

**FORMULATION OF SAND CORE OIL FROM RUBBER SEED AND SHEA  
BUTTER OILS FOR ALUMINIUM CASTING**

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**M.ENG/ME/07/0383**

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**DECLARATION**

I declare that this work titled “Formulation of sand core oil from Rubber Seed and Shea Butter Oils for Aluminum Casting” was carried out in its original form by Odiakaose Chili in the Department of Mechanical Engineering, ModibboAdama University of Technology Yola, Nigeria under the supervision of Engr. Dr. A. Raji. The works of other researchers used have been duly acknowledged.

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**ODIAKAOSE, CHILI**

**DATE**

## **DEDICATION**

This project is dedicated to Almighty God, the Creator and my inspiration, for my success in life.

## APPROVAL PAGE

This thesis titled “Formulation of Sand core oil from Rubber Seed and Shea Butter Oils for Aluminum Casting” by Odiakaose Chili meets the regulations governing the award of Mastersdegree of theModibboAdama University of Technology, Yola and is approved for its contribution to knowledge and literary presentation.

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## ABSTRACT

This research was conducted to formulate sandcore oil for Aluminum casting using locally available oils (Rubber seed - Shea butter oil) as an alternative to the imported foundry core oil. The physical and chemical properties such as, refractive index, specific gravity, pH value, iodine value and flash point of the formulated (Rubber seed - Shea butter oil) and existing core oil (linseed oil) were determined. The mixture was formulated by keeping clay, cereal binder and water percentage constant of 6wt%, 3wt% and 5wt%, respectively while the sand and the oil were varied between 83wt% to 85.5wt% and 0.5wt% to 3wt% at an interval of 0.5wt%, respectively, from which various specimen were then made and tested for green compression strength, dry compression strength, green tensile strength, dry tensile strength, green permeability and collapsibility. Maximum strengths of the cores were obtained at 3% oil content. The results of green compression strength of cores produced using formulated Rubber seed – Shea butter oils and linseed oil range from 20.336kN/m<sup>2</sup> to 40.006kN/m<sup>2</sup>, the dry compression strength results range from 570.006kN/m<sup>2</sup> to 634.006kN/m<sup>2</sup>, green tensile results range from 20.33kN/m<sup>2</sup> to 36.33kN/m<sup>2</sup>, dry tensile results range from 518.00kN/m<sup>2</sup> to 604.67kN/m<sup>2</sup>, permeability number ranges from 410.67 to 442.00 and collapsibility test results range from 166.67seconds to 291.38seconds. Based on the results the produced sand cores using formulated sand core oil have very good chemical and mechanical properties required for foundry core meant for aluminum castings.

**Keywords:** Rubber Seed oil, Shea Butter oil, Sand Core oil, Strength, Permeability, Collapsibility.

## TABLE OF CONTENTS

	<b>pages</b>
TITLE PAGE	i
DECLARATION	ii
APPROVAL PAGE	iii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
ABSTRACT	vi
TABLE OF CONTENTS	viii
LIST OF TABLES	xii
LIST OF FIGURES	xiii
LIST OF PLATES	xiv
LIST OF SYMBOLS	xv
<b>CHAPTER ONE: INTRODUCTION1</b>	
1.0 Introduction	1
1.1 Background of the Study	1
1.2 Statement of the Problem	3
1.3 Justification for the Study	3
1.4 Aim and Objectives	3
1.5 Scope of the Study	4
<b>CHAPTER TWO: LITERATURE REVIEW</b>	
2.1 Casting	5
2.1.1 <i>The Steps in Casting</i>	5

<i>2.1.2 Advantages and Disadvantages of Casting</i>	6
<i>2.1.3 Methods of Casting</i>	7
<i>2.1.4 Types of Casting Sand and Sand Moulds used in Foundries</i>	10
<i>2.1.5 Foundry Sand Testing and Equipment</i>	11
2.2 Core	16
<i>2.2.1 Types of Core</i>	16
<i>2.2.2 Core Making and Equipment</i>	16
2.3 Binders	25
<i>2.3.1 Types of Binder</i>	26
<i>2.3.2 Types of core oils and their Requirement</i>	27
<i>2.3.3 Core binding properties of fatty based oils</i>	28
<i>2.3.4 Core binding properties of Protein Bindersfor Aluminium casting</i>	33
<b>CHAPTER THREE: MATERIALS AND METHODS</b>	
3.1 Materials	39
<i>3.1.1 Rubber Seed oil</i>	39
<i>3.1.2 Shea butter oil</i>	39
<i>3.1.3 Clay and silica sand</i>	40
3.2 Methods	40
<i>3.2.1 Physical and Chemical Properties Determination</i>	40
<i>3.2.2 Test specimen preparation</i>	41
<i>3.2.3Experimental design</i>	42
<i>3.2.4 Core specimen testing</i>	42
<i>3.2.4.1Tensile Testing</i>	46

3.2.4.2 <i>Compressive Testing</i>	46
3.2.4.3 <i>Collapsibility Testing</i>	46
3.2.4.4 <i>Permeability Testing</i>	48
<b>CHAPTER FOUR: RESULTS</b>	
4.0 Introduction	49
4.1 Physical and Chemical Properties of the Formulated Core Oil and Linseed Oil	49
4.2 Mechanical Properties of the Core Made	51
4.2.1 <i>Green Compression Strength</i>	51
4.2.2 <i>Dry Compression Strength</i>	51
4.2.3 <i>Green Tensile Strength</i>	51
4.2.4 <i>Dry Tensile Strength</i>	55
4.2.5 <i>Permeability Properties</i>	55
4.2.6 <i>Collapsibility Properties</i>	55
<b>CHAPTER FIVE: DISCUSSION</b>	
5.1.0 Physio - Chemical Properties of Core Oil	59
5.2 Mechanical Properties of Core	59
5.2.1 <i>Green Compression Strength</i>	59
5.2.2 <i>Dry Compression Strength</i>	60
5.2.3 <i>Green Tensile Strength</i>	61
5.2.4 <i>Dry Tensile Strength</i>	61
5.2.5 <i>Permeability Properties</i>	63
5.2.6 <i>Collapsibility Properties</i>	64

## **CHAPTER SIX: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS**

6.1 Summary	66
6.2 Conclusions	67
6.3 Recommendations	68
<b>REFERENCES</b>	69
<b>APPENDICES</b>	73

## LIST OF TABLES

<b>Table</b>	<b>Pages</b>
1 Desired Mechanical Property Ranges of Sand Cores	20
2 Percentage of Core oil in the Core Sand and the Proportion of Rubber Oil - Shea Butter Oil in Percentage	45
3Physio-Chemical Properties of Linseed Oil and RSO-SBO at different Proportions	49

## LIST OF FIGURES

<b>Figures</b>	<b>Pages</b>
1 Types of Cores	18
2 Core Sand Mixer	22
3 Design Shape of the core for tensile strength test	44
4 Green Compression test graph of RSO-SBO and Linseed oil	52
5 Dry Green Compression test graph of RSO-SBO and Linseed oil	53
6 Green Tensile test graph of RSO-SBO and Linseed oil	54
7 Dry Tensile test graph of RSO-SBO and Linseed oil	56
8 Permeability test graph of RSO-SBO and Linseed oil	57
9 Collapsibility test graph of RSO-SBO and Linseed oil	58

