EVALUATION OF MOULDING PROPERTIES OF SAND IN NIGER STATE FOR ALUMINIUM CASTING AND OTHER FOUNDRY APPLICATIONS

Evaluation of moulding properties of sand in Niger State for casting and the effects of the sand mould on mechanical properties of aluminium cast is presented. The moulding properties includes; Permeability, Compactibility, Moisture Content, Green and Dry Strengths. Sand samples from five locations in Niger State, Zungeru, Tungan Mallam, Wuya, Gidan Mangoro and Tagwai Dam area villages were collected and evaluated according to the American Foundry Society (AFS) standard. Mechanical (Tensile and Hardness) and Metallographic tests were carried out on the aluminium cast specimen obtained from the five different sand samples to verify the sand test results. All the results of the five different sands evaluated were compared with that of satisfactory standard mould property ranges for sand casting, the values of result of the five sands evaluated were found to be out of range with that provided for aluminium alloy casting. Mechanical and Metallographic tests of the aluminium samples produced from the five different sand were carried out to validate the results from the sand tests. The sand tests results gave values that ranged between for Permeability 72.08 – 96.85, Green Compressive Strength 12.50 kN/m^2 – 48.67 kN/m^2 and 76.00 kN/m^2 – 116.67 kN/m^2 and Dry Compressive Strength 85.00 kN/m^2 – > 650.00 kN/m^2, While the satisfactory mould property ranges for sand casting for aluminium are Permeability 10-30, Green Compressive Strength 50 – 70 kN/m^2, Dry Compressive Strength 200-550 kN/m^2. The sand test results however of Wuya, Zungeru and Tagwai Dam area villages were found to be within the range for casting Heavy Grey Iron as provided by standard mould property range for sand casting, while the result of Gidan Mangoro village was in the range for Malleable Iron castings. Tungan Mallam sand results did not provide values within the range provided by the standard mould property range for sand casting in its natural state as provided in the table of standard.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

The greatest problem the Production Engineer faces is choice of solving problems with maximum output in terms of quality, quantity and cost of production. Manufacturing process is a production process which involves directly the change of form or dimensions of a finished part being produced from other forms or raw materials to produce the usable product. Manufacturing process is divided into six major groups namely Primary Shaping Processes [casting, powder metallurgy, plastic technology, bending and forging], Secondary Machining Processes [turning, threading, milling, drilling and gear cutting], Metal Forming Processes [forging, rolling, hot spinning, extrusion and drawing], Joining Processes [welding, brazing, soldering, riveting and bolt joints], Surface Finishing Processes [honing, super finishing, electroplating, metal spraying, painting and sand blasting] and Processes Effecting Change in Properties [annealing, normalising, hardening, tempering and grain refining], Singh (2006).

Primary shaping processes are manufacturing processes were a product is produced from an original raw material. Primary shaping processes produces finished products or parts into its usable or working form, Singh (2006). Casting is one of the earliest forms of metal forming processes and is defined as a technique of pouring metal in liquid form into a cavity of the shape desired called the mould, and allowing it to solidify, Khan (2005). Bala et.al (2013) noted that melting temperatures and solidification of metals occurs at a steady temperature. Solidification starts at melting temperature and forms a steady straight path on the cooling curve during the solidification as a result of the evolution of the latent heat of fusion. The chilling effect of the mould wall produces a thin skin of solid metal at the boundary instantly after pouring. Randomly shaped grains of tiny size form close to the mould wall, and big columnar grains positioned in the direction of the middle of the cast form afterword. The solid-liquid boundary goes completely all the way in the molten metal from the mould walls internally to the middle. Once solidification occurs at any position cooling continues. The cast is removed from the mould and cooling starts at ambient temperature.

The other primary shaping processes have been proven severally compared to casting to have the disadvantage of material waste, high cost implication, stress distribution problems like cracks, fatigue and creep as compared to products of casting. Casting processes is divided into different groups which are permanent and expendable mould pattern that includes sand casting, squeeze casting, die casting etc. While stressing the relevance of casting, Khan (2005) stated that, casting process is extensively used for the manufacture of products for almost all industries such as agriculture, construction, cement, chemical, petro chemical, aircraft, ship building etc. This clearly shows that the scope of casting cannot be over emphasized given its wide area of coverage and utilization. Sand casting, otherwise referred to as sand moulded casting, is a casting technique whereby sand is used as the mould material. It is reasonably cheap and has sufficient refractory property for steel foundry use. Khan (2005) identifies sand casting as the most widely used casting process in the casting industry, worldwide. Abolarin et.al (2010) share the view in stating that sand is the main moulding component utilized for casting globally for the production of variety of casts both ferrous and non ferrous metals, because sand has the properties essential for foundry application. In explaining the reason for the high utilization of sand casting Aweda and Jimoh (2009) noted the particle size of sand which is packed finely and tightly together provides an excellent surface for the mould. Sand moulds are designed to have a good collapsibility and accommodate shrinkage of cast metal in the process of solidification, which is to prevent defects in the cast metal. Sand casting also provides good surface finish because the molten metal poured in the mould flow freely and is closely packed with good permeability for better final cast finish.

The much desired development of Nigeria can only be achieved through industrialization and the back bone of any industrialized country is very much dependent on its production capacity from the availability of raw materials to the technology utilized in transforming the raw materials to finished products. Nigerian economy over the years has continue to depend on oil as the major source of revenue neglecting other sectors that would boost its industrial and economic development as highlighted by Abolarin et.al (2004). The abundance of mineral deposits all over Nigeria is greatly underutilized, sand being one of them. Asuquo et.al (2013) in investigating the nature and quality of Zircon sand from Jos Plateau State and sand samples from Idah, Kogi State for foundry application, noted that Nigeria is blessed with large quantity of natural resources that have numerous applications which can be used in producing expensive High Performance Engineering equipment, which are not being utilized to the optimum.

1.2 Problem Statement

Nigeria is aiming to be among the twenty most developed nations by the year 2020, this can only be achieved through rapid industrialization and this cannot be achieved without sufficient production that would serve the country and even provide for export to other nations. Sheidi (2012) noted that the production of castings is necessary for the development of every nation, as almost all human aspect is reliant upon casting for equipment in construction, transportation, petroleum, mining, farming, and in water supply. Nuhu (2008) noted the significance of Ajaokuta steel rolling company situated in Kogi state operating at full capacity will draw a large number of ancillary and small to heavy industries to the region that require large foundry plants for the spare and completely knocked down parts. Niger state with a land mass of 99,000 km^2 situated in central Nigeria and also the largest state in terms of land mass in Nigeria has tremendous potential in the casting industry if only it would be harnessed properly. The growing desire for increase in local content in the production industries and the quest for rapid industrialization in Nigeria necessitates that more and more local materials are being sought after to replace imported materials which Niger state provides.

1.3 Aim and Objectives of the Research

1.3.1 Aim of the Research

This research work aim at evaluating the moulding properties of sand from Zungeru, Wuya, Tungan Mallam, Gidan Mangoro and Tagwai Dam all in Niger State for casting and also to test the effects of the moulding sand evaluated on the mechanical properties of aluminium casts.

1.3.2 Objectives of the Research

The objective of the research is to identify whether the five selected area where the sand samples were taken from in Niger State meet the requirement for moulding and can be utilized for casting as well as to determine the effects of the moulding sand on cast aluminium.

1.4 Justification of the Study

Clearly, a preference exists for imported sands and clay over local ones by most foundries in Nigerian cast industries as stated by Ayoola et al (2010). This might not be unconnected with the processes involved in the acquisition, preparation and other processes of the sand for it to be suitable for casting, coupled also with the fact that little effort has been put in identifying and exploring local sands to see their suitability and practical ability in commercial quantity. The porosity, sizes and treatment of sand material affects the permeability, curing time and the quality of cast produced. Musa et.al (2012) conducted a comparative analysis of some selected clays in Niger state to investigate their refractory properties which gave satisfactory results. Igbokoda clay in south west Nigeria had shown good binding property for synthetic sand moulding, Loto and Omotoso, (1990). Abolarin et.al (2010) utilized river Niger sand with Tudun-Wada clays as binder which gave them a satisfactory result with the clay acting as substitute for bentonite used in foundry mould. This shows clearly that more research is required to find more alternatives to imported sands. Ayoola et.al (2010) found Oshogbo sand in Osun state suitable for use in foundry application for sand casting. Asuquo et.al (3013) investigated the characteristics of Zircon sand and the effect on foundry casting utilizing sand sample from Idah, Kogi state and Zircon sand from Jos, Plateau state which gave positive results. Aramide et.al (2011) in the quest of optimizing local silica sand from Ilaro, Osun state investigated the possibility of using recycled local Nigerian with the addition of binders in which desired results were obtained.

Clearly a lot of prospects exist for the utilization of local Nigerian sand in casting. Zungeru, Wuya, Tungan Mallam, Gidan Mangoro and Tagwai Dam area sand all in Niger State would provide alternate source for sand cast utilization considering its span and abundance. This would promote the local content initiative of the government and cut cost of procuring sand, this project is focusing on local sand in Nigeria to ascertain if it has sufficient properties to be used for foundry application satisfactorily.

1.5 Research Scope and Limitations

This project work is restricted to sand deposit located in five different locations of Zungeru in Wushishi Local Government Area, Wuya in Mokwa Local Government Area, Tungan Mallam in Paikoro Local Government Area, Tagwai Dam area and Gidan Mangoro in Bosso Local Government Area all in Niger State to test whether the sand samples were suitable enough to be utilized in sand casting of aluminium alloys and other foundry application.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Historical Development of Casting

Casting is an engineering process that has been in existence for ages and has continued to evolve with time and modernization. Khan (2005) identifies casting as the cardinal foundation of civilization, through which man unlocked his future, putting man in the direction of conquering his environment, with the source of casting believed to have originated from Mesopotamia traced to 5000 (BC) when gold, silver and copper were used for various application. From 5000 (BC), improvement of casting have been accomplished with time and technology. Cast iron plowshares were discovered in China around 233 (BC) while crucibles steels were first produced in India around 500 (AD). In 1455, pipe castings were made in Germany for conveying water. Vannoccio Biringuccio (1480-1539) made available the first documented foundry process in booklet form. While the first true foundry flask used sand casting was invented by Abraham Darby in 1709. Benjamin Huntsman in 1750 reintroduced the cast crucible steel process where the steel and cast are entirely melted to a uniform composition within the melt by forging and tempering. In 1809 Centrifugal Casting development was achieved by A. G Eckhardt in England. B. F Philbrook of Iowa in 1897 reintroduced the process of Investment Casting when he used it to produce dental inlays. The Shell Casting process was first applied during World War II by the German J. Cronning. H. F Shroyer who produced the first Full Mould process in 1958. The process for casting high production core making using Cold box process was realized by L. Toriello and J. Robins. The Japanese invented the V-Process method by the utilization of unbounded sand and a vacuum in 1971. The technology of rheocasting was achieved at Massachusetts Institute of Technology in 1971, Nasar (2009).

2.2 Casting Processes

A good cast cannot be produced effectively if the processes involved in its production, the mould type and other factors like bonding materials are poorly chosen. Based on the grouping of the processes involved in casting, various types of casting are established, each with its own properties, limitation, qualities etc. Casting could be done in different ways, but the processes are primarily divided into two groups namely Expendable and Non-Expendable based on mould casting type. It can also be classified based on bonding type which is also divided into two namely In-Organic binder processes and Organic binder processes, Khan (2005). Expendable mould casting is a casting process were temporary, non-reusable moulds are utilized in the production of casts. Once the cast is produced, the process of casting would have to be started from the initial stage completely. Expandable casting processes include Plaster, Shell, Investment, Sand castings etc. While Non-Expendable mould casting is a casting process in which the production cycle for producing cast does not need to be repeated from the beginning at the end of each production cycle. In Non-Expendable casting process, the moulds are halved into two and clamped to each other before the molten metal is poured into the mould which is cracked open after the molten metal solidify, producing a cast with the shape of the mould produced. This type of process includes Permanent, Die, Centrifugal and Continuous casting. Classification of casting based on moulding type and processes are given in Figure 2.1

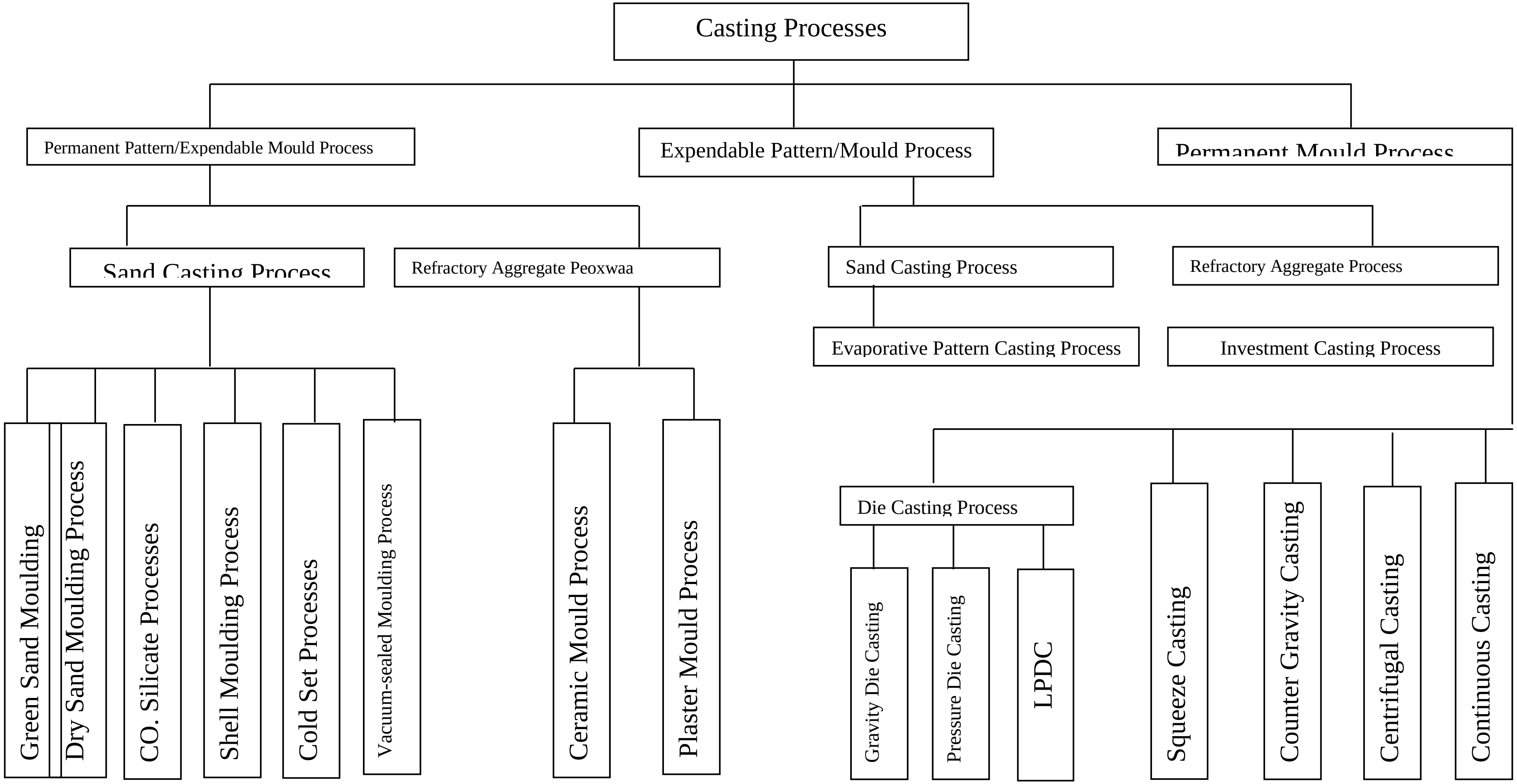

Figure 2.1 Classifications of Casting Processes (Khan, 2005)

2.3 Types of Casting

As cited earlier, casting is one of the oldest forms of technology used by man which has a wide range of application. It varies from period to period, region to region but the basic principle in casing is almost constant. There are various types and method of casting depending on the methods, shapes, size of cast to be produced. They include:

i. Sand Casting.
ii. Shell Casting.
iii. Plaster Casting.
iv. Investment Casting (lost-wax).
v. Permanent Casting.
vi. Die Casting.
vii. Centrifugal Casting.
viii. Continuous Casting.

