20	1.37	150.00	40.00	150.00	4.10	13.00
93	2	5	15.20	2.01	183.00	54.00	148.00	4.05	17.10
92	3	5	16.51	3.30	201.00	57.00	147.80	3.80	22.50
91	4	5	20.50	3.85	210.00	60.00	147.00	3.55	24.01
90	5	5	23.25	4.90	220.00	65.00	143.00	3.55	28.00

Table 4.21a Satisfactory mould property ranges for sand castings

Metal	Green compressive strength (kN/m^2)	Dry strength (kN/m^2	Permeability (No)
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: (Dietert 1966)

Table 4.21b Properties of moulding sand for use with various casting alloys

Casting Alloy	Minimum Sintering Temperature (^0C)	AFS Clay (%)	AFS Grain Fineness Number	Moisture (%)
Aluminum castings	1288	12-18	225-160	6.5-8.5
Brass and bronze castings	1288	12-14	150-140	6.0-8.0
Light grey iron casting	1288	10-12	200-180	6.5-8.5
Light grey iron squeeze molds	1316	12-14	120-87	6.0-7.5
Medium grey iron	1316	11-14	86-70	5.5-7.0
Medium grey iron synthetic sand	1343	4-10	75-55	4.0-6.0
Heavy grey iron, green or dry sand	1343	8-123	61-50	4.0-6.5
Light steel castings, green sand	1427	2.5-10	80-45	2.0-4.0
Heavy steel casting, green sand	1482	3-10	68-45	2.0-4.0
Heavy steel castings, dry sand	1427	3-10	60-45	4.0-6.0

Source: (McLaws 1971)

Table 4.22a Foundry properties results of River Niger beach sand using 1% water constant and varying percentages of starch

Sand %	Cassava Starch %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear (KN/M^2)	Permeability (No)	Moisture content %	Compactibility %
99	0	1	-	-	-	-	153.01	1.51	8.00
98	1	1	-	-	-	-	153.00	1.10	10.00
97	2	1	-	-	-	-	155.00	1.15	11.20
96	3	1	-	-	-	-	164.10	1.18	11.20
95	4	1	-	-	-	-	157.00	1.30	10.10
94	1	1	-	-	-	-	158.12	1.25	10.05

Table 4.22b Foundry properties results of River Niger beach sand using 2% water constant and varying percentages of added starch

Sand %	Cassava Starch %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compatibility %
98	0	2	-	-	-	-	156.94	2.50	8.53
97	1	2	-	-	-	-	156.00	2.40	10.20
96	2	2	-	-	-	-	159.20	2.15	11.25
95	3	2	-	-	-	-	164.10	2.50	12.00
94	4	2	-	-	-	-	160.00	2.50	12.50
93	5	2	-	-	-	-	160.00	2.30	12.62

Table 4.22c Foundry properties results of River Niger beach sand using 3% water constant and varying percentages of starch content.

Sand %	Cassava Starch %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compatibility %
97	0	3	-	-	-	-	158.00	2.62	10.00
96	1	3	-	-	-	-	156.10	2.87	10.25
95	2	3	-	-	-	-	165.00	2.84	12.00
94	3	3	-	-	-	-	170.15	2.90	13.01
93	4	3	-	-	-	-	167.10	2.50	13.20
92	5	3	-	-	-	-	165.12	2.60	13.20

Table 4.22d Foundry properties results of River Niger beach sand using 4% water constant and varying percentages of starch content.

Sand %	Cassava Starch %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compatibility %
96	0	4	-	-	-	-	156.00	4.00	10.00
95	1	4	-	-	-	-	150.11	3.72	10.24
94	2	4	-	-	-	-	160.00	3.90	10.50
93	3	4	-	-	-	-	170.15	3.67	12.15
92	4	4	-	-	-	-	171.20	3.40	12.18
91	5	4	-	-	-	-	175.00	3.35	12.21

Table 4.22e Foundry properties results of River Niger beach sand using 5% water constant and varying percentages of starch content.

Sand %	Cassava Starch %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compatibility %
95	0	5	-	-	-	-	154.00	5.11	10.10
94	1	5	-	-	-	-	145.00	4.15	10.15
93	2	5	-	-	-	-	156.00	4.20	10.30
92	3	5	-	-	-	-	165.20	4.30	11.10
91	4	5	-	-	-	-	170.00	4.20	11.25
90	5	5	-	-	-	-	175.00	3.85	12.15

Table 4.22f Foundry properties results of River Niger beach sand using 1% Starch content constant and varying percentages of water

Sand %	Cassava Starch %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compatibility %
99	1	0	-	-	-	-	153.50	1.01	8.00
98	1	1	-	-	-	-	153.00	1.10	10.00
97	1	2	-	-	-	-	156.00	2.40	10.20
96	1	3	-	-	-	-	156.10	2.52	10.25
95	1	4	-	-	-	-	150.11	3.72	10.24
94	1	5	-	-	-	-	145.00	4.15	10.15