## LIST OF PLATES

### PlatesPages

I Moulded Oil Core Test Specimens	43
II Tensile Core Strength Accessory	47

## LIST OF SYMBOLS/ABBREVIATIONS

FIIRO	Federal Institute of Industrial Research Oshodi
P	Permeability
V	Volume of air passing through the specimen
h	Height of specimen
<i>p</i>	Pressure of air
a	Cross sectional area of specimen
t	Time
AFS	American Foundry men Society
GCS	Green Compression Strength
DCS	Dry Compression Strength
GTS	Green Tensile Strength
DTS	Dry Tensile Strength
RSO	Rubber Seed Oil
SBO	Shea Butter Oil
TAN	Total Acid Number

## CHAPTER ONE

### INTRODUCTION

#### 1.0 Introduction

There are various manufacturing processes by which a product can be made; each process, however, has its own place and can particularly be adapted to certain specific applications. The real problem is to choose the most economical out of the processes. Foundry or casting is a process of forming metallic products by melting the metal, pouring it into a cavity known as mould, and allowing it to solidify. The molten metal takes the shape of the mould; the product is cooled, cleaned and machined to desired dimensions (Jain, 1986). According to Degramo *et al.* (2003), core oils are those oils that are used to produce cores in foundry practice for casting purpose, while cores are an integral part of the casting process, often serving a number of different functions simultaneously. When placed in a mould, they delineate the internal shape of the casting. They further stated that as a result of the increased demand for environmentally friendly core oils, there is a growing interest in binders that would offer substantial advantages in terms of cost, occupational health, safety and other environmental issues.

#### 1.1 Background of the Study

In conventional sand casting, the mould is formed around a pattern by ramming sand, mixed with the proper bonding agent, onto the pattern. Then the pattern is removed, leaving a cavity having the external shape of the casting to be made. If the casting is to have internal cavities or undercuts, sand cores are used to make them. Molten metal is poured into the mould, and after it has solidified the mould is broken to remove the casting (Archibald and Smith, 1988). In making moulds and cores, various agents can be used for bonding the sand; the agent most often used is a mixture of clay and water. Sand bonded with clay and water is called green sand. Sand bonded with oils or resins, which is very strong after baking, is used mostly for core (Sadgah, 2002).

A core is a device used in casting and moulding processes to produce internal cavities and re-entrant angles. The core is normally a disposable item that is destroyed to get it out of the piece (Degramo *et al.*, 2003). They are most commonly used in sand

casting, but are also used in die casting. An intriguing example of the use of cores is in the casting of engine blocks. For example, one of the general motors' 8 valves (Gm –v 8) engines requires 5 dry – sand cores for every casting. Cores are useful for features that cannot tolerate draft or to provide detail that cannot otherwise be integrated into a coreless casting or mould. But the main disadvantage is the additional cost to incorporate cores (Degramo *et al.*, 2003).

According to Busby (1992), binder system technology has responded to foundries' needs for better quality and productivity while reducing environmental impact. He further stated that popular core binders used in most modern foundries use very robust self setting methods that include instantaneous hardening techniques such as fast curing with gaseous and catalytic agents. Most of these current organic binders are predominantly based around phenol formaldehyde resins which though provide exceptional performance in respect of process robustness, easy breakdown and removal of the core sand after casting but are however environmentally not friendly. John and Elwin (2004) stated that organic binders are composed of corrosive acids and volatile organic compounds whose thermal breakdown products give out very foul, pungent odours and waste streams that are hazardous to health of users.

Ibitoye and Afonja (1996) showed that there is a need for development of environmentally friendly binder systems based around organic, inorganic or hybrid derivatives that would offer substantial advantages in terms of cost, occupational health safety and other environmental issues. They argued that the processes that would be involved in use of such binders should be simpler for easy adoption by foundries in developing economies like Nigeria to enable the industry to contribute its quota to national growth. They further stated that locally developed organic vegetable oil binders obtained from plant trees would be known for clean and non-toxicity.

It was observed that construction of efficient sand cores for castings needs different consumption of resources and significant manufacturing costs. Therefore, an efficient core binder, developed locally in a developing economy such as Nigeria, represent a major advancement in obtaining sand core of desirable performance and high strength in reducing the cost of production of casting (Ademoh, 2009).

## **1.2 Statement of the Problem**

The popular core binders used in Nigerian foundries for Aluminium casting are Dextrin, Protein binders and core oils (China wood oil, perrilla oil and linseed oil) some of which are too sophisticated and toxic, which makes them environmentally unfriendly, thus contributing to occupational health hazards. In addition, the binders are generally imported and hence are expensive which makes it difficult for the industry to contribute its quota to national growth.

There is need therefore to source for other locally available alternative binders. The formulation of Rubber seed (*Hevea brasiliensis*) and Shea butter (*Vitellaria paradox*) oils for Aluminium casting will offer a friendlier processing environment with no health threats to users and at cheaper cost.

## **1.3 Justification of the Study**

i Linseed oil is the most widely used oil for core binding purpose and is generally considered to be the ideal. The raw oil is employed in considerable quantities by foundries in Nigeria, both alone and mixed with roslin oil. However, the oil is largely imported into the country, which contributes to high cost of casting products. Rubber seed (*Hevea brasiliensis*) and Shea butter (*Vitellaria paradoxa*) oils, if well researched and produced in large quantity may replace existing imported core oils for Aluminium casting and will make cast Aluminium products cheaper.

ii Most popular core binders are not environmentally friendly and are toxic, which pose threats to the health of the end users i.e. foundry men. But if rubber seed oil and Shea butter oil are properly exploited, they will be environmentally friendly and may not be harmful to the health of the end users, and also will be a major advancement in Aluminium sand casting.

## **1.4 Aim and Objectives**

The study was conducted with the aim of formulating core oil from locally available Rubber seed (*Hevea brasiliensis*) and Shea butter (*Vitellaria paradox*) oils for Aluminium casting.

The following were the specific objectives;

- i. To formulate a core oil for Aluminium casting.
- ii. To produce core using the formulated core oil.
- iii. To compare the properties of the formulated core oil with the linseed oil.
- iv. To compare the properties of the produced core using formulated core oil with those of core made using linseed oil.

### **1.5 Scope of the Study**

The study is delimited to the formulation of core oil from locally available materials Rubber seed and Shea butter oils (RSO-SBO) at different mix ratio for Aluminium casting, production of core from the formulated oil, determination of the physio-chemical properties of the formulated oil and determination of functional properties of the produced cores. The functional properties include only green compression strength, dry compression strength, green tensile strength, dry tensile strength, permeability and collapsibility.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Casting

There are various manufacturing processes by which a product can be made; each process, however, has its own place and can particularly be adapted to certain specific applications. Thus, whenever a product can be manufactured by two or more processes, the real problem is to choose the most economical out of them (Archibald and Smith, 1998).

Titov and Stepanov (1982) defined casting as a process of forming metallic products by melting the metal, pouring it into a cavity known as the mould, and allowing it to solidify. In this way the molten metal takes the shape of the mould, and then the product is cleaned and machined to desired dimensions.

##### *2.1.1 The Steps in Casting*

L.L. Doe cited by Mikhailov (1989), stated that metal casting is normally carried out by the following steps:

Pattern making: This is the first step in the casting of a job. The pattern is a model of the job and is made of a suitable material, commonly wood or metal, and is used to make the mould. The success of a casting process depends a lot on the quality and the design of the pattern.