2.3.1 Sand Casting

In sand casting, sand is the most important material, it provides the mould material. The mould is prepared and a pattern of the casting to be produced is made and the molten metal is poured and allowed to solidify. Sand casting process accounts for the largest percentage of all types of casting globally. Sand casting utilizes close packing and pressing of sand around a pattern to form a cavity, thereupon the pattern is removed. Silica (SiO_2) is the major component of sand used for sand casting and most common sand casting process used in the foundry industry is green sand moulding which is very much suitable to different types of casting in sizes of less than half kilogramme to 4.64 tonnes, while for heavy castings, dry sand moulds are best suited. Sand casting is better utilized in casting iron and steel at their high melting temperatures but also predominates for aluminium, brass, bronze, and magnesium, Guma (2012).

2.3.2 Plaster Casting

Plaster casting uses Plaster of Paris as the moulding material and is a process which is similar to sand casting in terms of working principle and also uses mould process that is non – reusable and it can only applied in casting non-ferrous materials. The type of cast produced by the application of this process ranges from small castings of 30 g to big casts of up to 45 kg. Additives are added to the Plaster of Paris to add to its strength, permeability and other properties that augment the quality of the plaster mould which include magnesium oxide or talc to eradicate cracking and cut down setting time, while lime and cement inhibits expansion during baking and glass fibres add to the strength. In Plaster casting, sand is capable of being utilized as filler, Degarmo et.al (2003).

The mould is made in the ratio of (70–80) % gypsum and (20–30) % additives and mixed thoroughly with the additives. The pattern is covered with the plaster and the unit shaken so that the plaster fills any small gap. The pattern is removed from the mould when the plaster sets and to eliminate surplus water from the mould, the mould is baked between 120 °C and 260 °C. The molten metal is poured into the baked mould which is held together and the metal allowed to solidify, prior to opening the mould. Plaster casting produces excellent dimensional accuracy and surface finish, because of the low thermal conductivity and heat capacity of the mould which allows the metal to cool slower than in sand mould and allows the metal fill thin cross-sections which makes it feasible to cast near net shape cast as thin as 0.6 mm which is cost effective in casting complex parts. The biggest problem of the plaster casting is its inability to resists high temperature and can only be used for metals like aluminium, copper and zinc that are non-ferrous and have low melting temperature. At molten metal temperature above 1200 °C the plaster mould would melt and destroy the mould. The presence of sulphur in the gypsum which reacts with iron makes casting of ferrous materials incompatible using plaster casting, Kalpakjian and Schmid (2006).

2.3.3 Shell Casting

Shell casting is comparable to sand casting, but for the mixtures of sand (3-6) % resin that holds the grains as one. Aluminium and magnesium castings can produce an average of 13.5 kg as a regular limit although it is feasible to cast products of between (45-90) kg. In this process, sand and cement are blown on the heated metallic pattern for a definite period of time depending on the shell thickness desired, Khan (2005).

2.3.4 Investment Casting

Investment casting process is used for massive production of near net shape parts with complex designs with huge cut in cost of production because it provides the capacity for accurate replication of cast. Cast parts are produced from the exact pattern and reproduced in multiples to the desired quantity, with a high degree of dimensional accuracy. A pattern usually in wax or plastic form is surrounded by a ceramic material which is allowed to solidify with the shaped wax or plastic inside it. Upon solidification, the wax pattern is melted out and molten metal poured into the cavity. Investment casting process is affected by factors which include firing temperature, silica sand of different grain fineness numbers, the temperature of molten metal poured and firing time. It is used for casting dental tools, electrical equipment, guns, hand tools, jewellery, machine tools, agricultural equipment, Singh and Singh (2013).

2.3.5 Die Casting

Die casting is a casting process whereby under high pressure, molten metal is poured into the mould cavities called dies that have been produced by machining. Die casting are used predominantly for non-ferrous metals like copper, zinc, aluminium based alloys, although ferrous metal die casting are achievable. This kind of casting process is utilized for casting high volume, high detail and value added economy priced cast parts. In die casting, the metal is poured under pressure into the cavity compared to permanent moulding, due to high injection pressure in die casting, narrow sections, complex shapes and fine surface details are easily be produced. The die is made up of two parts, the stationery die or cover die which is fixed to the die casting machine and the second part called the ejector die which is moved out for the ejection of the casting, Khan (2005).

2.3.6 Centrifugal Casting

Centrifugal casting does not depend on pressure and gravity; it generates the force feed by itself using a temporary sand mould held in a rotating chamber at up to 900 N. The mould is rotated about its central axis as the metal is poured into the mould. The lighter part of the alloy that includes slag, oxides and other impurities being are separated from the metal and segregates towards the centre, as a result of application of centrifugal force on the metal as it solidifies, Khan (2005). This method of casting is often used for jewellery casting, because the centrifugal force enables the rather viscous liquid metals to run all the way via very tiny passages and into fine shapes such as leaves and petals.

2.3.7 Continuous Casting

In continuous casting, molten metal is poured continuously and the metal solidifies against the walls of the mould and it is at the same time removed from the base of the mould under a sequence which maintains a solid and liquid interface at a steady point with time. Continuous casting is the best method of casting metal on an uninterrupted basis and it is suited for large production of simple shapes which are identical in nature. Continuous casting accounts annually for over 500 million tons of steel, 20 million tons of aluminium, 1 million tons of copper, nickel, and other metals. It is notable from other solidification processes by its steady state nature and it suits best when all of its aspects function in regular non-stop manner. Continuous casting compared to other casting processes is expensive but its operating cost is lower, Thomas (2001).

2.4 Sand Casting

Sand casting also called sand moulded casting is a casting technique whereby a pattern is covered with sand to produce a cavity through which molten metal is poured to take up the shape of the mould after solidification and cooling. Sand casting is a very robust metal forming process which gives the foundry man option of casting means with an unlimited choice of metals and alloys that can be casted singly or by the millions in multiple shapes and sizes and of changing weight from a few grams to hundred of kilograms. Sand casting is the most common type of casting utilized in the world today with over 70 % of casting produced by sand casting, Ammen (1979).

2.5 Types of Sand

2.5.1 Silica Sand

Silica sands can withstand high temperature and have high refractoriness capacity. They are easily accessible, cost effective and have the advantage of being used repeatedly for multiple numbers of times in as much as the characteristic of the sand is within range of usage. Silica sand cannot be used in its natural state without the addition of binders and it is obtainable in different size and shapes. The major deficiency of silica sand is its high expansion rate and fusion with metals, Ammen (1979).

2.5.2 Natural Moulding Sand

Natural moulding sand are sands found in nature and are used in producing moulds as they are found without the addition of any additive. The organic content in this type of sand is much which affects the moulding property of the sand based on the quantity of the organic content present, Ammen (1979).

2.5.3 Synthetic Sand

Synthetic sands do not have clays in them or have very minute clay content. Synthetic sand requires appropriate quantity of clays to be added to them to be able to acquire the binding property needed for casting. Clays in sand provides the holding strength of the sand mould, its holding ability during the process of casting, as the molten metal exerts pressure on the sand poured, Ammen (1979).

2.6 Types of Sand Mould

2.6.1 Green Sand Mould

Green sand mould is the most accepted and best type of sand mould as observed by Higgins (1974). Nuhu (2008) noted that green in the term green sand denotes the presence of moisture in the moulding sand, this implies the sand is not baked or dried. It is easy and simple to make, a mixture of sand, clay and water is mixed in appropriate proportion according to the desired need.

Properties of Green-Sand Moulds

i. Green sand moulds possess adequate strength for most cast application.

ii. Green sand moulds possess excellent collapsibility.
iii. Green sand mould allows for good passage of gases (permeability).
iv. It is the cheapest in application. (www.thelibraryof manufacturing.com/type of sand/casting, accessed 13 July 2012).

2.6.2 Dry Sand Mould

In dry sand mould process, the mould is baked in an oven over the temperature range of (149- 433) ℃ for (8 – 48) hours, before the pouring of molten metal so as to dry the mould. Drying of the sand mould increases the strength of the mould and hardens its internal surfaces. Dry sand moulds are produced using organic binders rather than clays.

Properties of Dry Sand Mould

i. Dry sand moulds gives better dimensional accuracy of cast pattern than green sand.
ii. Dry sand moulds gives superior surface finish than those of green sand mould.
iii. Dry sand mould generally is limited to manufacture of medium and large castings.
iv. Distortion is more pronounced in dry sand mould.
v. The rate and speed of casting is reduced as a result of the drying time of the mould. (www.thelibraryof manufacturing.com/type of sand/casting, accessed 13 July 2012).

2.6.3 Skin-Dried Mould

Skin dried mould is comparable to that of green sand mould, but the major difference is that the mould cavity is surface dried to a depth of (12.70 – 25.40) mm for skin – dried mould. Drying is achieved with the use of torches, heating lamps and drying it in air.

Properties of Skin-Dried Moulds

i. The dimensional accuracy, surface finish comparable to that of dry - sand mould.
ii. Skin-dried mould is simpler and easier to accomplish than that of dry-sand mould.

iii. Skin-dried mould needs special bonding materials to fortify the mould cavity surface. (www.thelibraryof manufacturing.com/type of sand/casting, accessed 13 July 2012).

2.7 Moulding Materials and Properties

A large array of moulding sands is utilized in foundries with different types of sands being utilized which include moulding, backing, facing, core and parting sands. For a sand to be suitable for aluminium casting it should posses the following characteristics which includes; the ability to withstand the high pressures and temperatures of the molten metal, permit gases and air vent into it. It should stick together, pack around a pattern, fill all positions in the mould box and also stick to walls of the moulding box. The sand should also freely collapse and not fused with the metal. Moulding materials should possess the following properties in order to be suitable for foundry application which includes the following; Refractoriness, Permeability, Green Strength, Dry Strength, Hot Strength, Collapsibility, Bala and Khan (2013). Percentage composition of natural moulding sand suitable for casting is given in the range of (18 – 30) % clay, (6 – 8) % water content, Silica (70 – 75) % and 5 % (maximum) additives were necessary, (http://materialz.weelby.com/casting_2nd_half.pdf, accessed 15 July 2014).

2.7.1 Refractoriness

It is the ability of the sand to withstand the temperature of the molten metal being poured into the mould and the sand not fusing with the metal. Silica sand has the best temperature resistance capacity, Das (2010).

2.7.2 Permeability

Permeability is ability of air and gas to pass through pores. When casting, high quantity of gas and steam is generated from the environment and as a result of chemical reaction of the metal while liquefying in the mould which leads to defects in the cast that affects the physical and mechanical property of the cast, thus the need allow the gases to escape. To overcome this challenge the moulding material must be permeable. Permeability is the ability of the mould to allow adequate passage of gases and aiding in releasing the gases that are generated and trapped in the mould cavity, Das (2010).

2.7.3 Green Strength

The moulding sand that have moisture in them is defined as green sand. Green sand particles must possess the capacity to hold on together and to provide adequate holding capacity to the mould. The strength of the green sand must be sufficient enough to resist the pressure of the molten metal, hold together and not lose the shape of the mould created, Das (2010).

2.7.4 Dry Strength

The temperature of molten metal at the point of pouring is very high, the green sand around the mould cavity immediately dries up which is due to evaporation of the moisture. The sand in this state is said to be dry. The dry sand is under pressure from the hot metal and must be able to withstand the pressure and maintain the shape of the mould. The ability of the sand to this is referred to as dry strength, Das (2010).

2.7.5 Hot Strength

Hot strength temperature is the maximum temperature the mould would attain when molten metal is poured into the mould and the moisture in the sand is evaporated. The capability of the sand mould to resist and endure the temperature and pressure of the molten metal and maintain its desired pattern cavity is termed hot strength, Das (2010).

2.7.6 Collapsibility

Collapsibility is ability of the moulding sand and the solidified cast to freely separate without any resistance. After solidification and cooling, the cast contracts and shrinks, the ability of the cast to freely contracts without the interference of the moulding sand which can cause cracks and defects in the casts is essential in producing quality castings. In addition to the moulding properties stated they should be cost effective, re – usable and possess excellent thermal conductivity, Das (2010).

2.8 Ridsdale-Dietert Universal Sand Strength Machine (Hand Operated)

The Universal Sand Strength machine and accessories are used to measure Compression, Shear, Tensile and Transverse strengths of moulding materials by method of dead weight loading. The Ridsdale - Dietert Universal Sand Strength machine comprises of three (3) key components, Pusher Arm, Frame and Pendulum Weight. The pusher arm is motivated with the help of a small hand wheel which, through a gear box which moves a pinion connected in a rack on the quadrant. The pendulum weight moves on ball bearings and can be stimulated by the pusher arm through a test specimen, from a vertical position, through 90°, to a horizontal position, with addition of load on the sand mould specimen. A magnetic rider is motivated up a standard scale by the pendulum weight and shows the position were failure of the test piece occurs.