Table 4.22g Foundry properties results of River Niger beach silica sand using 2% Starch content constant and varying percentages of water

Sand %	Cassava Starch %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compatibility %
98	2	0	-	-	-	-	155.75	1.11	8.10
97	2	1	-	-	-	-	155.00	1.15	11.20
96	2	2	-	-	-	-	155.20	2.15	11.25
95	2	3	-	-	-	-	165.00	2.84	12.00
94	2	4	-	-	-	-	160.00	3.90	10.50
93	2	5	-	-	-	-	156.00	4.20	10.30

Table 4.22h Foundry properties results of River Niger beach silica sand using 3% starch content constant and varying percentages of water

Sand %	Cassava Starch %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compatibility %
97	3	0	-	-	-	-	159.80	1.10	8.52
96	3	1	-	-	-	-	159.00	1.18	11.20
95	3	2	-	-	-	-	164.10	2.50	12.00
94	3	3	-	-	-	-	170.15	2.90	13.01
93	3	4	-	-	-	-	170.15	3.67	12.15
92	3	5	-	-	-	-	165.20	4.30	11.10

Table 4.22i Foundry properties results of River Niger beach silica sand using 4% Starch content constant and varying percentages of water

Sand %	Cassava Starch %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compatibility %
96	4	0	-	-	-	-	157.00	1.01	8.40
95	4	1	-	-	-	-	157.00	1.30	11.10
94	4	2	-	-	-	-	160.00	2.50	12.50
93	4	3	-	-	-	-	167.10	2.50	13.20
92	4	4	-	-	-	-	171.20	3.40	12.18
91	4	5	-	-	-	-	170.10	4.20	11.25

Table 4.22j Foundry properties results of River Niger beach silica sand using 5% starch content constant and varying percentages of water

Sand %	Cassava Starch %	Water %	Green Compression (KN/M^2)	Green Shear (KN/M^2	Dry-Compression (KN/M^2)	Dry Shear	Permeability (No)	Moisture content %	Compatibility %
95	5	0	-	-	-	-	159.10	1.00	8.41
94	5	1	-	-	-	-	158.12	1.25	10.05
93	5	2	-	-	-	-	160.00	2.30	12.62
92	5	3	-	-	-	-	165.12	2.60	13.20
91	5	4	-	-	-	-	175.00	3.30	12.21
90	5	5	-	-	-	-	170.00	3.85	12.15

Table 4.23a Other properties tested

Refractoriness:		
Pure silica sand 1388^0C	Mixed with 5% bentonite + 5% water 1460^0C	Mixed with 5% Ukpor clay + 5% water 1475^0C
Fusion point:		
Pure silica sand 1390^0C	Mixed with 5% bentonite 1464^0C	Mixed with 5% Ukpor clay 1480^0C

Clay content in sand: 0.084%

Table 4.24a Tensile test result of Al-10% Cu alloy produced from the moulding mixture of 5% bentonite and 5% water

Cross sectional area	Guage length (mm)	Force (N)	Elongation (mm)	% Elongation	Stress (N/m^2)	Strain
28.30	96	1525	0.05	0.052	53.89	0.0005
28.30	96	4405	0.151	0.16	155.65	0.00160
28.30	96	6940	0.250	0.26	245.23	0.0026
28.30	96	7500	0.280	0.29	265.02	0.0029
28.30	96	8640	0.41	0.43	305.30	0.0043
28.30	96	8820	0.56	0.58	311.66	0.0058
28.30	96	9540	0.750	0.78	337.10	0.0078
28.30	96	9615	0.840	0.86	339.75	0.0088
28.30	96	9740	0.98	1.02	344.17	0.0102
28.30	96	9315	1.45	1.51	329.15	0.0151
28.30	96	8260	1.68	1.75	291.88	0.0175

Table 4.24bTensile test result of Al-10% Cu alloy produced from the moulding mixture of 5% Ukpor clay and 5% water

Cross sectional area	Guage length (mm)	Force (N)	Elongation (mm)	% Elongation	Stress (N/m^2)	Strain
28.30	96	1430	0.08	0.08	50.53	0.0008
28.30	96	4890	0.25	0.26	172.79	0.0026
28.30	96	5640	0.31	0.32	199.29	0.0032
28.30	96	7725	0.46	0.48	272.97	0.0048
28.30	96	8515	0.54	0.56	300.88	0.0056
28.30	96	8905	0.87	0.91	314.66	0.0090
28.30	96	9500	0.95	0.99	335.68	0.0098
28.30	96	9540	1.13	1.18	337.10	0.0118
28.30	96	8491	1.12	1.67	300.04	0.0117
28.30	96	7390	1.34	1.40	261.13	0.0140

Table4.24c Tensile test result of Al-10%Cu alloy produced from the moulding mixture of 4% Ukpor clay and 3% water