Moulding and core making: Mould is the cavity which is formed with the help of the pattern in a suitable mould material, commonly the moulding sand. Sometimes a hole or a recess is required in the casting. This is achieved by placing a suitable core in the mould. The shape of the core corresponds to the shape of the hole or recess. The cores are usually made of sands having compositions much different from the moulding sand.

Melting and pouring: Once the mould is made, it is ready to receive the molten metal. At this stage, the metal is melted in a suitable furnace depending upon the amount and the

nature of the metal. When the metal is completely molten, it is tapped in a suitable ladle and then poured in the mould.

Cleaning: After the metal has been poured in the mould the whole assembly is allowed to cool thus solidifying the metal. When the process of solidification is complete, the casting is taken out. The casting at this stage, however, is not in the same form in which it is desired and cleaning is essential.

### ***2.1.2 Advantages and Disadvantages of Casting***

According to Eckey (1988), the main advantages of casting process over other fabrication processes are as follows:

Parts with very intricate shapes can be produced by casting at a cheaper rate.

Certain metals and alloys, due to their certain metallurgical properties, cannot be shaped by mechanical working, whereas, they can be cast without any difficulty. Cast iron, for example, is difficult to fabricate by mechanical working because of its brittleness behaviour, but it can be easily cast into various shapes.

In most of the cases, the process of casting is done with accuracy; thus reducing the machining time to a great extent.

As compared to other manufacturing processes, the casting technique is simple, due to the fact that the number of operations in this technique is minimum.

It gives a faster rate of production and the total time per unit production is minimized.

Castings exhibit uniform properties in all the directions i.e. longitudinal, lateral and diagonal.

Machinability and Vibration damping capacity are better in cast metals, for example cast iron.

In certain light metals, strength, lightness and good bearing qualities can only be produced by casting.

A better and controlled metal distribution is possible in casting, thereby increasing the fatigue strength of the product.

A wider range of alloys having various composition and properties can be cast easily.

The disadvantages of casting processes are as follows:

Casting is not economical when parts to be made are in small quantity in number.

Cast metals are susceptible to various defects like porosity, shrinkage, blow holes, segregation and hot tears.

Process control and monitoring is difficult.

Casting is susceptible to metallic projections.

A misrun of molten metal in the mould (lack of completeness due to failure of the metal to fill the mould cavity) is experienced in casting.

Insufficient volume of the molten metal is another disadvantage in casting.

Casting is susceptible to coldshorts, laps, inclusions and cracking.

### ***2.1.3 Methods of Casting***

Casting of metals can be carried out by different methods as listed below:

Sand casting is the process in which molten metal is poured into a mould cavity made of sand mixture where it solidifies to take the shape of mould cavity. Massalski (1989) reported that the main advantages of sand casting are versatility (a wide variety of alloys, shapes, and sizes) and low cost of minimum equipment when a small number of castings are to be made. Among its disadvantages are low dimensional accuracy as well as low strength as a result of slow cooling, which are typical for aluminium sand castings. Sand casting methods generally include green sand casting, dry sand casting, shell mould casting, investment casting and core mould casting (Christopher, 2004).

The basic difference between green and dry sand casting is the strength in the moist (green strength) and the strength in the dry state (dry, baked or cured strength). In dry sand casting, the completed mould is kept at a temperature of about 250°C to dry the sand. The drying produces much stronger mould and eliminates moisture that could cause blow hole defects (Christopher, 2004).

According to Kakutani and Mininura (1988), lost-wax, investment, or precision-casting process permits the accurate casting of highly alloyed steels and of nonferrous alloys which are impossible to forge and difficult to machine. The procedure consists of making an accurate metal die into which the wax or plastic patterns are cast. The patterns are assembled on a sprue and the assembly sprayed, brushed, or dipped in slurry of a fine-grained, highly refractory aggregate, and a proprietary bonding agent composed chiefly of ethyl silicate. This mixture is then allowed to set. The pattern is coated repeatedly with coarser slurries until a shell of the aggregate is produced around the pattern. The moulds are allowed to stand until the aggregate has set, after which they are heated in an oven in an inverted position so that the wax will run out leaving a mould cavity that will receive the charge of metal.

Rollason (1982) stated that in the permanent-mould casting, fluid metal is poured by hand into metal moulds and around metal cores without external pressure. The moulds are mechanically clamped together. Of necessity, the complexity of the cores must be minimal, in as much as they must be withdrawn for reuse from the finished casting. Likewise, the shape of the moulds must be relatively simple, free of re-entrant sections and the like, or else the mould itself will have to be made in sections, with attendant complexity. Metals suitable for this type of casting are lead, zinc, aluminium and magnesium alloys, certain bronzes, and cast iron.

For making iron castings of this type, a number of metal-mould units are usually mounted on a turntable. The individual operations, such as coating the mould, placing the cores, closing the mould, pouring, opening the mould, and ejection of the casting, are performed as each mould passes certain stations. The moulds are preheated before the first casting is poured. The process produces castings having a dense, fine-grained structure, free from shrink holes or blowholes. The tool changes are relatively low and better surface and closer tolerances are obtained than with the sand-cast method. Permanent mould casting does not maintain tolerances as close or sections as thin as the die-casting or the

plaster-casting methods. Yellow brasses, which are high in zinc, are not cast by the permanent-mould process because the zinc oxide fouls the moulds or dies.

The semi permanent mould casting differs from the permanent mould casting in that sand cores are used, in some places, instead of metal cores. The same metals may be cast by this method. This process is used where cored openings are so irregular in shape, or there are so much undercut, that metal cores would be too costly or too difficult to handle. The structure of the metal cast around the sand cores is like that of a sand casting. The advantages of permanent mould casting in tolerances, density, appearance, etc., exist only in the section cast against the metal mould. Graphite moulds may be used as short-run permanent moulds since they are easier to machine to shape and can be used for higher-melting point alloys, e.g., steel. The moulds are softer, however, and more susceptible to erosive damage. Steel railroad wheels may be made in these moulds and can be cast by filling the mould by low-pressure casting methods. In the slush casting process, the cast metal is allowed partially to solidify next to the mould walls to produce a thin section, after which the excess liquid metal is poured out of the permanent mould (Peter, 1996).

Chaudhury (1997) stated that in centrifugal casting process the metal is under centrifugal force, developed by rotating the mould at high speed. This process, used in the manufacture of bronze, steel, and iron castings, has the advantage of producing sound castings with a minimum of risers. In true centrifugal castings the metal is poured directly into a mould which is rotated on its own axis.

Obviously, the shapes cast by centrifugal casting method must have external and internal geometries which are surfaces of revolution. The external cast surface is defined by the internal surface of the water-cooled mould; the internal surface of the casting results from the effective core of air which exists while the mould is spun and until the metal solidifies sufficiently to retain its cast shape. All cast-iron pipes intended for service under pressure (e.g., water mains) is centrifugally cast. The process is extended to other metals falling under the rubric of tubular goods.