Plate 2.1: Ridsdale-Dietert Universal Sand Strength Machine, FIIRO Laboratory

The machine is placed on a rigid bench and the pusher plate equivalent to the zero '0' mark on the scale. The felt washer is set in place in the recess of the hand wheel boss and the hand wheel on the pinion shaft. The compression/shear heads is placed in the position of compression / shear compartment. The weight arm is moved a little and the metric standard 50 mm × 50 mm test specimen is placed between the compression / shear heads so that the surface of specimen upmost in the ramming operation is looking towards the right hand of the compression/shear head. The magnetic rider is positioned against the pusher plate and a minimum of 6 mm clearance is provided for between the bumper and the lug on the weight arm. The sample is loaded by rotating the hand wheel at a regular steady rate (25 kN/m^2 green compression in 10 s) until the specimen fails. The compression / shear value is read on the magnetic rider. By changing the direction of motion of the hand wheel, the weight goes back to zero and finally removing the sand from the compression / shear heads. The same procedure is applied for the Dry Compressive/Shear Strength but the sand specimen is baked in the oven at 110 °C for two hours and kept to cool prior to the tests being conducted, Ridsdale and Ridsdale (2009).

2.9 Permeability

Permeability is defined by the American Foundry Society (AFS) as that physical characteristic of moulded sand that permits gas to vent into it and it has no unit. It is calculated by determining the amount of air passage through the AFS standard 50 mm diameter × 50 mm height cylindrical specimen under a specific known pressure. To determine permeability, is to accurately ascertain the period required for 2000 ml of air at known pressure to pass through a standard AFS 50 mm diameter × 50 mm height cylindrical specimen using a permeability metre and the permeability of the sand is calculated by reading the time taken for air at a calculated pressure to pass through the test material. The body of the permeability metre is an aluminium casting made up of a water tank and base. Contained in the water tank is a balanced air drum which floats, with the weight of the tank cautiously measured and produced to sustain a steady air pressure of 100 mm during its fall, Ridsdale and Ridsdale (2009).

Plate 2.2: Ridsdale-Dietert AFS permeability Meter, FIIRO Laboratory

Permeability is calculated by the following equation:

$$P = \frac{vh}{pat} \qquad 2.1$$

where
P = permeability number
v = Volume of air in millilitres (ml)

h = Height of test specimen (cm)
p = pressure of air (cm of water)
a = Area of specimen (cm^2)
t = Time (s)

The standard technique of determining the permeability needs a volume of 2000 ml of air to be vent through the specimen approximately of height 50 mm and diameter 50 mm. By substitution method, the equation becomes

$$P = \frac{30072}{(air\ pressure) \times (Time)} \qquad 2.2$$

2.10 Moisture Content

The property of moulding sand which identifies the amount of water in the sand is referred to as moisture content. When the water present in the moulding sand is low, the strength of the sand is low and when it is high it affects the permeability of the sand negatively, thus moisture content needs to be balanced to get a good mould. The principle of drying the sample to a constant weight is one of the techniques used measuring moisture content by using a drying equipment which can be a oven, hot plate, field stove or anything appropriate for drying the wet sand specimen at a constant temperature not beyond 150 ° C and a balance which is sensitive to 0.1 percent (0.05 g) of the weight of the sand to be weighed and also the ability equivalent to the maximum moist weight (50 g) of the sand specimen to be weighed. The moisture teller is a strong machine that has a variable thermostatic control and durable thermometer for measuring the moisture content with a fan which propels air within and around the thermostat, the heated air is spread into sand specimen and leaves through a 500 mesh base of the drying pan. 50g of the sand specimen is efficiently made moisture free in a time range of 3 to 4 minutes because of the enormous velocity of air and temperature range of (65 – 149) °C of the air. The moistened specimen is measured and recorded as wet weight of sample (A). The sand in this case is moist due to the addition of controlled amount of water. The wet sample is dried to a constant weight, after which the sample is allowed to cool. The cooled sample is then weighed and recorded as the dry weight of sample (B), Ridsdale and Ridsdale (2009).

The moisture content is thus calculated by the following equation:

$$\%W = \frac{A - B}{A} \qquad 2.3$$

where:

% W = Percentage moisture content in the sample;
A = Weight of wet sample (grams); and
B = Weight of dry sample (grams)

Plate 2.3: Dietert Moisture Teller, FIIRO Laboratory

2.11 Mechanical Properties

Mechanical property is the characteristics of the material which reveals how a material behaves when a certain force is exerted onto the material. It provides the reaction of material under the influence of external force. Materials generally show different reaction when external forces are applied to them due to reasons which include chemical composition (heterogeneous or homogenous) of the material, loading type (gradual or sudden) and the structures of the material. Some materials show high ductility, the capacity of the material under stress to stretch and extend without fracture, while some exhibit high brittleness under loading and do not stretch markedly before breaking and failing when loaded. The type of method used to exert loading influences the mechanical property, whether applied gradually or suddenly or the loading is uniform or it is not uniform. Also another factor that influences the mechanical property of material is the temperature of melting, pouring and curing. These mechanical properties which mostly are physical properties determine the suitability and applications of materials in various engineering processes. They include Strength, Hardness, Ductility, Toughness, Plasticity and Resistance, Gourd (1988).

Tensile strength test involves the use of tension by the application of external force to the material to establish the load that would cause failure of the material. It determines the maximum load a material can endure before it fails. In every structure for engineering purpose, each link will undergo tension due to forces that are externally induced due to the working conditions, when the resultant of force applied equates to zero, the component or member is in equilibrium. The force impacted on a material externally in equilibrium is opposed by forces that are internally generated in the material. Hence when a bar is loaded to constant tension or compression, which is applied all over the cross section uniformly, an internal force also sets up and distributes uniformly across the bar, the bar is said to be subjected to a normal stress, the tensile strength test is measured in terms of stress (σ) which is defined as the force applied per unit area of the application of force. By applying certain amount of force/load (P) to a localised area of the material (A), the material deforms naturally and increases in length if the force applied is tensile, the material stretches and deforms which gives the stress on the material, Hearn (2000).

$$\sigma = \frac{P}{A} \qquad 2.4$$

Generally, Pascal (pa) is the unit of stress. where 1 pa = 1 N/m^2

As stated above when the material is subjected to tension due to gradual application of force/load, it deforms and stretches which causes the length of the material to increase and original material becomes strained. Strain provides the level of material deformation and is defined as the rate of change in length to the original length. Strain has no units, Hearn (2000).

$$e = \frac{\Delta L}{L_o} \qquad 2.5$$

Where
L_o = Original Length
ΔL= Change in Length

When a material is loaded it deforms and would return to its initial position if the elastic limit is not exceeded when the external force applied is removed and if the load applied is beyond the elastic limit of the material, there is permanent deformation and the material does not return to the original position. The value of the stress equivalent to the limit force is termed elastic limit. When the elastic limit of the material is exceeded the material deforms and moves to the plastic stage where the material fails to return to its original position when the load is removed. Hooke's law states that provided the elastic limit of a material is not exceeded when loaded, the stress is directly proportional to the strain.

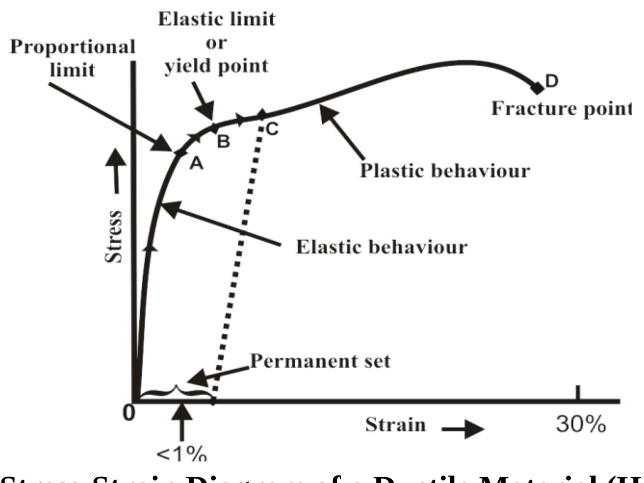

Figure 2.2: Stress-Strain Diagram of a Ductile Material (Hearn, 2000).

Ductility is a mechanical test that measures the plasticity of materials as a result of tensile stress loading. Metals that elongate and decrease in area significantly to the point of necking before fracture such as aluminium and copper are said to be ductile, while metals that fracture and fail with no necking and have negligible elongation such as cast iron are called brittle material. The methods of elongation and reduction area are used to calculate ductility. Elongation is defined as the percentage ratio of the change in length to the original length, where by the specimen original length is measured before loading and also measured after fracture by holding together the broken piece in whole position as final length and calculated in percentage

$$\Delta E = \left(\frac{L_f - L_0}{L_0}\right) 100 \qquad 2.6$$

where

L_f = final length of specimen
L_o = original length of specimen

The second method of measuring ductility is by reduction area (ΔA) of the specimen under tension where the ratio of the change in area to the original area in percentage is measured, Gourd (1988).

$$\Delta A = \left(\frac{A_0 - A_f}{A_0}\right)100 \qquad 2.7$$

where
A_o = Original Area of specimen
A_f = Final Area of specimen

The universal testing machine is the most utilized machine for tensile strength tests. It has two crossheads, one of the head is adjustable to fit the span of the specimen and the other is driven to apply tension to the test specimen. There are two types of universal testing machine, the hydraulic machine and the electromagnetic machine which are mainly differentiated by load application mechanism. Electro-mechanical machines are based on a changeable speed electric motor, a gear reduction mechanism, and one, two, or four screws that drive the crosshead in the down and up direction loading the tested material in tension or compression. Hydraulic testing machines are based on either a single or dual acting piston that drives the crosshead up or down. The machine manually operated, the orifice of a pressure compensated needle valve is adjusted to regulate the rate of loading. The machine must have the adequate capacity for testing the specimen. There are three main parameters: speed, force capacity and precision, Davis (2004).

Plate 2.4: Universal Testing Machine, FIIRO Laboratory

2.12 Hardness

Hardness is a measure of the difficulty of scratching of a material. Hardness is also a measure of resistance of a solid material to different variety of permanent shape alteration when a force is applied to the material. Macroscopic hardness is mainly characterized by strong intermolecular bonds. The reaction of solid materials when loaded is intricate, leading to different methods of measuring hardness which includes indentation hardness, rebound hardness and scratch hardness. Hardness relies essentially on plasticity, elasticity, toughness, ductility, strength, strain and viscosity, Kareem (2013).

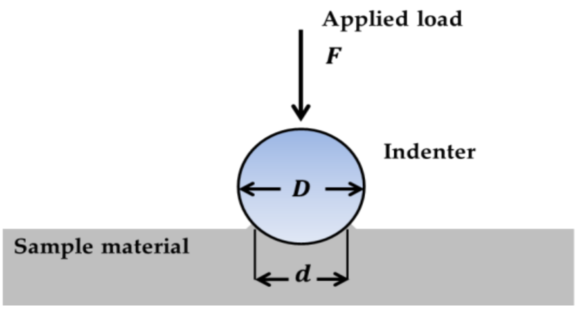

Figure 2.3: Hardness Testing

$$HB = \frac{(0.102)\,(2)\,F}{\pi D\,(D - (D^2 - d^2)^{\frac{1}{2}})} \qquad 2.8$$

where
F = Applied Force
D = Diameter of Indenter
d = Diameter of Indention

i. Indentation Hardness Tests: Indention hardness is determined by the magnitude of deformation or plastic flow of the material. The deformation is obtained by measuring the level of indentation or by calculating the area. Soft materials provide greater depth of penetration and area of indention. Rockwell and Brinell hardness tests use the principle of indention hardness. Rockwell hardness tests is evaluated by the depth created by a specific indenter due to the application of an amount of force on the test material, while Brinell hardness test is obtained by the impression produced by forcing a specific indenter into the test material under a certain amount of force for a particular duration of time. In higher automated Brinell testing systems, hardness is evaluated by the depth of impression, a technique comparable to the Rockwell test in basic principle, Chandler (1999).

ii. Rebound Principle Test: Rebound principle is dynamic in nature where the tup which is a diamond tip hammer is released from a defined elevation onto the surface of the work material. The height of rebound of the hammer is the measure of material hardness of the material. Rebound principle relies strongly on the elastic limit of the material than the work-hardening and tensile strength properties which indentation tests depends on. Scleroscope and the Leeb are based on this concept, Chandler (1999).

iii Scratch Hardness Test: In scratch hardness test, an instrument made up of a microscope, stage, sliding weight to apply loads to 3g, and a diamond point is used to evaluate hardness. The diamond is shaped in a semi circle blade like edge at an inclination of 45° which is then scratched on the work material. The work material scratch is compared with that of known standard. This method of hardness testing was developed to overcome the shortcoming of the Mohs scale by eradicating the personal judgment factor and minimizing the overlap of hardness varying values of different materials. Another type of scratch hardness testing uses a file, Chandler (1999).

2.13 Microstructure

Microstructure is a term used to describe the structure of a prepared surface of material as shown by a microscope higher than 25 × magnification. It can be generally categorized into metallic, polymeric, ceramic and composite. The physical qualities of materials like the toughness, strength, ductility, temperature behaviour, hardness and wear resistance is affected by the microstructure, which significantly affects the choice of utilization of the materials in industrial application. The metallic atoms in each crystal are arranged to either one of the seven crystal lattice systems probable for metals adequately (cubic, triclinic, hexagonal, monoclinic, rhombohedra, tetrahedral, and orthorhombic). The direction of arrangement of the matrices vary from crystal to adjoining crystal, leading to difference in the manifestation of each face viewed of the interconnected crystals on the galvanized surface. Symmetrical crystals are usually unstressed and grow in all directions equally, ASM Metals Handbook (1985).

Optical microscopy is the major means of investigating the microstructure of materials. It shows the effects of processing, heat treatment, fabrications and service conditions. In general, metallographic examination is achieved by steadily increasing the magnification until the feature required is found. Light microscopy is the most widely used method of examining microstructure and generally it is useful to approximately 1500 x. Features above 0.1 µm can be seen and the resolution illustrates the size and distribution of precipitates and second phase particles, again light microscopy also show grain size and orientation of material. On the other hand, light microscopy does not show the fine precipitates that occur during precipitation hardening and it also fails to show dislocations, but with special metallographic techniques and etching practices, the presence of dislocations can be inferred to see the fine precipitates and dislocations with the aid of a Transmission Electron Microscope, MacKenzie and Totten (2006).