Cross sectional area	Guage length (mm)	Force (N)	Elongation (mm)	% Elongation	Stress (N/m^2)	Strain
28.30	96	1410	0.25	0.26	49.82	0.0026
28.30	96	4204	0.60	0.63	148.55	0.0063
28.30	96	6565	0.65	0.68	231.98	0.0068
28.30	96	6847	0.85	0.89	241.94	0.0088
28.30	96	7450	1.05	1.09	263.25	0.0110
28.30	96	7980	1.30	1.35	281.98	0.0140
28.30	96	8450	1.58	1.65	298.59	0.0160
28.30	96	8310	2.30	2.4	293.64	0.0240
28.30	96	7906	2.64	2.75	279.36	0.0280
28.30	96	6535	2.75	2.86	230.92	0.0290

Table4.24d Tensile test result of Al-10%Cu alloy produced from the moulding mixture of 3% bentonite and 5% water

Cross sectional area	Guage length (mm)	Force (N)	Elongation (mm)	% Elongation	Stress (N/m^2)	Strain
28.30	96	1350	0.13	0.14	47.70	0.0014
28.30	96	4152	0.35	0.36	146.71	0.0036
28.30	96	5354	0.56	0.58	189.19	0.0058
28.30	96	6450	0.84	0.88	227.92	0.0088
28.30	96	7608	0.98	1.02	268.83	0.0102
28.30	96	7980	1.34	1.40	281.98	0.0139
28.30	96	8245	1.67	1.74	291.34	0.0174
28.30	96	8150	1.86	1.94	287.98	0.0194
28.30	96	7628	2.50	2.60	269.54	0.0260
28.30	96	6237	2.3	2.40	220.00	0.02396

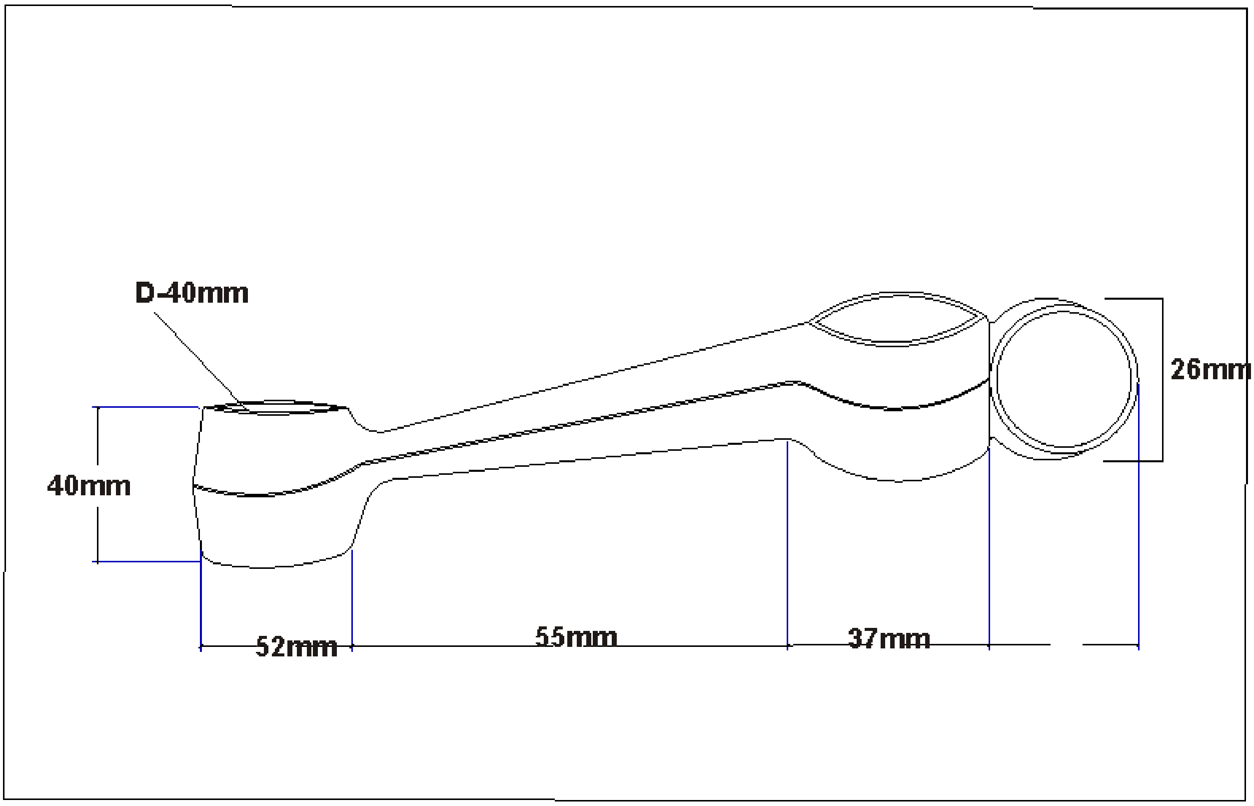

Plate 2: Upperarm of a Mercedes