Die casting machines consist of a basin holding molten metal, a metallic mould or die, and a metal transferring device which automatically withdraws molten metal from the basin and forces it under pressure into the die. Hot chamber die casting and cold chamber

die casting machines are the two forms of die casting machines in use generally. Lead, tin, and zinc alloys containing aluminium are handled in piston machines. Aluminium alloys and pure zinc, or zinc alloys free from aluminium, rapidly attack the iron in the piston and cylinder and require a different type of casting machine. The pressures in a piston machine range from a few hundred to thousands of lb/in<sup>2</sup> (N/m<sup>2</sup>) (Higgins, 1997).

#### ***2.1.4 Types of Casting Sand and Sand Moulds used in Foundries***

There are different types of casting and moulding sands, which can be grouped as green sand and dry sand. According to Horst (1990), green sand is the simplest casting sand form; green sand constitutes sand, water, and clay. Green sand requires less equipment to work with. Almost all sand cast moulds for ferrous castings are of the green sand type. Green sand can be categorized into two main types - natural and synthetic.

Lewis (1997) stated that natural sand is the one that is obtained from ground. Characteristics of natural sand may vary depending on source it was obtained from. The clay content is about 11 – 30 % and the clay is generally kaolin. Synthetic sand is more commonly used. Synthetic sand means clean, graded sand in the required grain size in which clay can be added as desired. These types of sand permits the users to more closely control the attributes of the sand.

Dry sand moulds are made with green sand but are baked prior to use. The use of dry sands bonded with resins or water glass results in better surface finishes and dimensional accuracy, but corresponding decrease in cooling rate, the surface is usually given a refractory wash before baking to prevent erosion and to produce a better surface finish (Avenier, 1974). Somewhat the same effects are obtained if the mould is allowed to air-dry by leaving it open for a period of time before pouring, or it is skin-dried by using a torch, infrared lamps, or heating elements directed at the mould cavity surface (Horst, 1990).

As described by Bolton (1991), core moulding makes use of assembled cores to construct the mould. The sand is prepared by mixing with oil, or cereal, forming in core boxes, and baking. This process is used where the intricacy of the casting requires it. Bolton (1991) noted that carbon dioxide process moulds are made in a manner similar to the green sand process but use sand bonded with sodium silicate. When the mould is

finished, carbon dioxide gas is passed through the sand to produce a very hard mould with many of the advantages of dry sand and core moulds but requiring no baking.

Floor and Pit Moulding are applied when large castings are to be produced, these may be cast either directly on the floor of the foundry or in pits in the floor which serve as the flask. Loam moulding is a variation of floor moulding in which moulding material composed of 50 percent sand and 50 percent clay (approx) is trowel onto a brickwork surface and brought to dimension by use of patterns, sweeps, or templates (Christopher, 2004).

### ***2.1.5 Foundry Sand Testing and Equipment***

According to A.H Zrimsek and G.J Vingas cited by Jain (1986), the ever increasing demand for higher accuracy and good surface finishing of castings necessitates certainty in the quality of foundry sands. Some of the tests adopted for core are discussed below:

#### **(A) TESTS**

In strength test, sand mixtures are tested for their compressive strength, shear strength and tensile strength. For performing these tests, adequately rammed samples are used. Although the shape of the test specimen differs a lot according to the nature of the test, but specimens for all types of the strength tests can be prepared with the help of a typical rammer and its accessories. To prepare cylindrical specimens for green sand testing, a defined amount of mixed sand is weighed and compress to a height of 50 mm by three repeated ramming. The weighed sand is poured into the ram tube mounted on the bottom. The weight is lifted by means of the hand lever and the tube filled with sand is placed on the apparatus and the ramming unit is allowed to come down slowly to its original position. Three blows are given on the sample by allowing the rammer weight to fall by turning the lever. After the three blows the mark on the calibrated ram rod should lie between the markings on the calibrated stand. The specimen for dry mixed sand is the same, just that the sand is baked in an oven before testing. The specimen for testing shear strength is of square cross section having an area of  $5 \text{ cm}^2$  and a length of 172 mm, and the specimen for testing tensile strength is of figure 8 shape. Different strength tests are made on a strength tester, the apparatus has a horizontal hydraulic press. Oil pressure is built up

by operating the hand wheel. The pressure developed is read on the pressure manometers. The hydraulic press pushes the plunger. Deformation is then measured on the dial. In compression test the load is applied on the specimen by turning the hand wheel. The manometer reads when the specimen fails which gives the compression strength directly (Gupta and Kaushish, 1996).

Permeability test is defined as the volume of air in cubic centimetre passing through a sand specimen in  $1\text{cm}^2$  cross sectional area and 1 cm height, at a pressure difference of  $1\text{gm/cm}^2$  in one minute. In the case of American Foundry men Society (A.F.S) standard permeability meter, 2000 cubic centimetre of air is passed through a sand specimen (5.08 cm in height and  $20.268\text{ cm}^2$  cross sectional area) at a pressure of  $10\text{ gm/cm}^2$  and total time in seconds is recorded. In general, permeability is expressed as a number and can be calculated from equation 1.

$$P = \frac{Vh}{pat} \quad 1$$

Where;

P = permeability.

V = volume of air passing through specimen in c.c.

h = height of specimen in cm.

P = pressure of air in  $\text{gm/cm}^2$ .

a = cross- sectional area of the specimen in sq.cm.

t = time in minute.

Therefore  $P = 2000 \times 5.08 / 10 \times 20.268 \times t \times 60$

$P = 3007.2 / t$  (sec). (Gupta and Kaushish, 1996)

In Shatter Index Testing, the sand core specimen is made into 50 mm diameter by 50 mm height cylindrical shape according to America Foundry men Society (AFS) standard specimen which is rammed usually by 10 blows and it is allowed to fall on a  $\frac{1}{2}$  inch mesh

sieve from a height of 6ft. The portion of sand retained on the sieve is weighed and it is expressed as percentage of the total weight of the specimen and is a measure of shatter index (Davis, 1978).

## (B) EQUIPMENTS

Rapid Sand Washer: This machine is used for rapid screen analysis of moulding sands and also for the determination of the clay content of moulding sand which is made by agitating a sample of the sand in a weak tetrasodium pyrophosphate solution in a glass beaker, then siphoning off the clay bearing solution using the special clip-on siphon tube. The process of re-diluting, agitating and siphoning is repeated until the solution is clear. The sand grains collected in the beaker are then dried and weighed, and the clay content is calculated from the loss in weight. The sand grains are normally retained for grading by sieving.

Sieve Shaker: Is sand testing equipment that utilizes a vibratory action which moves the sample over the sieve in a unique way, whilst rapid vertical movements keep the apertures from binding. Features of the equipment include digital, vibration and amplitude control, continuous or intermittent vibration control, 0-99 minute timer. In addition, it has no rotating parts to wear out, unique quick release sieve clamping device which holds up to eight full height or eighteen half height sieves. It is Suitable for 200 mm or 8 inch diameter sieves (Ridsdale & Co. Ltd, n.d).

Test Sieves: These are woven wire mesh sieves designed to combine minimum weight with maximum rigidity, and are manufactured with no joints in the circumference to ensure complete freedom from any corners where test material may lodge 60 degrees angle bevel leads onto the mesh. Lid and receiver are also available which nest smoothly with the sieves.

Sieves are usually made with brass frames and phosphor bronze mesh, but stainless steel frames and mesh are also available (Ridsdale & Co. Ltd, n.d).