Plate 2.5: Microscope, rellwin.en.made-in-china.com, accessed 5th May, 2013.

Surface preparation is the procedure whereby the test sample is cut into the required sizes and its condition made desirable for viewing under the microscope to provide a clear picture of the structure under examination. Cutting to size is achieved with a hack saw, then mounting of the specimen is done, followed by grinding of the surface and finally polishing the specimen to achieve a smooth and flat surface that is suitable for viewing under the microscope. Metallographic etching on the other hand is a technique applied to show features of metals at atomic levels. These characteristics include the shapes, grain boundaries, precipitates and foreign bodies. By investigating the character and distribution of the various features, metallurgists are able to predict and explain physical nature and failures of a given sample of metal.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The following equipment and materials were used for sand, casting and testing processes;

3.1.1 Sand Testing Equipment

i. Ridsdale - Dietert universal sand testing machine

ii. Moisture teller

iii. Permeability meter

iv. Sand rammer

3.1.2 Casting Process Equipment

i. Rammers
ii. Trowels
iii. Brush
iv. Hand saw
v. Measuring tapes
vi. Jack plane
vii. Wooden pattern
viii. Moulding box
ix. Silica sand
x. Aluminium alloy

3.1.3 Tensile Test Equipment

i. Huggenberger universal testing machine
ii. Micrometer screw gauge
iii. Venire calliper
iv. Dividers
v. Gauge mark
vi. Jig
vii. standard sand cast aluminium alloy test piece

3.1.4 Hardness Test Equipments

i. Brinell hardness test machine.

ii. Gauge.

3.1.5 Metallographic Test Equipments

i. Hack saw.
ii. Rotary pre-gradner and B.G – 20 Belt grinder.
iii. Binocular metallurgical microscope.
iv. Hydrofluoric acid.

3.2 Methodology

3.2.1 Sand Location

The sand deposit required for this research work was sourced locally, from Zungeru, Wuya, Tungan Mallam, Tagwai Dam and Gidan Mangoro villages in Niger State as seen in Figure 3.1. The selection of locations was done putting into consideration the geographical spread in the state (all the three senatorial zones) in consultation with some local blacksmith.

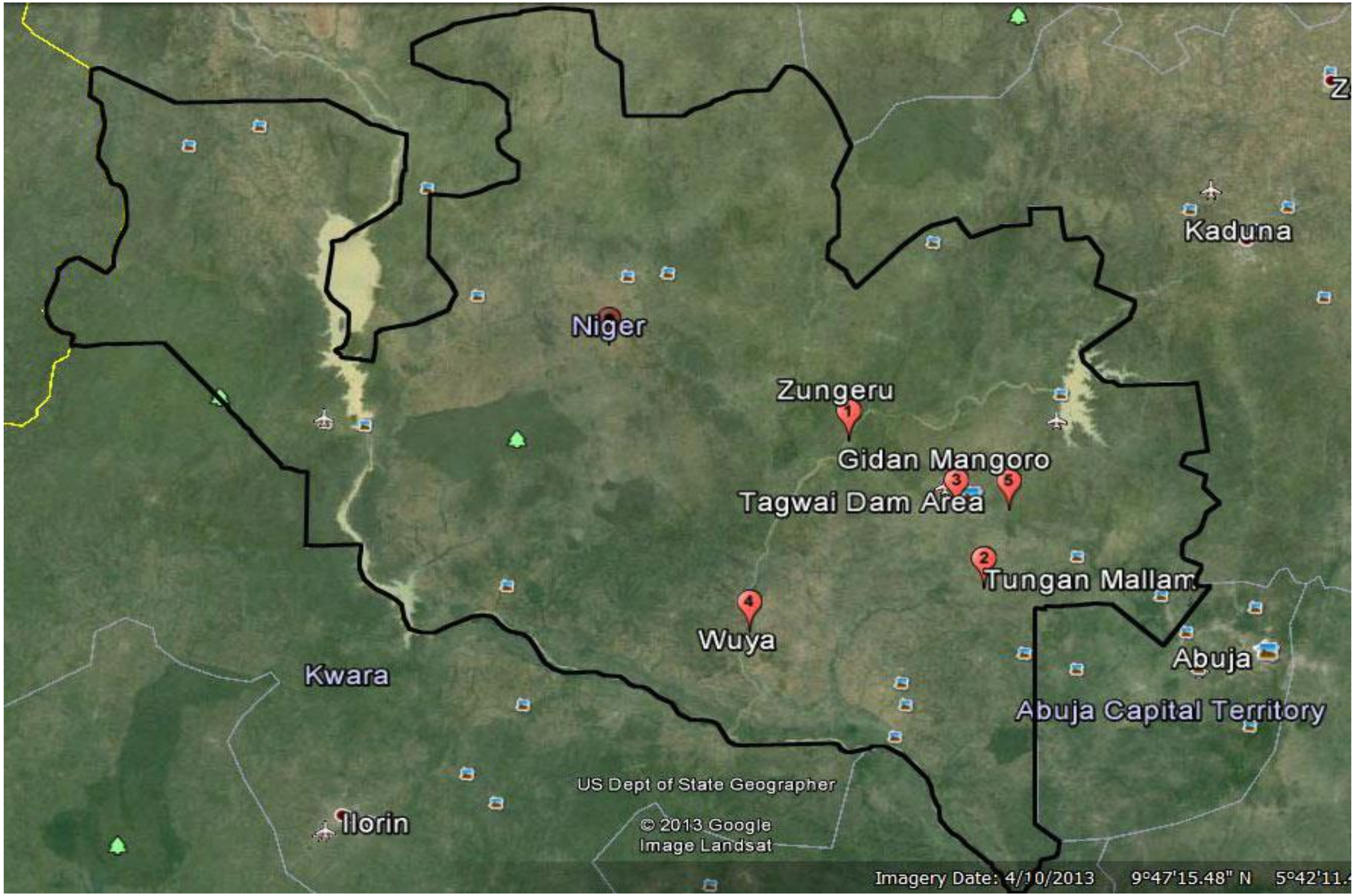

Figure3.1: Map of Niger State Showing the Different Locations of the Sand Deposit, Google Earth Viewed 21st January, 2014

3.2.2 Sand Testing

Each of the test specimens from the sand was subjected to the relevant sand mould test such as Green Compressive Strength, Green Shear Strength, Dry Compressive Strength, Dry Shear Strength and Permeability test. All the sand tests were carried out with the Ridsdale – Dietert universal sand strength machine at the Federal Institute of Industrial Research Oshodi (FIIRO). The test samples were prepared in accordance with the American Foundry Society (AFS) specification for the preparation of moulding sand test samples using Ridsdale - Diertert sand rammer to produce a (50 mm diameter by 50 mm height) specimen. For the purpose of this research the sieve size of 750 microns was used in accordance with the standard set for minimum sand particle size by American Foundry society (AFS). Test sample specimens were prepared for laboratory experiments from various moulding sand mixtures.

3.2.2 Sample Preparation

The sand to be tested was put in the sand crusher and ground to fine particle sizes, after which it was sieved using the 750 microns sieve size according to the American Foundry Society (AFS) standard for sand casting purpose The quantity of sand and water (1 kg) in total were measured using percentage weight method based on the varying proportion of sand and water needed for each of five different sand samples and the mixture was then thoroughly mixed to achieve even mixing of sand and water using a laboratory mixer. After thoroughly mixed, the mixture was discharged from the mixer through the discharge opening at the bottom of the mixer. 150 g of the moist sand specimen was weigh-balanced and poured into the specimen tube. The tube with the sand sample inside it was positioned in the sand rammer and then rammed with three drops of the standard weight of 6.6 kg to produce a 50 mm diameter and 50 mm height sand specimen. The specimen was ejected from the tube with the aid of specimen extractor. This procedure was utilized for the preparation of the standard test specimens for the varying water content compositions by weight of the water at 6 %, 7 %, 8 %, 9 % and 10 % for the moulding sand mixtures. The equipment used for sand testing were all Ridsdale – Dietert equipment which includes Universal Sand Testing Machine to measure compressive and shear strength, the Moisture Teller to calculate moisture present in the sand, Permeability Metre to calculate the permeability of the sand, Sand Rammer to measure the compactibilty of the sand specimen and to produce the 50 mm diameter × 50 mm height sand specimen and Sand Crusher to crush and grind the soil to smooth and fine sand particles.

Plate 3.1: 50 mm × 50 mm Sand Specimen

Plate 3.2: Baked 50 mm × 50 mm Sand Specimen

3.2.3 Casting Process

For the purpose of this research the aluminium utilized is an alloy and not pure aluminium. Sand casting was utilized for the research and the pouring aluminium temperature of 680 °C from the furnace was used. The following processes were involved in the casting process during the research:

3.2.3.1 Pattern Making and Moulding Process

Two types of pattern were used for the casting, a rectangular pattern of length 150 mm, breadth 30 mm and thickness 6 mm, with a cylindrical pattern of height 150 mm and radius of 15 mm. A mahogany wood was used to produce the patterns with the dimensions as stated. The rectangular pattern was used to produce cast for hardness tests and microstructure analysis, while the cylindrical pattern was used to produce cast for tensile test. The patterns were cut to dimension using a hand hack saw and smoothened using a jack plane. A small allowance was allowed in the vertical surface to help in the quick and easy removal of the aluminium cast from the sand mould during moulding process. There are different types of moulding processes as stated earlier, the green sand mould, dry sand mould and skin – dry mould. For the purpose of this research green sand mould was used because green sand mould has excellent bonding capacity which is provided by clay and water present in the sand mould and also green sand mould easily retains the shape and the impression imparted on to it under pressure. The sands utilized were fully natural without the addition of bentonite and other additives because the sand samples were observed to have high clay content to act as binder. The cope and drag part of the mould was produced using wood. Both cope and drag were filled with sand and rammed. The pattern was placed in between the cope and drag and rammed around. As the sand is packed, it develops strength and becomes rigid within the flask. Both cope and drag are moulded in the same way, but the cope was provided with a sprue. The gating-system parts of the mould cavity were also made to allow for simple entry of the molten metal. Cope and drag halved, the mould was made and pattern withdrawn, the core was set into the mould cavity to form the internal surfaces of the casting. The cope and drag were closed. The cope was weighted down and clamped to the drag to prevent it from floating when the aluminium metal is poured.

3.2.3.2 Melting of Aluminium Alloy

Melting of aluminium alloy was done in a fuel-fired crucible furnace, when the alloy was sufficiently molten in liquid state, the mixture was thoroughly mixed and slag removed. The melting temperature of aluminium is 650 ℃ while the pouring temperature is 680 ℃ . Melting of the aluminium alloy took an hour and fifteen minutes, because if it is poured at melting temperature, aluminium solidifies quickly and there would not be uniform composition of the mould.

3.2.3.3 Pouring of Molten Aluminium

Pouring was done using a ladle designed for the purpose, the ladle was used to scoop the molten metal and taken to the mould. The metal was poured into the mould cavity through the gating system that was provided for while preparing the mould. The cavity of the gating system is done to ensure easy and free flow of molten metal into the mould, to prevent erosion, turbulence and abrasion of the mould walls which can affect the shape of the cast, and even introduce foreign bodies into the final cast as a result of sand particles that would have mixed with the molten metal while pouring.

Plate 3.3: Pouring of Molten Aluminium Metal into the Mould

3.2.3.4 Solidification and Cooling of Cast

The molten aluminium is poured directly into the sand cavity through the gating system. The poured aluminium is allowed to solidify and cool with the cast produced taking the shape of the core produced by the pattern.

Plate 3.4: Knock Out of Aluminium Cast

3.3 Tensile Test Procedure

Mechanical tests were carried out on the aluminium cast produced to determine its mechanical strength. Tensile test was carried out using the Universal Testing Machine at the Strength and Materials Laboratory, Ahmadu Bello University, Zaria. The aluminium cast was machined to ASTM E-8 standard size in dimension for tensile strength testing of gauge length of 30 mm, Ayoola et.al (2012). The test piece was inserted into the jaws of the universal testing machine and gripped firmly. Tensile force was then applied gradually using 5 kN load, the loading was applied continually, at steady rate of 5 kN until the aluminium cast fractures and fails. The graph of the loading was traced by the scriber which is wrapped round a drum attached to the universal testing machine. The maximum load before fracture was read and recorded. The fractured test piece was removed completely from the universal testing machine, the broken parts are placed back together to measure the increase in length as well as the necking diameter to allow for the calculation of elongation and reduction in area.

Plate 3.5: Alumiunm Cast Samples after Tensile Tests

3.4 Hardness Test Procedure

Hardness test is carried out to ascertain the level or degree of resistance of material to wear, cutting, crushing etc. when the material is under loading. Hardness also is used to identify how material deforms under localised loading. The lower the hardness number, the greater the resistance to deformation, although it also depends on the loading and the methods applied when applying the load. Hardness test was carried out at the foundry laboratory in FIIRO, Oshodi, using a Brinnel Hardness testing machine. The Brinnel Hardness test utilises a steel ball which is used to press on the material under testing under certain load conditions, thereby leaving an indention which is measured using a calliper to calculate the hardness of the material. The aluminium specimen was placed in position under the testing machine. The test was carried out using a 10 mm diameter steel ball. The test piece was then brought into contact with the steel ball and the gradual application of force was applied. The loading was done until a clear indention was made. After the indention had been made, the load was removed and the steel ball removed from the top of the aluminium cast test piece leaving an indention on the cast. The diameter of the indention was measured using a venire calliper and the force applied was recorded.

Plate 3.6: Aluminium Cast Samples Showing Indention of Hardness Tests

3.5 Metallographic Test Procedure

The microstructure or metallographic test was carried out at the Metallurgical and Materials Engineering Laboratory of University of Lagos. The processes involved in metallographic test include specimen preparation, grinding, polishing, etching and observation under the microscope. The cast aluminium test piece was cut to section using a hack saw. The next procedure was the grinding of the aluminium test specimen to get a good flat surface after filing the specimen to wipe away the hack saw marks on it with a file, the specimen was then washed thoroughly with water to remove all particles and grit that remained stuck to the specimen after filing. Grinding was done using the B.G-20 Belt grinder and utilizing finer grades abrasive papers to ensure better surface finish. Water was used as lubricant and rubbing of the specimen was to and fro in a direction that was at 90° to the direction of the scratches left by the filling. The first abrasive paper used had the coarsest surface of all the grade of abrasive paper, it was rubbed to and fro until scratches from the filling surface was removed. The specimen was then washed with water to remove all the grit. The process was repeated with a finer grade after turning the specimen through 90° until the scratches of the first the coarser abrasive paper were removed, the specimen was washed again to remove all the grits. The process was repeated with finer abrasive papers until a very fine surface was produced. These grinding of the specimen by successive finer surface grade paper were to allow for the finest surface finish to be achieved by replacing coarser scratches with finer ones. The aluminium test specimen was then washed in warm water, rinsed thoroughly and allowed to dry. Etching is a process that is used to improve the visibility. Etching was done using a chemical reagent of 0.5% hydrofluoric acid. The aluminium test specimen was immersed in the hydrofluoric acid and left for twenty seconds and then removed. After etching and drying up of the aluminium test specimen, the specimen was then placed in position under the microscope, the positioning of the specimen was done in such a way that it was placed perpendicular to optical axis of the microscope. The image of the micro structure of the specimen was seen through the eye piece which is designed to allow for high magnification of very minute details of the test specimen which include grain boundaries that have been etched to produce grooves, also precipitate particles and inclusions were revealed. The image produced by the microscope under high magnification was viewed.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

The Sand test, Mechanical tests and Metallographic tests results respectively of the five different sands are presented.

4.1.1 Sand Test Results and Analysis

The test results of the five sands tested which includes Permeability, Green Compressive Strength, Green Shear Strength, Dry Compressive Strength, Dry Shear Strength, Compactibility and Moisture Content percentage results are shown Tables (4.1 – 4.5) with the percentage water content increased by single percentage from 6% - 10%.

4.1.1.1 Tungan Mallam Sand Test Results

The sand test results of Tungan Mallam sand is provided in Table 4.1

Table 4.1 Sand Test Result of Tungan Mallam

Water (%)	6	7	8	9	10
Permeability	96.85	96.42	96.11	90.83	87.55
Green Compressive Strength (kN/m^2)	22.17	21.71	21.33	16.67	12.50
Green Shear Strength (kN/m^2)	4.17	5.15	5.83	6.97	8.00
Dry Compressive Strength (kN/m^2)	85.00	162.16	232.50	318.92	400.00
Dry Shear Strength (kN/m^2)	50.00	66.77	77.50	93.87	110.00
Compactability (%)	42.86	42.74	42.64	42.53	42.42
Moisture (%)	6.00	7.00	8.00	10.00	10.00

In Table 4.1, with the percentage water content increased by single percentage from 6 % to 10 %, the Permeability of Tungan Mallam sand generally decreased from 96.85 to 87.55, the Green Compressive Strength from the results shows that there is a decrease in strength with the addition of water as the Green Compressive Strength reduced from 22.17 kN/m^2 to 12.50 kN/m^2. The Green Shear Strength increased from 4.17 kN/m^2 when the water content was 6 % to 8.00 kN/m^2 when the water content was 10 %. Also increase in percentage water content led to an increase in both Dry Compressive and Dry Shear Strengths respectively with Dry Compressive Strength increasing from 85 kN/m^2 at 6 % water content to 400.00 kN/m^2 at 10 % water content while the Dry Shear Strength increased from 50.00 kN/m^2 to 110.00 kN/m^2 for increase in water content from 6 % to 10 %. The result shows that the Compactibility of the sand decreased with increase in content of water from 42.86 % to 42.42 %. The Compactibilty of Tungan Mallam sand showed the least difference of all the sand tested and the Moisture content showed ann increase as expected with the increase in water content from 6 % to 10 %.

4.1.1.2 Zungeru Sand Test Results

The sand test results of Zungeru sand is provided in Table 4.2

Table 4.2 Sand Test Result of Zungeru

Water (%)	6	7	8	9	10
Permeability	75.14	73.33	72.29	72.10	72.08
Green Compressive Strength (kN/m^2)	116.67	99.52	83.30	90.00	96.83
Green Shear Strength (kN/m^2)	59.00	40.00	21.83	26.06	30.67
Dry Compressive Strength (kN/m^2)	402.50	389.19	367.50	424.32	470.00
Dry Shear Strength (kN/m^2)	102.20	106.25	110.00	122.92	130.00
Compactability (%)	44.12	46.09	48.44	48.50	48.57
Moisture (%)	8	9	10	10	10

The result of the tests carried on Zungeru sand is shown in Table 4.2, Permeability, Green Compressive Strength and Green Shear Strength respectively of the Zungeru sand just like that of Tungan Mallam showed a decreasing effect with increase in water content as the permeability decreased from 75.14 to 72.08 and the Green Compressive Strength reduced from 116.67 kN/m^2 to 96.83 kN/m^2, while the Green Shear Strength decreased from 59.00 kN/m^2 to 30.67 kN/m^2 respectively. The Dry Compressive Strength, Dry Shear Strength and Compactibility increased with increase in water content as the Dry Compressive Strength from 402.50 kN/m^2 to 470.00 kN/m^2, while the Dry Shear Strength increased from 102.20 kN/m^2 to 130.00 kN/m^2 and the Compactibility of Zungeru sand improved from 44.12 % to 48.57 %. There was an increasing effect with the moisture content increasing from 8 % to 10 % for water content tests between 6 % and 10 %.

4.1.1.3 Gidan Mangoro Sand Test Results

The sand test results of Gidan Mangoro sand is provided in Table 4.3

Table 4.3 Sand Test Result of Gidan Mangoro

Water (%)	6	7	8	9	10
Permeability	84.16	82.50	82.25	80.00	78.70
Green Compressive Strength (kN/m^2)	48.67	40.11	32.50	33.81	35.33
Green Shear Strength (kN/m^2)	8.50	9.09	9.50	9.71	9.83
Dry Compressive Strength (kN/m^2)	200.00	432.43	>650	600	552
Dry Shear Strength (kN/m^2)	37.50	120.83	200.00	375.00	552.00
Compactability (%)	44.44	47.83	52.19	46.09	41.94
Moisture (%)	6	8	10.00	10.00	10.00

Table 4.3 provide the sand test result for Gidan Mangoro. It shows that Gidan Mangoro sand exhibited decrease in Permeability when the amount of water in the sand is increased, the Permeability reduced from 84.16 to 78.70 when the water percentage was increased from 6 % to 10 %. Again the Green Compressive Strength reduced with increase in water as it reduced from 48.67 kN/m^2 to 35.33 kN/m^2 between 6 % and 10 % water content. The Green Shear Strength increased marginally when the water content was varied between 6 % and 10 % from 8.5 kN/m^2 to 9.83 kN/m^2. The result of the Dry Compressive Strength of Gidan Mangoro sand indicates that with increase in water content there is a corresponding increase in the strength of the sand in the dry state generally although it showed the greatest strength at 8% water content and subsequently reduced at 10 % water content, the Dry Compressive Strength increased from 200.00 kN/m^2 at 6 % to 552 kN/m^2 at 10 % and the Dry Shear Strength increased from 37.50 kN/m^2 to 552.00 kN/m^2. For the Compactibility of Gidan Mangoro sand, the result indicates that there is a reduction in Compactibiltiy with increase in water content from 44.44 % to 41.94 % and finally the result shows that there is an increase in moisture in the sand as a result of increase in water content from 8 % to 10 %.

4.1.1.4 Tagwai Dam Area Sand Test Results

The sand test results of Tagwai Dam Area sand is provided in Table 4.4

Table 4.4 Sand Test Result of Tagwai Dam Area

Water (%)	6	7	8	9	10
Permeability	75.92	74.58	74.22	74.44	74.82
Green Compressive Strength (kN/m^2)	108.00	91.91	78.67	77.14	76.00
Green Shear Strength (kN/m^2)	22.67	23.30	24.00	22.42	21.67
Dry Compressive Strength (kN/m^2)	528.50	594.60	>650.00	>650.00	>650.00
Dry Shear Strength (kN/m^2)	106.50	137.50	161.50	177.08	185.00
Compactability (%)	54.48	54.61	54.84	55.11	56.00
Moisture (%)	6.00	7.00	8.00	10.00	12.00

The result shown above in Table 4.4 gives the Permeability of Tagwai Dam area sand as 75.92 at 6 % decreasing to 74.82 at 10 %. Also the Green Compressive Strength of Tagwai Dam area shows a decreasing effect on the compressive strength of sand in green state, the Green Compressive Strength decreased from 108.00 kN/m^2 to 76.00 kN/m^2 for increase in water content to 10 %. The Green Shear Strength also reduced from 22.67 kN/m^2 to 21.67 kN/m^2 with increase in percentage water content in the sand. The Dry Compressive Strength of the sand showed that Tagwai Dam area sand had the best Dry Compressive Strength. It shows an increase in strength from 528.50 kN/m^2 to >650 kN/m^2 (650 kN/m^2 is the highest calibration on the scale of the machine). The Dry Shear Strength also increased with percentage water content increase from 6 % to 10 % in the sand as Dry Strength increased from 106.50 kN/m^2 to 185 kN/m^2. Also the relationship between the Compactibility of the sand in percentage with percentage in water content shows that with increase in water there is a corresponding increase in Compactibilty of the sand from

54.48 % to 56.00 %. Again the moisture content increased with increase in water content from 6 % to 12 %.

4.1.1.5 Wuya Sand Test Results

The sand test results of Wuya sand is provided in Table 4.5

Table 4.5 Sand Test Result of Wuya

Water (%)	6	7	8	9	10
Permeability	79.56	77.33	75.35	77.92	77.83
Green Compressive Strength (kN/m^2)	111.50	114.29	119.90	110.00	102.00
Green Shear Strength (kN/m^2)	41.17	40.05	39.75	37.25	36.00
Dry Compressive Strength (kN/m^2)	410.00	372.97	335.00	416.22	485.00
Dry Shear Strength (kN/m^2)	80.00	97.17	114.00	131.25	145.00
Compactability (%)	45.71	46.96	48.74	49.95	51.72
Moisture (%)	10.00	10.00	12.00	14.00	16.00

Table 4.5 shows the Permeability fluctuating by decreasing from 79.56 with addition of water then increasing again to 77.83. Both Green Compressive and Green Shear Strengths decreased with the addition of water to the sand as the Compressive Strength decreased from 111.50 kN/m^2 to 102.00 kN/m^2 and the Shear Strength decreased from 41.17 kN/m^2 to 36.00 kN/m^2 with the addition of water up to 10 % respectively. Increase in percentage water content in the sand also led to the corresponding increase in the Dry Compressive and Dry Shear Strengths respectively, as the Dry Compressive Strength increased from 410 kN/m^2 to 485.00 kN/m^2 and a corresponding increase in Dry Shear Strength from 80.00 kN/m^2 to 145.00 kN/m^2 respectively. There is also an increase in percentage Compactibility of Wuya sand with increase in water content to the sand as it increased

from 45.71 % to 51.72 % when the water in the sand was increased. Finally, the percentage Moisture content in Wuya sand like all the sand tested indicated increase in moisture retention with increase in the amount of water in the sand and Wuya sand exhibited the highest moisture retaining capacity of 10 % to 16 % with increase in the percentage of water.

4.2 Variation of Sand Moulding Properties with Increase in Water Content

The variation of the parameters measured with increase in water content and the effect of the water content increase on the moulding properties of the five sands tested which helps in identifying and optimizing the best sand water ratio combination is shown Figures (4.1 – 4.7)

4.2.1 Variation of Permeability with Increase in Water Content

Variation of permeability with increase in water content is provided in figure 4.1

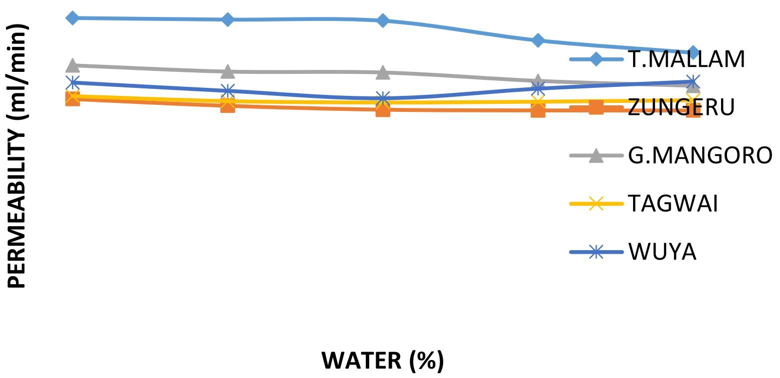

Figure 4.1: Variation of Permeability with Water Content

Figure 4.1 provides the relationship between Permeability and water content on natural moulding sand tested. Increasing the percentage water content, the green Permeability decreased for all the sand deposits, Tungan Mallam sand from 96.85 to 87.55, Zungeru sand from 75.14 to 72.08, Gidan Mangoro from 84.16 to 78.70, Tagwai Dam area sand from 75.92 to 74.82 and Wuya sand from 79.56 to 75.35. The decreasing permeability could be attributed to the fact that water acts as obstacle to the pores in the sand thereby preventing the free passage of air through the sand. Increasing the water leads to the excess water filling the pores in the sand, which bring about a corresponding reduction in the Permeability value of the sands. This can be explained by the fact the clay particles generally which acts as binder and are sticky and highly plastic easily block the pores and prevent free passage of air which is the measure of Permeability.