Laboratory Sand Mixer Machine: This machine has two specially shaped blades mounted on solid steel cone which rotates at a speed of 35 rpm. Time Switch is incorporated in the machine for starting and switching off the motor and can be set for periods up to 15 minutes. The machine is designed for making small scale mixtures from 1-2 kg in the

laboratory. The blade assembly is driven directly from the output shaft of a robust hp geared motor. Fixed breakers on the side of the pan churn up the mixture and give very efficient blending in a few minutes. Sand is readily discharged by pulling out the door at the base of the pan. Another important feature is the ease with which the complete blade assembly can be removed to facilitate cleaning. A cut out switch is fitted to prevent operation of the motor when the safety grill is raised (Ridsdale & Co. Ltd, n.d).

Moisture Teller: Is an instrument that is used for rapid and accurate determination of moisture in moulding sands in which preheated air is passed through the material to be tested which is contained in a tared sample pan with special woven wire base. The sample is weighed, and then dried for a specified time at a thermostatically controlled temperature. After the moisture has been removed, the material is again weighed. The quick action of the Moisture Teller is due to the hot air being blown through a thin layer of the material. A feature of this machine is that a large sample (50 grams) is used, thus increasing the accuracy of the method. The Moisture Teller can also be used to determine moisture in materials other than moulding sands (E.g. iron ore, crushed sinter, coal, metal powder, salt, hay, yarn, soap powder, malt and dried or shredded foodstuffs). Pans deeper than the normal 50 mm depth can be provided to accommodate an equivalent weight of material if this is less dense than moulding sand. Sliding Weight Scales: These scales have been specially designed for use in the sand testing laboratory. Small weights are not required for weighing samples up to 210 grams. This range is quite adequate for all test specimens which usually weigh from 140-180 grams. The total capacity of 2 kilograms is achieved, if required, using additional weights and, with a sensitivity of 0.2 grams, this is sufficient for most research and control tests (Ridsdale & Co. Ltd, n.d).

Digital Balance is used for easy weighing of sand samples used for preparing test specimens. It is designed with combined funnel and scoop to avoid physical loss of sample when transferring to specimen tubes. Flat platform digital balance has a capacity of 1200 g, readability 0.1 g, linearity  $\pm 0.1$  from 0-600 g,  $\pm 0.2$  from 601-1200 g. It has several weighing as well as parts counting mode (Ridsdale & Co. Ltd, n.d).

Sand Rammer is used to ram cylindrical specimens to AFS (2" diameter x 2" height) specifications for use on the universal sand strength machine to determine the functional properties of sand core, the Shatter Index Tester is used to determine toughness or plasticity or the green compression strength machine, Universal Sand Strength Machine or

High Strength Testing Machine is used to determine compressive strength. By using suitable accessories with the Sand Rammer, it can also be used to determine density, shear strength, tensile strength, transverse strength or splitting strength (Ridsdale & Co. Ltd, n.d).

Laboratory Core Baking Oven is used to bake core specimen in the laboratory. The temperature range of 30°- 300°C is precisely controlled by a solid state controller with thermocouple sensor, a fail safe thermostat is incorporated. The inclusion of large area heating elements, mineral wool insulation and a forced convection fan ensures optimum thermal efficiency with rapid heat up. The flow of air through the oven is be controlled by adjustable vents in the back. The case is fabricated with mild steel and stainless steel interior (Ridsdale & Co. Ltd, n.d).

The Electric Permmeter is used for quick permeability testing, which measure the permeability of the actual mould surface in permeability units by employing the orifice method and the pressure drop is indicated on a very sensitive gauge graduated directly in Permeability Units (Ridsdale & Co. Ltd, n.d). Core Permeability Tube is used for determining the permeability of dry sand, baked or cured core sand specimens after they have been stripped from the specimen tube. This specially shaped tube is fitted with an internal rubber sleeve which is inflated to seal the curved surfaces of the specimen. Under test, air can only pass through the specimen between the flat faces. This tube can be used with either the Permeability Meter or Electric Permmeter. Shatter index test is a simple control test which has been standardized by a standard AFS. The green sand test specimen is ejected from a specimen tube and falls 6 ft. (1.83 m) on to a steel anvil mounted in the centre of the 13.2 mm mesh British Standard Test Sieve, the percentage of the total weight of the fractured sand specimen which remains on the test sieve is weighed and it is expressed as percentage of the total weight of the specimen and is a measure of shatter index (Ridsdale & Co. Ltd, n.d).

Universal Sand Strength Machine (hand operated) is an accurate machine consists of three major parts; frame, pendulum weight, and pusher arm. The pendulum weight swings on ball bearings which are mounted on a steel shaft. Various accessories may be easily attached to perform different tests such as compression, shear, tensile, transverse and splitting strength. When testing green-sand cores, the test heads are placed in the lower holes of the pusher arm and weight, while for dry sand core, the core is inserted in the

upper hole where the breaking force is increased by a factor of five (The breaking force can be increased by a further factor of three by using the High Dry Strength Accessory). A magnetic rider on the scale records the position at which the specimen collapses, and the strength of the sand is read direct from the scale. The Universal Sand Strength Machine is a deadweight testing machine which will stay in calibration indefinitely (Ridsdale & Co. Ltd, n.d).

## **2.2 Core**

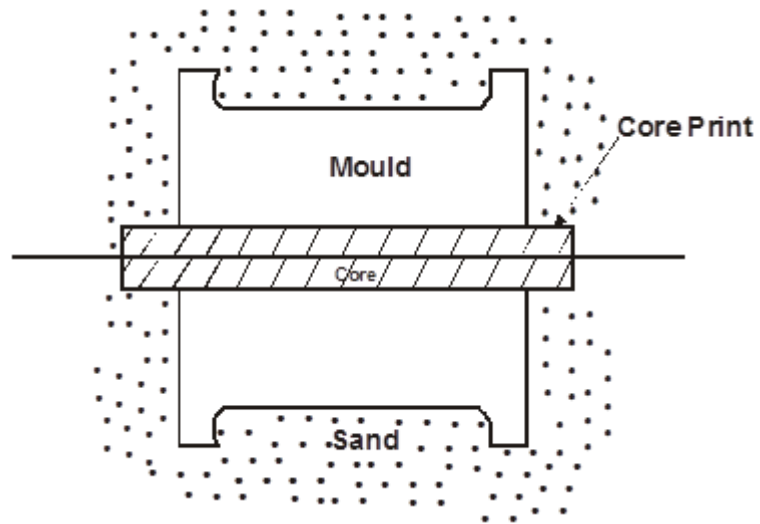
Cores are bodies of sand and are generally required to form the hollow interiors of the casting. Sometimes cores are also used to shape those parts of a casting that are very difficult or very costly to produce directly from the pattern, for example, over hangs or back drafts where it becomes difficult to withdraw the pattern from the mould (Todd *et al*, 1994).