4.2.2 Variation of Green Compressive Strength with Increase in Water Content

Variation of Green Compressive Strength with increase in water content is provided in figure 4.2

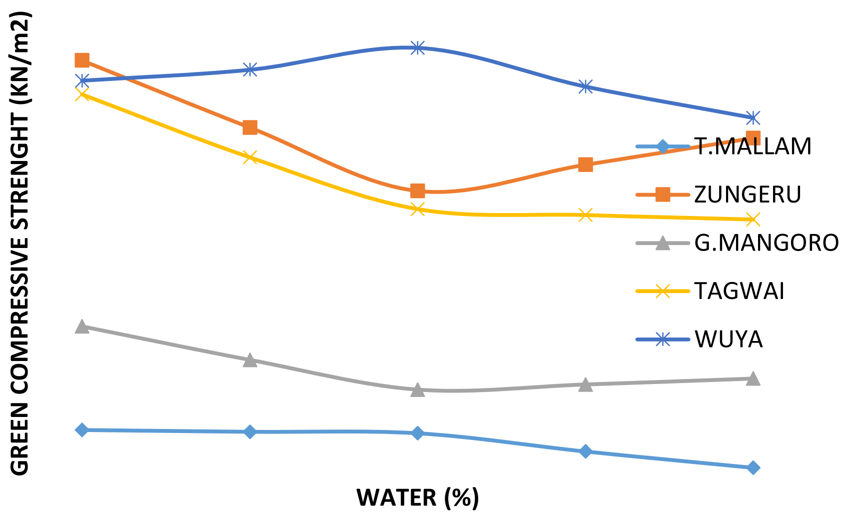

Figure 4.2: Variation of Green Compressive Strength with Water Content

The relationship between water content and Green Compressive Strength is provided in Figure 4.2. The Green Compressive Strength is expected to rise with increase moisture content that is water content up to the temper point. Temper point is the point at which increase in water content stops in corresponding increase in Green Compressive Strength, beyond temper point rise in water content leads to decrease Green Compressive Strength. For all the sand tested, they all gave the highest compressive value at 6 % water content and showed decreasing values for the 7 %, 8 %, 9 % and 10 % water content respectively as the water content was increased in percentage, although the Green Compressive Strength of Zungeru and Gidan Mangoro sand decreased generally they gave their minimum values at 8 % and then increased at 9 % and 10 % but lower than 6 % and 7 % in general. The Green Compressive Strength of Tungan Mallam sand decreased from 22.17 kN/m^2 to 12.50 kN/m^2, while that of Zungeru sand decreased from 116.67 kN/m^2 to 96.83 kN/m^2, also the Green Compressive Strength of Gidan Mangoro sand decreased from 48.67 kN/m^2 to 35.33 kN/m^2, also the Green Compressive Strength of Tagwai Dam area sand decreased from 108.00 kN/m^2 to 76.00 kN/m^2. And finally the Green Compressive Strength of Wuya sand decreased from 111.50 kN/m^2 to 102.50 kN/m^2. Clearly increase in water content led to general reduction in Green Compressive Strength regardless of whether it alternated or not. Reduction in Green Compressive Strength as a result of addition of water content indicates the presence of surplus moisture in the sand mould. It is clear therefore, that in order to maintain adequate Green Compressive Strength and plasticity of sand the percentage of added water should be kept moderate. Wuya sand showed the greatest Green Compressive Strength in general while Tungan Mallam sand had the least Green Compressive Strength.

4.2.3 Variation of Dry Compressive Strength with Increase in Water Content

Variation of Dry Compressive Strength with increase in water content is provided in figure 4.3

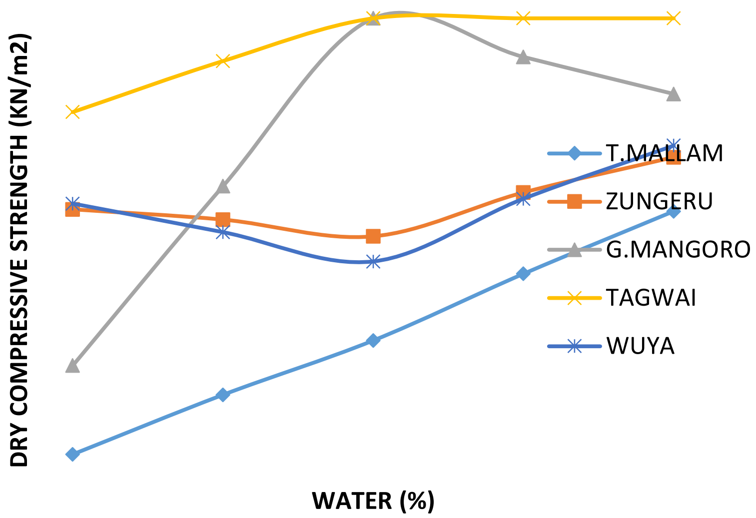

Figure 4.3: Variation of Dry Compressive Strength with Water Content

The Dry Compression Strength rises when water content for all the five sand tested were increased as shown in Figure 4.3. The Dry Compressive Strength of Tungan Mallam increased from 85.00 kN/m^2 to 400.00 kN/m^2 for increase in water content from 6 % to 10 %. The Dry Compressive Strength of Zungeru sand at 6 % was 402.50 kN/m^2 and subsequently increased to 470.00 kN/m^2 at 10 % water content. While the Dry Compressive Strength of Gidan Mangoro sand increased from 200.00 kN/m^2 to ˃650 kN/m^2 (650.00 kN/m^2 is the highest calibration of the testing machine) at 8 % water content respectively, it then decreased to 552.00 kN/m^2 at 10 % water content. The Dry Compressive Strength of Tagwai Dam area sand when the water content was increased from 6 % to 10 % also increased from 528.50 kN/m^2 to 594.60 kN/m^2. Finally the Dry Compressive Strength of Wuya sand also increased when the water content was increased from 6% to 10% from 410.00kN/m^2 to 485.00kN/m^2. Increase in Dry Compressive Strength with addition of water indicates the sand can take in additional moisture. Dry Compressive Strength provides the limits the sand in dry state indicates the pressure intensity the molten metal can endure while solidification is taking place in the mould. This property makes large castings using dry sands to be more suiting. Tagwai Dam area sand gave the best result for Dry Compressive Strength while that of Tungan Mallam gave the lowest result.

4.2.4 Variation of Moisture Content Strength with Increase in Water Content

Variation of moisture content with increase in water content is provided in figure 4.4

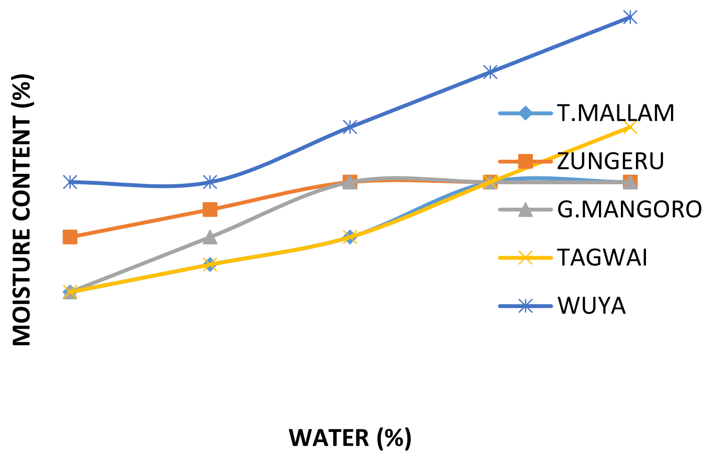

Figure 4.4: Variation of Moisture Content with Water Content

The Moisture Content increases with increase in water content. The Moisture Content of Tungan Mallam sand increased from 6 % to 10 % when the water content was increased from 6 % to 10 % respectively. Also the Moisture Content increased from 6 % to10 % for water content of 6 % to 10 % for Zungeru sand. While the Moisture Content for Gidan Mongoro sand increased from 6 % to 10 % respectively. The Moisture Content of Tagwai Dam area sand also showed an increment from 6 % to 12 % when water content was increased from 6 % to 10 %. Finally the result of Wuya sand also showed consistency with those of the other sand tested by increasing from 10 % to 16 % for increase in water content from 6 % to 10 % water content respectively. The increase in Moisture Content with the increase water content can be explained by the fact that as the water is mixed with the sand, the water is absorbed by the sand and also occupy the pores present in the sand, the more water is added the greater the Moisture Content in the sand until it reaches its saturation point when the sand can no longer be able to absorb more water and thus it floats. Sand with high clay content tends to reach their limit earlier than coarser sand because of their finer particle nature and higher plasticity. This is consistent with the observations by Ahmed and Nuhu (2008) 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, additional water is held up as free water thereby accounting for the continuous increase in Moisture Content observed in Figure4.4

4.2.5 Variation of Conpactibility with Increase in Water Content

Variation of Compactibility with increase in water content is provided in figure 4.5

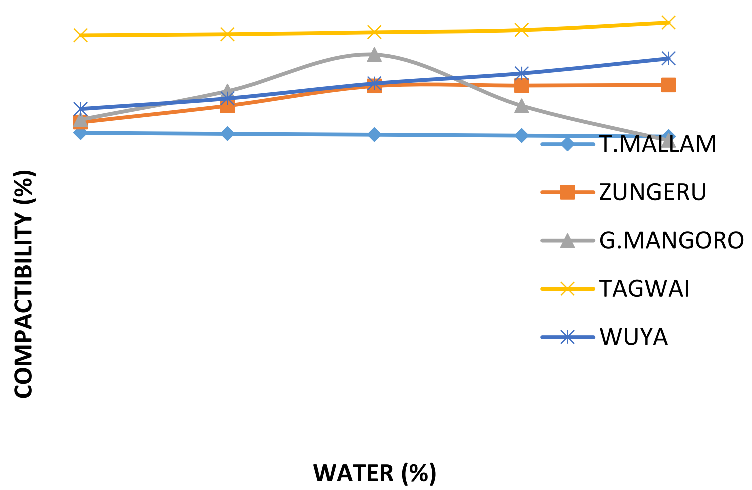

Figure 4.5: Variation of Compactabilty with Water Content

Compactability basically shows the level of temper and relative wetness of a mixture of moulding sand. It gives a value in percentage which is applied in verifying sand reliability for automation and quality control. Compactability calculates the percentage reduction in height of loose mass of sand under the effect of controlled compaction. Compactability has direct relationship with the capability and ability of a moulding sand to mould uniformly which is an important aspect in the production of near perfect casting products. The right analysis of Compactibility can help in the reduction of movement of the wall of the mould which is a major source of shrinkage. Compactibility is measured as a percentage and it provides the relationship that exists between moulding sand preparation, transportation, sand compaction characteristics and composition through the mould cycle. Figure 4.5 shows Compactability increasing with increase in water content for Zungeru, Tagwai Dam Area and Wuya sand. The Compactability of Gidan Mangoro sand increased between 6 % and 8 %, then it decreased for 9 % and 10 % water content, while that of Tungan Mallam sand decreased generally with increase in water content. Compactability for Zungeru sand increased from 44.12 % to 48.52 % when water content was increased from 6 % to 10 %. It also increased for the test conducted on Tagwai Dam area sand from 54.48 % to 56.00 % for water content respectively. Furthermore the test carried out on Wuya sand also showed increase in Compactability from 45.71 % to 51.72 % with water content, while the Compactabilty of Gidan Mangoro sand fluctuated by first increasing and subsequently decreasing from 44.44 % when water content was 6 % to 46.09 % when water content was increased to 9 % and finally decreased to when water content was increased to 10 %. Finally the Compactability of Tungan Mallam sand decreased with increase in water content from 42.86 % to 42.42 % with increase in water content from 6 % to 10 %. Tagwai Dam area sand had the best Compactibility while Tungan Mallam sand had the least Compactibility of all the sand tested.

4.2.6 Variation of Dry Shear Strength with Increase in Water Content

Variation of Dry Shear Strength with increase in water content is provided in figure 4.6

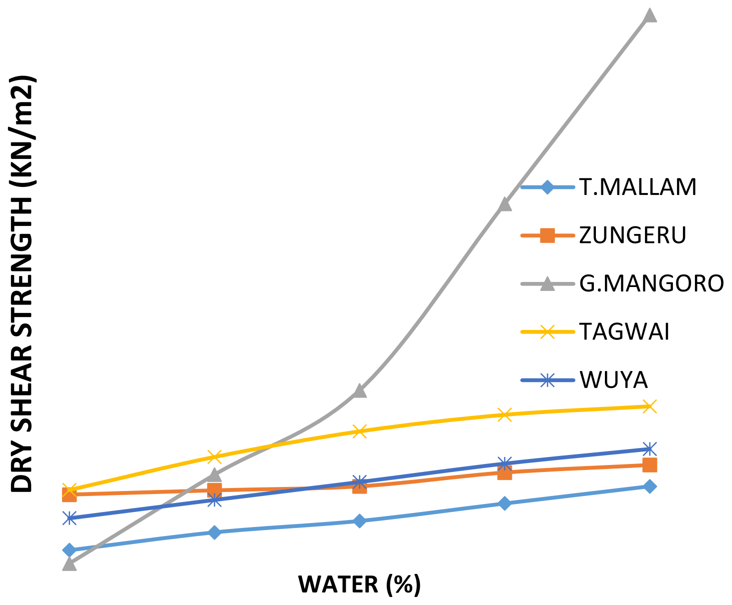

Figure 4.6: Variation of Dry Shear Strength with Water Content

Figure 4.6 shows Dry Shear Strength increased with increase in water content for all the sand tested. Dry Shear Strength increased for Tungan Mallam sand from 50.00 kN/m^2 to 110.00 kN/m^2 for water content increase from 6 % to 10 %. The result of the Dry Shear Strength also increased for Zungeru sand from 102.20 kN/m^2 to 130.00 kN/m^2, also the Dry Shear Strength of Gidan Mangoro sand increased from 37.50 kN/m^2 to 552.00 kN/m^2 with increase in water content from 6 % to10 %. Dry Shear also increased for Tagwai Dam area sand from 106.50 kN/m^2 to 185.00 kN/m^2 and finally Wuya sand also showed increase in Dry Shear Strength from 80.00 kN/m^2 to 145.00 kN/m^2 when the water content was increased from 6 % to 10 %.

4.2.7 Variation of Green Compressive Strength with Increase in Water Content

Variation of Green Shear Strength with increase in water content is provided in figure 4.7

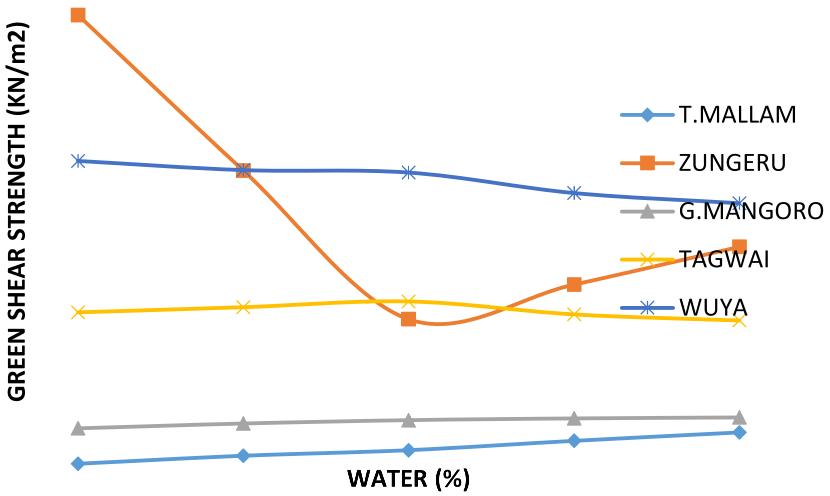

Figure 4.7: Variation of Green Shear Strength with Water Content

Green Shear Strength increased with increase in water content for Tungan Mallam sand from 4.17 kN/m^2 to 8.00 kN/m^2 when the water content was increased from 6 % to 10 %. The Green Shear Strength of Zungeru sand decreased from 59.00 kN/m^2 for 6 % water content to 30.67 kN/m^2 at 10 % water conent. While Gidan Mangoro sand Green Shear Strength increased from 8.50 kN/m^2 to 9.83 kN/m^2 for water content percentage increase from 6 % to 10 %. Also the Green Shear Strength of Tagwai Dam area sand fluctuated by increasing from 22.67 kN/m^2 when the water content was increased initially but subsequently decreasing with increase in water content to 21.67 kN/m^2. Finally, the Green Shear Strength of Wuya sand decreased from 41.17 kN/m^2 to 36.00 kN/m^2 with increase in water content from 6 % to 10 % as seen in Figure 4.7. Tungan Mallam sand exhibited the least Green Shear Strength in general while Wuya sand gave the best and most consistent Green Shear Strength of the all the sand tested.

4.3 Evaluation of the Sand for Metal Casting

In other to use a particular type of sand for casting and the type of metal that can be cast in it to produce a good cast, it must meet certain conditions by comparing it with that of standard value. The satisfactory mould property ranges for sand casting is provided in Table 4.6.

Table 4.6 Satisfactory Mould Property Ranges for Sand Castings

Metal	Green Compressive Strength (kN/m^2)	Dry Compressive Strength (kN/m^2)	Permeability
Heavy Steel	70-85	1000-2000	130-300
Light Steel	70-85	400-1000	125-200
Heavy Grey Iron	70-105	350-800	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

(Ademoh and Ahmed, 2009)

To determine the adequacy of the five locally sourced sands from Niger state, Tungan Mallam, Zungeru, Gidan Mangoro, Tagwai Dam area and Wuya, the values of their results was compared with that of standard values in Table 4.6. The comparison showed that the tests results of Wuya, Tagwai Dam area and Zungeru had values that fall within the range of Heavy Grey Iron cast utilization, while the result of Gidan Mangoro falls within the range of Malleable Iron and finally the result of Tungan Mallam did not provide satisfactory result that fall within the range of the standard values in Table 4.6

4.4 Mechanical Tests Results and Analysis

Casting of the same aluminium alloy using the five different sands under the same experimental condition was to ensure uniformity and ascertain the effects of the five different moulding materials (sands) on the aluminium cast produced. Casting of the aluminium alloy was done in order to verify and validate the sand test results.

For aluminium alloy AA6063 to be suited for wide range engineering applications such as clutch case, switch gear covers, tool handles, gear boxes, crankcase, as well as when reasonable mechanical properties are required, its mechanical properties must meet certain requirements. The British Standard 1490 provides the mechanical standard properties for which alloy of aluminium must possess for it to be suitable for the engineering application mentioned above to include, the Tensile Stress range (140 – 170) N/mm^2, Percentage Elongation (2 – 3) % and Brinell Hardness Number (65 – 80). These casting properties allow it to be utilized for the casting of moderately thin forms as well as where pressure tight castings are needed.

When the aluminium alloy appropriate for marine on deck castings, intricate castings, manifolds, thin section, car fittings, as well as chemical and dye industry castings, and also were welding parts are needed, the British Standard 1490 also provides the mechanical standard properties for which alloy of aluminium, the Tensile Stress range (160 – 190) N/mm^2, Percentage Elongation (5 – 10) % and Brinell Hardness Number (50 – 55). (www.hadleighcastings.com/uploads/LM alloys, accessed 20 August 2013).

The mechanical tests results of the aluminium casts from the five different sands tested which include the Tensile Stress, Hardness, Elongation and Reduction Area are presented in Tables (4.7 – 4.11).

4.4.1 Mechanical Tests Results of Aluminium Cast Sample Using Tungan Mallam Sand

The mechanical test results of aluminium cast sample using Tungan Mallam sand is seen in Table 4.7

Table 4.7 Mechanical Tests Results of Aluminium Cast Sample Using Tungan Mallam Sand

S/ No	Original Length (mm)	Final Length (mm)	Elongation (%)	Original Diameter (mm)	Final Diameter (mm)	Reduction Area (%)	Ultimate Tensile Stress (N/mm^2)	Average Elongation (%)	Average Reduction Area (%)	Average Ultimate Tensile Stress (N/mm^2)	Hardness (HB)
1	30	31.58	5.27	6.00	5.85	4.94	136.76	4.90	4.94	129.26	42.26
2	30	31.25	4.17	6.00	5.85	4.94	121.95				
3	30	31.58	5.27	6.00	5.85	4.94	131.07				

Table 4.7 presents the mechanical test results of Tungan Mallam aluminium cast sample. The average tensile stress of 129.26 N/mm^2, average percentage elongation of 4.90 %, also an average reduction area of 4.94 % and Brinell hardness number of 42.26. The tensile stress and Brinell hardness number falls below the British Standard 1490 to be suited for wide range engineering applications such as clutch case, switch gear covers, tool handles and gear boxes. It is also not suitable for the aluminium alloy required for marine on deck castings, intricate castings, manifolds, thin section, car fittings, as well as chemical and dye industry castings, and also were welding parts are needed.

The high permeability number of 96.11 compared to the satisfactory range of 10 – 30 implies that cooling and solidification is quick. The lower the permeability number the longer the period of cooling and vice versa. The higher permeability number indicates that solidification and cooling of the cast was quicker than normal, which affects the grains formation, size and shape. These generally affect the mechanical properties of the cast thereby making it less ductile and more brittle, ultimately affecting the tensile strength and the hardness of the cast.

4.4.2 Mechanical Tests Results of Aluminium Cast Sample Using Zungeru Sand

The mechanical test results of aluminium cast sample using Zungeru sand is seen in Table 4.8

Table 4.8 Mechanical Tests Results of Aluminium Cast Sample Using Zungeru Sand

S/No	Original Length (mm)	Final Length (mm)	Elongation (%)	Original Diameter (mm)	Final Diameter (mm)	Reduction Area (%)	Ultimate Tensile Stress (N/mm^2)	Average Elongation (%)	Average Reduction Area (%)	Average Ultimate Tensile Stress (N/mm^2)	Hardness (HB)
1	30	31.58	5.27	6.00	5.82	5.91	102.57	4.71	5.59	114.99	39.66
2	30	31.25	4.17	6.00	5.85	4.94	127.43				
3	30	31.41	4.70	6.00	5.82	5.91	114.99				

Table 4.8 presents the mechanical test results of Zungeru aluminium cast sample. The average tensile stress of 114.99 N/mm^2, average percentage elongation of 4.71 %, also an average reduction area of 5.59 % and Brinell hardness number of 39.66. The tensile stress and Brinell hardness number falls below the British Standard 1490 to be suited for wide range engineering applications such as clutch case, switch gear covers, tool handles, gear boxes and crankcase. It is also not suitable for the aluminium alloy required for marine on deck castings, intricate castings, manifolds, thin section, car fittings, as well as chemical and dye industry castings, and also were welding parts are needed.

The high permeability number of 72.29 compared to the satisfactory range of 10 – 30 implies that cooling and solidification is quick. The lower the permeability number the longer the period of cooling and vice versa. The higher permeability number indicates that solidification and cooling of the cast was quicker than normal, which affects the grains formation, size and shape. These generally affect the mechanical properties of the cast thereby making it less ductile and more brittle, ultimately affecting the tensile strength and the hardness of the cast.

4.4.3 Mechanical Tests Results of Aluminium Cast Sample Using Gidan Mangoro Sand

The mechanical test results of aluminium cast sample using Gidan Mangoro sand is seen in Table 4.9

Table 4.9 Mechanical Tests Results of Aluminium Cast Sample Using Gidan Mangoro Sand

S/No	Original Length (mm)	Final Length (mm)	Elongation (%)	Original Diameter (mm)	Final Diameter (mm)	Reduction Area (%)	Ultimate Tensile Stress (N/mm^2)	Average Elongation (%)	Average Reduction Area (%)	Average Ultimate Tensile Stress (N/mm^2)	Hardness (HB)
1	30	31.25	4.17	6.00	5.85	4.94	132.45	4.54	5.59	128.44	44.14
2	30	31.25	4.17	6.00	5.82	5.91	116.32				
3	30	31.58	5.27	6.00	5.82	5.91	136.55				

Table 4.9 presents the mechanical test results of Gidan Mongoro aluminium cast sample. The average tensile stress of 128.44 N/mm^2, average percentage elongation of 4.54 %, also an average reduction area of 5.59 % and Brinell hardness number of 44.14. The tensile stress and Brinell hardness number falls below the British Standard 1490 to be suited for wide range engineering applications such as clutch case, switch gear covers, tool handles, gear boxes and crankcase. It is also not suitable for the aluminium alloy required for marine on deck castings, intricate castings, manifolds, thin section, car fittings, as well as chemical and dye industry castings, and also were welding parts are needed.

The high permeability number of 82.25 compared to the satisfactory range of 10 – 30 implies that cooling and solidification is quick. The lower the permeability number the longer the period of cooling and vice versa. The higher permeability number indicates that solidification and cooling of the cast was quicker than normal, which affects the grains formation, size and shape. These generally affect the mechanical properties of the cast thereby making it less ductile and more brittle, ultimately affecting the tensile strength and the hardness of the cast.

4.4.4 Mechanical Tests Results of Aluminium Cast Sample Using Tagwai Dam Area Sand

The mechanical test results of aluminium cast sample using Tagwai Dam Area sand is seen in Table 4.10

Table 4.10 Mechanical Tests Results of Aluminium Cast Sample Using Tagwai Sand

S/No	Original Length (mm)	Final Length (mm)	Elongation (%)	Original Diameter (mm)	Final Diameter (mm)	Reduction Area (%)	Ultimate Tensile Stress (N/mm^2)	Average Elongation (%)	Average Reduction Area (%)	Average Ultimate Tensile Stress (N/mm^2)	Hardness (HB)
1	30	31.25	4.17	6.00	5.85	4.94	120.23	4.54	5.26	118.81	39.34
2	30	31.25	4.17	6.00	5.85	4.94	124.32				
3	30	31.58	5.27	6.00	5.82	5.91	111.89				

Table 4.10 presents the mechanical test results of Tagwai Dam aluminium cast sample. The average tensile stress of 118.81 N/mm^2, average percentage elongation of 4.54 %, also an average reduction area of 5.26 % and Brinell hardness number of 39.34. The tensile stress and Brinell hardness number falls below the British Standard 1490 to be suited for wide range engineering applications such as clutch case, switch gear covers, tool handles, gear boxes and crankcase. It is also not suitable for the aluminium alloy required for marine on deck castings, intricate castings, manifolds, thin section, car fittings, as well as chemical and dye industry castings, and also were welding parts are needed.

The high permeability number of 74.22 compared to the satisfactory range of 10 – 30 implies that cooling and solidification is quick. The lower the permeability number the longer the period of cooling and vice versa. The higher permeability number indicates that solidification and cooling of the cast was quicker than normal, which affects the grains formation, size and shape. These generally affect the mechanical properties of the cast thereby making it less ductile and more brittle, ultimately affecting the tensile strength and the hardness of the cast.

4.4.1 Mechanical Tests Results of Aluminium Cast Sample Using Wuya Sand

The mechanical test results of aluminium cast sample using Wuya sand is seen in Table 4.11

Table 4.11 Mechanical Tests Results of Aluminium Cast Sample Using Wuya Sand

S/ No	Original Length (mm)	Final Length (mm)	Elongation (%)	Original Diameter (mm)	Final Diameter (mm)	Reduction Area (%)	Ultimate Tensile Stress (N/mm^2)	Average Elongation (%)	Average Reduction Area (%)	Average Ultimate Tensile Stress (N/mm^2)	Hardness (HB)
1	30	31.58	5.27	6.00	5.85	4.94	123.17	4.90	5.26	114.17	39.25
2	30	31.25	4.17	6.00	5.82	5.91	102.64				
3	30	31.58	5.27	6.00	5.85	4.94	116.70				

Table 4.11 presents the mechanical test results of Wuya aluminium cast sample. The average tensile stress of 114.17 N/mm^2, average percentage elongation of 4.90 %, also an average reduction area of 5.26 % and Brinell hardness number of 39.25. The tensile stress and Brinell hardness number falls below the British Standard 1490 to be suited for wide range engineering applications such as clutch case, switch gear covers, tool handles, gear boxes and crankcase. It is also not suitable for the aluminium alloy required for marine on deck castings, intricate castings, manifolds, thin section, car fittings, as well as chemical and dye industry castings, and also were welding of cast parts are needed.

The high permeability number of 75.35 compared to the satisfactory range of 10 – 30 implies that cooling and solidification is quick. The lower the permeability number the longer the period of cooling and vice versa. The higher permeability number indicates that solidification and cooling of the cast was quicker than normal, which affects the grains formation, size and shape. These generally affect the mechanical properties of the cast thereby making it less ductile and more brittle, ultimately affecting the tensile strength and the hardness of the cast.

4.5 Chemical Composition

The aluminium alloy used for the experiment was obtained from the Nigerian Aluminium Extrusion Company, Lagos. The chemical composition of the aluminium alloy AA6063 is shown in Table 4.12

Table 4.12 Chemical Composition AA6063 (Al-Si-Mg)

Alloying Element	Al	Si	P	Ca	Ti	V	Cr	Mg
Percentage Composition	87.45	10.87	0.2	0.05	0.019	0.12	0.068	0.20

Alloying Element	Mn	Fe	Ni	Cu	Zn	Pb	As	Sn
Percentage Composition	0.29	0.27	0.007	0.034	0.015	0.007	0.06	0.34

The chemical composition of the aluminium alloy is essential as it influences the mechanical properties of the alloy and it is based on the chemical composition that a standard range of mechanical values which sets limits to the application and suitability of the alloy for a particular purpose is made.

4.6 Metallographic Test Result and Analysis

The metallographic results show the microstructure of the cast from the five different sand samples. The microstructures generally consists of fine crystals of aluminium, magnesium silicide (Mg_2Si), and AlMgSi phases. These structures basically consists of primary alpha solid solution of magnesium silicide in rich solid aluminium (α) in a matrix of eutectic magnesium silicide (Mg_2Si). The aluminium rich portion of the Al-Mg_2Si is a precipitation of the magnesium silicide (Mg_2Si). The primary solid solution of silicon in aluminium is revealed in white patches while the eutectic magnesium silicide (Mg_2Si) is seen dark patches in the micrographs in Plates 4.1-4.5. There is also a very thin gray structure indicating the presence of Fe_3SiAl_2.