### ***2.2.1 Types of cores***

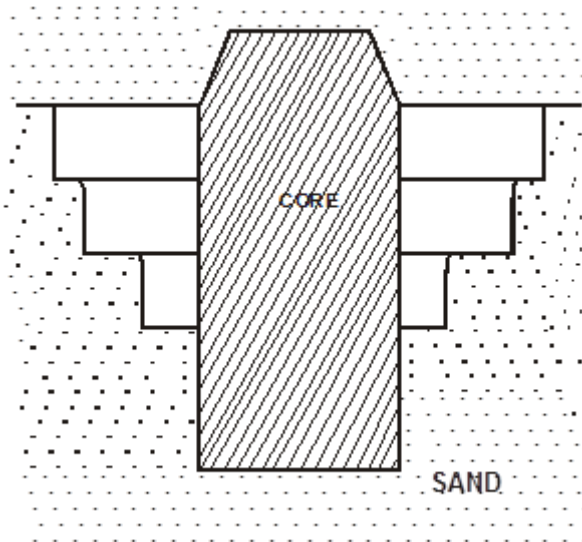
R.H Greenel cited by Mathew and Wainko (1983), stated that there are different types of cores depending upon their shapes and position in the mould as follows:

**Horizontal core:** This is the most common variety of cores. It is mostly cylindrical in shape and is placed in the mould horizontally as shown in Figure 1(a). Horizontal cores are given support at two ends and thus they rest on the core prints provided by the pattern. Horizontal cores are placed at the parting lines such that one half lies in the cope and the other half in the drag.

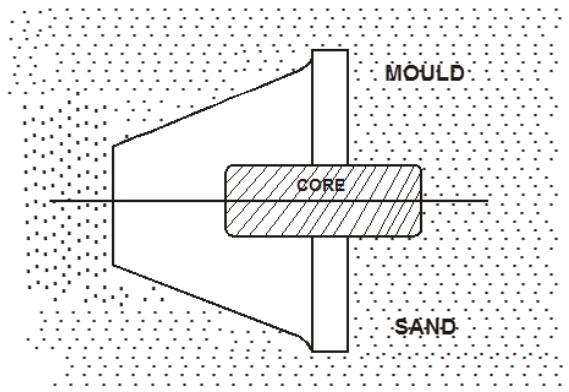
**Vertical cores:** These cores are similar in shape to that of the horizontal core but they are placed in a vertical position as shown in Figure 1(b). They are placed both in the cope and drag. They are usually tapered and the top is more than the bot



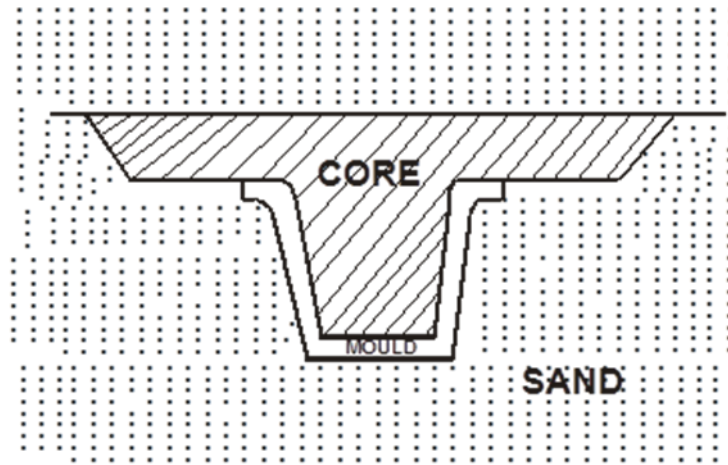
(a)



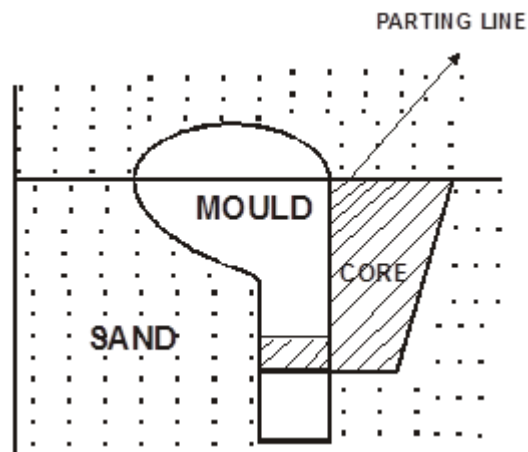
(b)



(c)



(d)



(e)

Figure 1. Types of Cores

(a) Horizontal (b) Vertical (c) Balance (d) Hanging or Cover (e) Wing

Balanced cores: These cores are used when a blind hole along a horizontal axis is required as shown in Figure 1(c). These cores are supported at only one end and as such the core prints are made sufficiently long enough to give the proper bearing surface. If the core is sufficiently long, it may be supported at the other end by means of chaplets. These chaplets are made of the same metal of which the casting is required, because the chaplets are to fuse with the metal.

Hanging or cover core: These cores are used when the casting is to be completely moulded in the drag by ramming the entire pattern in the drag and the core is required to be suspended from the cope. When the core, while hanging from the cope, have no any support at the bottom in the drag it is called a hanging core, but if it has its support in the drag, it is called a cover core as shown in figure 1(d). Usually these cores are reinforced by wire for increasing the strength.

Wing core: These are used when the axis of the desired hole does not coincide with the parting line of the mould i.e., either the core is required to be placed above or below the parting line. As shown in Figure 1(e), the side of the core print is given sufficient amount of taper so that the core can be placed readily in the mould.

### ***2.2.2 Core Making and Equipment***

Gupta and Kaushish (1996) stated that the environment in which the cores exist is much different from that of the mould. They further stated that sand cores are frequently employed in the production of hollow metal castings. Massalski (1989) reported that the primary problem with sand cores in aluminium castings revolves around collapsibility during shakeout. A cold box core for iron uses 1.2-4.4% of the resin in the core mix. The same core for aluminium requires 0.5-3%. The amount is reduced, so it will become loose during shakeout. Less resin also jeopardizes the bond strength when the molten metal interacts with the core (Lafay and Neltner, 2002).

In order to prepare a rigid core the sand is mixed with a binder and packed or rammed into a form of the desired shape. This core box is subsequently removed and the core is then baked (in the case of oil binders) until the core is sufficiently hard to withstand the usual handling in the foundry. Titov and Stepanov (1982) stated that the desired mechanical property of sand cores ranges as given in the Table 1.

Table 1: Desired Mechanical Property Ranges of Sand Cores

Cores for	Green Strength	Permeability	Tensile
types of alloy	Compressive	No	Strength
castings	[kN m <sup>2</sup> ]		[kN m <sup>2</sup> ]
Class I iron/steel	3-6	130-150	700-1000
Class II iron/steel	5-10	100	500-700
Class III iron/steel	10-16	100	350-600
Class IV iron/steel	15-25	70	200-300
Class V	20-35	70	80-150
Iron/steel			
Bronzes	3-5	90	400-600
Copper			
Intricate Aluminum	3-7	100	500-700
Non-intricate Aluminum	6-15	80	400-600
Magnesium cores	60-150	80	300-500

(Source: Titov and Stepanov, 1982)

The core has to withstand the severe action of hot metal which completely surrounds it and therefore, special considerations have to be given while selecting core sand for core making. These considerations are as follows:

The permeability of the core sand must be sufficiently high as compared to that of the moulding sands so as to allow the core gases to escape through the limited area of the core prints.

The core sand should not possess such materials which may produce gases while they come in contact with molten metal.

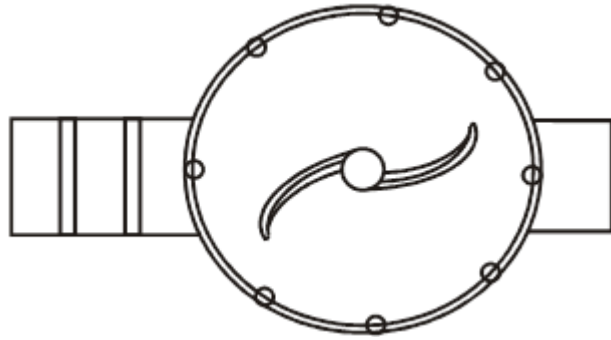
As the cores are subjected to very high temperature, the core sand should be highly refractory in nature.

The core sand should be collapsible in nature, i.e. it should disintegrate after the metal solidifies, because this property will ease the cleaning of the casting (Oliver and Miller, 1999).

Core making basically consists of the following four steps namely: core sand preparation, core making, core baking and core finishing.

According to Clark (1997), core preparation entails homogeneous and satisfactory mixing of core sand. Homogeneous mixing of the sand is not possible by hand and, therefore, for better and uniform properties the core sands are generally mixed with the help of any of the following mechanical means. Roller mills, Core sand Mixer, Vertical revolving arm type and Horizontal paddle type.

Clark (1997) also reported that in roller mills, the rolling action of the Mullers along with the turning over action caused by the plough results in uniform and homogeneous mixing. Roller mills are suitable for core sands containing cereal binders, whereas the core sand mixer is suitable for all types of core binders. These machines perform the mixing of core sand most thoroughly. A typical core sand mixer is shown in Figure 2.



*Figure 2: Core sand mixer*

*(Source: Clark, 1997)*

After preparing the core sand by mixing the sand thoroughly with a binder the next step is the core making which is normally done by machines, the machines are broadly classified into core blowing machines, core ramming machines and core drawing machines.

Core blowing machines: The basic principle of core blowing consists of filling core sand into the core box by using the medium of compressed air. The velocities of the compressed air are kept high to obtain a high velocity of sand particles, thus ensuring their deposit in the remote corners of the core box. As the sand with high kinetic energy comes, the shaping and ramming is done simultaneously in the core box. The core blowing machines can be classified into two basic groups, small bench blowers and large floor blowers (Todd *et al.*, 1994).

Heine and Rosenthal (1985) described small bench blowers as quite economical for core rooms having low production. The bench blower was first introduced in the early 1940s. Because of the simplicity of design, and high comparative productivity, bench blowers became readily popular. A cartridge type bench blower was considered to be a part of the core box equipment. However, one cartridge may be used for several boxes of approximately the same size. The cartridge is filled with sand and then the core box and cartridge are placed in the machine for blowing. The right handle clamps the box and the left hand blows the core. In a swing type bench blower, the sand magazine swings from the blowing to the filling position. There is another type of bench blower, which has a stationary sand magazine. This eliminates the time and effort of moving the magazine from filling to the blowing position. The floor model blowers have the advantage that they lend themselves more readily to automation. Mostly, these floor model blowers have stationary sand magazine and automatic controls. One of the major difficulties in core blowing is the channelling of sand in the magazine. The channelling, to a good extent may be prevented by agitating the sand in the sand magazine (Heine and Rosenthal, 1985).

Core ramming machines: Core can also be prepared by ramming core sands in the core boxes by machine based on the following principles: Jolting, Squeezing and Slingsing. Out of these three, machines based on jolting and slingsing are more common for core making.

Jolt moulding machine: In this machine, the pattern is placed on a platen attached to the top of an air cylinder. After the table is raised, a quick-release port opens, and the piston,

platen, and mould drop free against the top of the cylinder or striking pads. The impact packs the sand. The densities produced by this machine are greatest next to the parting line of the pattern and softest near the top of the flask. This procedure can be used for any flask that can be rammed on a moulding machine. As a separate unit, it is used primarily for medium and large work. Where plain jolt machine is used on large work, it is usual to ram the top of the flask manually with an air hammer.

Squeezing Machine: Squeezing machine can be either classified as hand -operated squeezers or air-operated moulding machines. These machines are suitable for shallow moulds. Squeezer moulding machines produce greatest sand density at the top of the flask and softest near the parting line of pattern. Air-operated machines are also applied in vertical moulding processes using flaskless moulds. Horizontal impact moulding sends shock waves through the sand to pack the grains tightly.

Sand Slinger: Is the most widely applicable type of ramming machines. It consists of an impeller mounted on the end of a double-jointed arm which is fed with sand by belt conveyors mounted on the arm. The impeller rotating at high speed gives sufficient velocity to the sand to ram it in the mould by impact. The head may be directed to all parts of the flask manually on the larger machines and may be automatically controlled on smaller units used for the high-speed production of small moulds.

Core Drawing Machines: The core drawing is preferred when the core boxes have deep draws. After ramming sand in it, the core box is placed on a core plate supported on the machine bed. A rapping action on the box is produced by a vibrating vertical plate. This rapping action helps in drawing off the core box from the core. After rapping, the core box is raised leaving the core on the core plate ( E.D Howard, 1959 cited by Jain, 1986).

Cook (1991) stated that core is baked after the core is prepared; they are baked in a baking furnace. He stated that the main purpose of baking is to drive away the moisture and harden the binder, thereby giving strength to the core. The core is normally baked at a temperature of 200°C for 1 to 2 hrs; the core drying equipments are usually of three types which are of batch type oven, continuous type oven and the dielectric bakers.

Cook (1991) further described batch type ovens as ovens that are used for baking variety of cores in batches. The cores are generally placed either in drawers or in racks which are finally placed in the ovens that are usually fired with gas oil or coal.

Continuous type oven are preferred for mass production. In this type, core carrying conveyors or chain move continuously through the oven. The baking time is controlled through the oven. The baking time is controlled by speed of the conveyor. These continuous type ovens are generally suited to small cores.

Dielectric bakers are based on dielectric heating. In this type of furnaces, the core plates are not used because they interfere with the potential distribution in the electrostatic field. To avoid this interference, cement bonded asbestos plates may be used for supporting the cores. The main advantage of these ovens is that they are faster in operation and a good temperature control is possible with them (Cook, 1991).

Hofmann (1978) stated that core finishing is the next step after core baking; the cores are given certain finishing operations before they are finally set in the mould. The fins, bumps or other sand projections are removed from the surface of the cores by rubbing or filing. The dimensional inspection of the cores is very necessary. Cores are also coated with refractory or protective materials to improve their refractoriness and surface finish.

### **2.3.0 Binders**

According to Wilson and Faraday (2009), the main purpose of the core binder is to hold the sand grain together, impact strength and a sufficient degree of collapsibility. Beside these properties, the binder should be such that it produces minimum amount of gas when the molten metal is poured in the mould. Although, foundry binders are required to be none poisonous, no pungent smell, not harmful when touched directly by skin, should not be poisonous to the water or environment when leaked out from the waste sand, easy to be decomposed and erased i.e. the sand should be very easy to recycle (environmentally friendly). Apart from high tensile strength, good flowability of the sand, good surface property, easy shake out under casting temperature, resistance of moisture absorption and low gas evolution are also required. In general, binders are inorganic as well as organic, but organic binders are preferred because they are combustible and are destroyed by heat at a high temperature which gives the core sand sufficient collapsibility.

Special binders are used in core sands to add strength with the oldest binder being vegetable oil, although synthetic oil is now used, in conjunction with cereal or clay. Generally, the binder is introduced into the core sand. This is then baked in a convection oven between 200 and 250°C. The heat causes the binder to cross-link or polymerize (R.H Greenel cited in Mathew and Wainko, 1983).