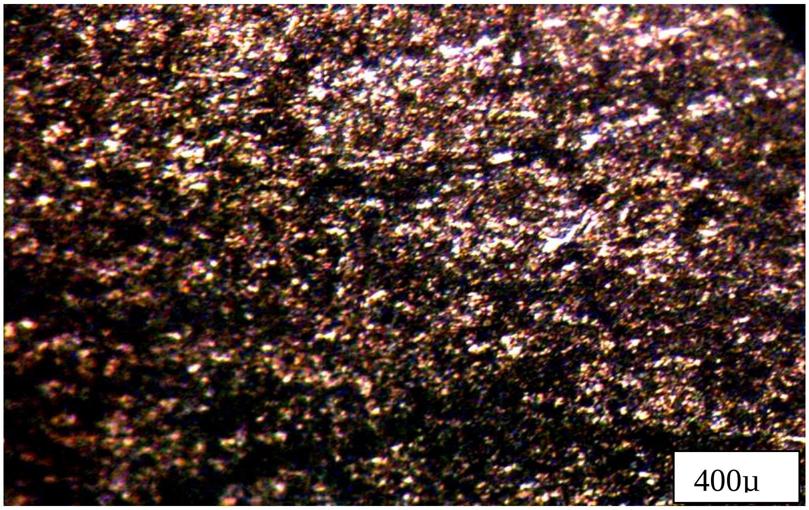

Plate 4.1 Micrograph of etched Aluminium test sample using Gidan Mangoro sand

Plate 4.1 shows the microstructure cast of aluminium produced from Gidan Mangoro sand specimen. The white patches of the primary alpha solid solution of silicon in aluminium (α) in matrix form is very visible and the dark patches of magnesium silicide (Mg_2Si) is also seen. A very thin gray colour structure is also seen indicating the presence of Fe_3SiAl_2 in the aluminium alloy.

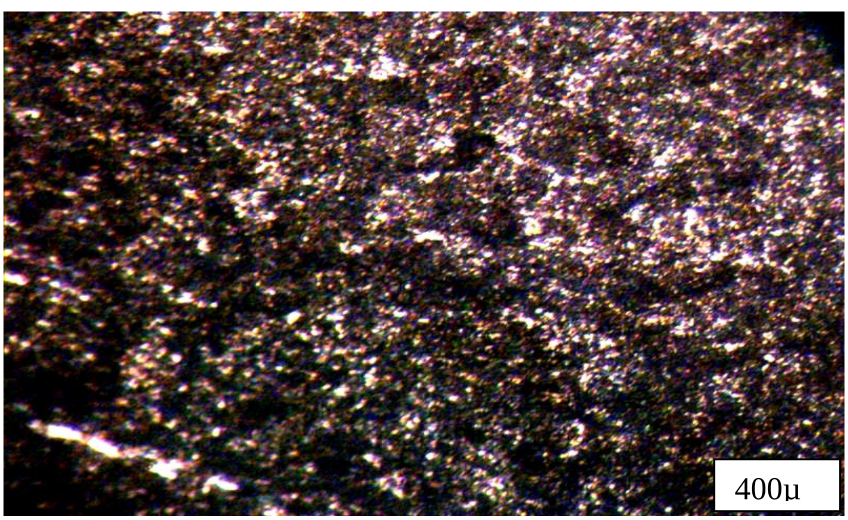

Plate 4.2 Micrograph of etched Aluminium test sample using Tungan Mallam sand

Plate 4.2 shows the microstructure of aluminium specimen produced from Tungan Mallam sand. As in the Plate 4.1, the white patches of primary alpha solid solution of silicon in aluminium in matrix form (α) is visible but it is not as pronounced as that of Plate 4.1. There is also the presence of dark patches of magnesium silicide (Mg_2Si) from the microstructure as seen Plate 4.2. It also has a thin gray colour structure indicating the formation of Fe_3SiAl_2 in the alloy.

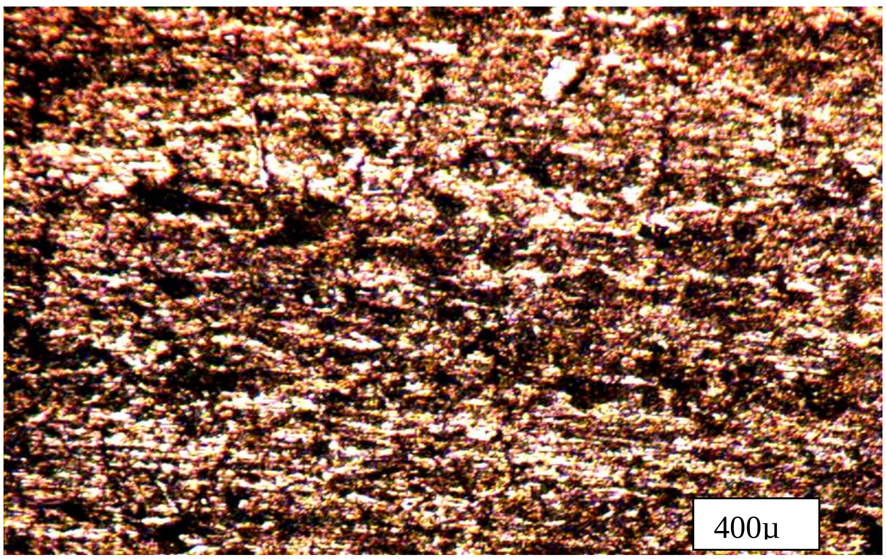

Plate 4.3 Micrograph of etched Aluminum test sample using Tagwai Dam sand

Plate 4.3 provides the microstructure aluminium sample of Tagwai dam area sand. The microstructure show the presence of white patches indicating the primary alpha solid solution of silicon in aluminium (α) in matrix form and also the dark patches of magnesium silicide (Mg_2Si) in eutectic state from observation made. The white patches are more pronounced in Plate 4.3 than in Plate 4.1.

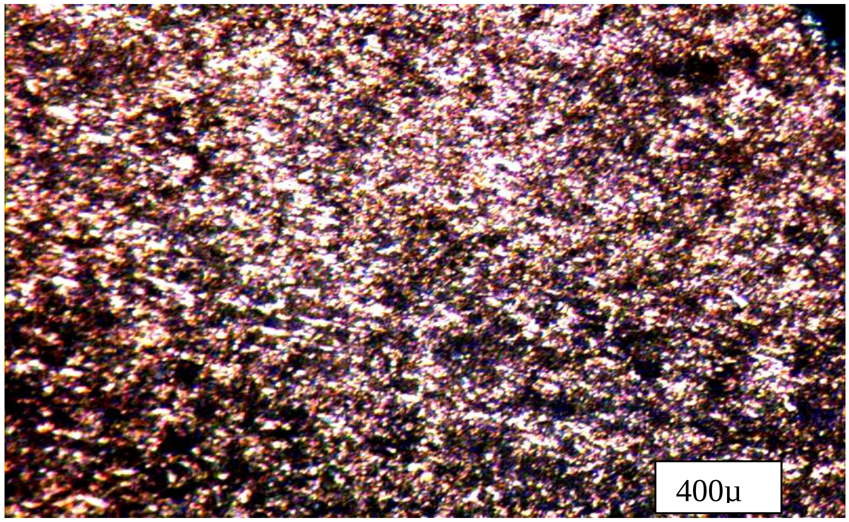

Plate 4.4 Micrograph of etched Aluminium test sample using Wuya sand

Plate 4.4 shows the microstructure of aluminium cast produced from Wuya sand. The microstructure of Plate 4.4 shows similar characteristics in terms of primary alpha solid solution of silicon in aluminium (α) in matrix form and magnesium silicide (Mg_2Si) in the eutectic state with the microstructure of Plate 4.3. There is also a presence of very thin gray colour structure of Fe_3SiAl_2, just like that of Plate 4.1

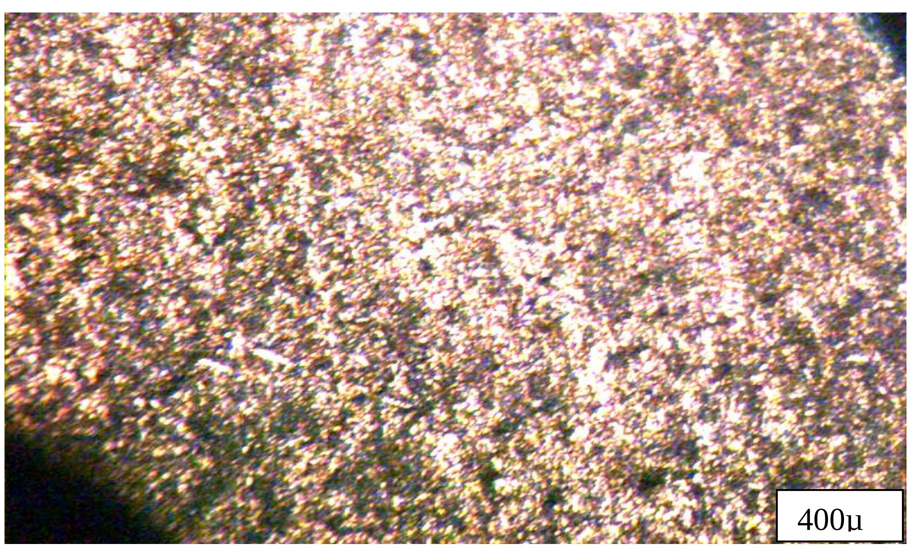

Plate 4.5 Micrograph of etched Aluminium test sample using Zungeru sand

Plate 4.5 which provides the microstructure of specimen of aluminium produced from Zungeru sand also shows a similar pattern. The microstructure of Plate 4.5 is similar to that of Plate 4.4. There is very visible white patches of primary alpha solid solution of silicon in aluminium (α) in a matrix of eutectic magnesium silicide (Mg_2Si). The microstructure of Plat 4.5 shows a very thin gray colour presence of Fe_3SiAl_2.

The aluminium alloy cast was produced for all the five sand tested. From figure 4.1 which provides the permeability results from the five sand tested shows that the sand with low permeability had microstructures in which the white patches of primary alpha solid solution of silicon in aluminium (α) to be more pronounced which include the microstructure results from Zungeru, Tagwai and Wuya sand. These sands exhibited very similar permeability number while the sand test result with higher permeability showed less white patches of primary alpha solid solution of silicon in aluminium (α) with Tungan Mallam sand microstructure showing the least primary alpha solid solution of silicon in aluminium (α). The relationship between the microstructure and permeability can be explained by the fact that permeability is a measure of gas passage through the sand. The ability of air to pass through sand affects the temperature of casting and the rate of cooling which consequently affects the solidification process and time, and the solidification process affects the types of phase and grains formed. Again it can be seen that average tensile strength and the hardness values of the three sands from Zungeru, Tagwai and Wuya were very close as compared to the other values which implies that the microstructure of the sand produced are in agreement with the mechanical tests carried out.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The sand test analysis of Tungan Mallam, Zungeru, Gidan Mangoro, Tagwai Dam area and Wuya sand all in Niger State has been carried out. The five different sand samples were used to produce aluminium cast, mechanical and metallographic test were conducted on the cast to verify the suitability of the five different sands for casting using aluminium alloy.

For the sand test, the different sands underwent Permeability, Moisture Content, Green Compressive Strength, Green Shear Strength, Dry Compressive Strength, Dry Shear Strength and Compactabilty tests. The sand test was carried out by varying the water content between 6 % and 10 % which is the acceptable range for aluminium casting. The Green Compressive Strengths generally decreased from 22.17 kN/m^2 to 12.50 kN/m^2 for Tungan Mallam, while Zungeru from 116.67 kN/m^2 to 96.83 kN/m^2, also Gidan Mangoro from 48.67 kN/m^2 to 35.33 kN/m^2, Tagwai Dam from 108.00 kN/m^2 to 76.00 kN/m^2 and Wuya from 111.50 kN/m^2 to 102.00 kN/m^2. The permeability number also generally decreased for all the five sands tested from 96.85 to 87.55 for Tungan Mallam, 75.14 to 72.08 for Zungeru, 84.16 to 78.80 for Gidan Mangoro, 75.92 to 74.82 for Tagwai Dam area and 79.56 to 75.35 for Wuya. While the Dry Compressive Strength generally increased for all the sand tested from 85.00 kN/m^2 to 400.00 kN/m^2 for Tungan Mallam, 402.50 kN/m^2 to 470.00 kN/m^2 for Zungeru, 200.00 kN/m^2 to $>$ 650.00 kN/m^2 for Gidan Mangoro, 528.50 kN/m^2 to $>$ 650.00 kN/m^2 for Tagwai Dam area and 410.00 kN/m^2 to 485.00 kN/m^2 for Wuya. The results of the tests were compared with those of known standard values of satisfactory moulding property ranges for sand casting, Ademoh and Ahmed (2009). Results showed that all the sand were not suitable for use in casting aluminium alloy as all the sand test results were out of range of the standard mould property range value for sand casting using aluminium alloy as provided by the moulding range standard for sand casting, but the sands were found to be within the range for satisfactory sand casting of other type of metals as follows based on the results which were obtained as follows, Wuya, Tagwai Dam area and Zungeru sand respectively were found to be in the range for use in the cast of Heavy Grey iron, while Gidan Mangoro sand was found to be suitable for use in the cast of Malleable iron. Finally, Tungan Mallam sand result gave values that were not within the range of the standard moulding property range in its natural state. The Mechanical test carried out included tensile strength, hardness, elongation and reduction area tests respectively. Results from the mechanical tests of the aluminium casts from all the five different sand were also compared with that of known standard ranges of mechanical tests for aluminium alloy casted using sand casting in order to validate the sand test results.

5.2 Recommendations

From the research carried out, further research on the following are recommended

1. The sand deposit based on the test result has shown qualities and properties suitable for heavy grey iron cast and malleable iron, it should therefore be tested in the production of heavy grey iron and malleable iron cast to prove its validity.
2. All the sand used in the research were naturally sourced and no additives was added, it is recommended that further research on the sand with addition of additives like bentonite, silica sands to see if they can be suitable for use in other sand casting process.

3. All the sand from Gidan Mangoro, Tungan Mallam, Tagwai Dam, Wuya and Zungeru are not recommended for aluminium casting. If the sand from the five different locations were to be used for aluminium casting, then the aluminium products produce by these sands should not therefore be used for productions of automobile mechanical parts such as, crank shaft, piston and ring, propeller, sleeve, fuel burning exhaust, top cylinder etc. to avoid short life span due to shortest failure.

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