### ***2.3.1 Types of Binders***

According to Cable (1991), binders can be listed as organic and inorganic, while common sand binders are molasses, cereal binders, dextrin, thermo setting, sulphate binders and core oils. Molasses is a secondary binder to increase the hardness on the core, it is used in the form of molasses water and it is sprayed on the core before baking. Cable (1991) also stated that cereals binder are organic binders which include corn starch and wheat flour starch that is commonly used with core oil to provide green, baked compression strength and collapsibility, which varies from 0.25 to 3.0% by weight in the sand while dextrin is normally added to increase the baked strength and also the collapsibility of the core. Protein binders are organic binders that are protein in nature such as gelatine, casein and Gmbond which forms biopolymeric bonds and cures through dehydration rather than chemical reaction. They are used to increase collapsibility. He further stated that pitch binders have low moisture absorption rate and are used extensively for large iron cores. Thermo setting resins are inorganic binders normally obtained by chemical reactions, example of thermo setting resin are phenol formaldehyde and urea formaldehyde. They have the advantage of low temperature baking, collapse readily, produce small amount of gas and high strength. Sulphate binders (lignin) are brown powders consisting of a sulphonate salt made from waste liquor of the sulphate and are commonly used with certain amount of clay, while Core oils consists of blend of various ingredients mainly the vegetable oils, mineral oils, animal oils and other such materials. Among the vegetable oils, the more important are linseed oils and soya beans oils. In the mineral oil group only those oil which polymerize on baking are preferred, like Rosin oil which is used to increase the collapsibility, as well as baked strength. Generally the green strength of oil bonded core sand is low where as the baked strength is sufficiently high. Core oil is in liquid state when it is mixed with the sand but form a coherent solid film holding the sand grain together when it is baked. Although drying of certain oils occur at

room temperature, but this can be expedited by increasing the temperature and this is why core made with core oils are usually baked (Cable, 1991).

### ***2.3.2 Types of Core Oils and their Requirements***

There are different types of core oils that is used in foundry practice for casting purpose, these include; Linseed oil, P – 78 oil, Kenslip oil, Kleen strup, Melon seed oil, Castor oil, Neem oil, Beniseed oil, Corn oil, Fish oil and Cotton seed oil.

A. Tella cited by Mathew and Wainko (1983), stated the following requirements for core oils;

Mixing: The viscosity of the binder should allow ready mixing and uniform distribution throughout the sand, each particle receiving a thin coat of binder.

Oxidation: The binder when mixed with sand must not oxidize so rapidly as to gum up the core box and mixing table or machine. After the box is rammed with the sand binder mixture the core should leave the box clean.

Green bond: The green bond or strength before baking should be such as to prevent the core from losing its shape when placed in storage or in handling when transferred from the cast table to the oven.

Baking: The binder should not be susceptible to over baking or burning, but from the standpoint of economy of heat and time, it should give a core of high strength quickly and at the lowest temperature possible. The gases produced on baking should not be offensive or highly inflammable.

Core strength: The binder should produce a core of high transverse strength on baking so that it can be handled without breaking easily. The core should be sufficiently rigid to prevent the edges and details from crumbling on handling. Baked tensile strength is the most critical of all core properties in metal casting and solidification because as cores are interior implants within mould cavities, cores are usually subjected to severe thermal conditions and high temperature induced failure that can in turn cause casting defects (Gilson,1993).

Behaviour in the mould: When the molten metal is poured into the mould, the core should remain rigid until the metal in contact with it has set. The binder should burn out completely leaving no appreciable ash when the hot metal comes in contact with the core. The latter should be sufficiently porous as to allow the gases evolved to vent easily through it. The binder should not generate an unduly large volume of gas upon decomposition. The core should collapse readily to allow for the contraction of the casting and permit subsequent ease of cleaning. According to H.W Dieter cited by Mathew and Wainko (1983), collapsibility within the range of 60 – 120s are considered as fast with the consequence of the production of cracks and warpage in casting where as those greater than 480s are regarded to be slow, which result in metal penetration in castings, collapsibility which is between fast and slow is considered moderate and acceptable in casting (120 – 480s).

### ***2.3.3 Core-binding Properties of Fatty -based Oils***

Olakanmi and Arome (2009) stated that many cores have been made from fatty – based oil binders. In their contributions, they worked on the characterisation of the core binding properties of fatty based oils using beniseed and melon oils, with the view of finding alternative to the imported foundry core oil.

Sand samples were collected, mixed, washed and allowed to dry. Core-sand mixtures (sand, clay, wheat, water) containing either beniseed or melon oil in varying proportions were prepared. They assessed the Green permeability, Green Compression Strength (GCS), Green Shear Strength (GSS), Baked Compression Strength (BCS) and bulk density based on AFS Mould and Core Test standards. They also assessed the practical applications of the core oils (beniseed and melon seed oil) by casting three bushings made in large, medium and small sizes in an aluminium alloy with core sand. The analysis of the values obtained for green permeability of the core sand mixes containing either melon and beniseed oils (irrespective of the proportions) indicates that gases and vapour could easily permeate the pores of the cores made with these core oils, thereby reducing defect formations in the casting.

Ademoh (2009) determined effect of addition of linseed oil to Nigerian gum Arabic grades 2 and 4 on baked tensile strength of sand cores used as implants in foundry moulds. The tensile strength specimens were oven baked at 200°C for 1 – 3 hours and then

oven cooled to room temperature before the test. The permeability and shatter index specimens were made and tested in the green state. He found out that addition of linseed oil to plain grades 2 and 4 Nigerian gum Arabic caused property enhancements. The effects are in the form of increased tensile strength of baked cores of about 12% and reduced baking period of about 1 hour. Permeability and shatter index were marginally reduced by about 3% over cores bonded with plain gum Arabic.

Ademoh (2010) also carried out research on the evaluation of tensile strength of foundry cores made with hybridized binder composed of Neem oil and Nigerian gum Arabic. The Neem oil was found to contain unsaturated fatty acid made up of 41% oleic acid, 20% linoleic acid, 20% stearic acid and 18% palmitic acid as its major active ingredients. The core specimens were bonded with 3% of each of four commercial grades of Nigerian gum Arabic and 0.5 – 3% varied weight of neem oil. They were oven baked at 200°C for 1-3 hours then oven cooled to room temperature before the tests. The results show that hybrid binders made of 3% grade 3 gum Arabic and 0.5% neem oil baked at 200°C for 1 hour were suitable for class III – IV iron/steel, copper bronze, non – intricate aluminium and magnesium cores while those made of 3% gum Arabic grade 3 with 1.5 – 3% neem oil baked for 1<sup>1</sup>/<sub>2</sub> hour were suitable for class II iron/steel, brass and intricate aluminium cores. Tensile strength increased with increased baking period up to 2<sup>1</sup>/<sub>2</sub> hour after which it gradually decreased at each composition of hybrid binder. Reduction in bond strength could only be accounted for by a reduction of chemical reactivity between sand and binder constituents or by burning some binder. The benefits of mixing neem oil with Nigerian gum Arabic as hybrid binder is more pronounced when cores are baked at about the melting temperature of grade of gum Arabic involved. Baking cores below melting point marginally improves bond strength while baking them at temperatures well above melting point depresses tensile strength of cores

Ademoh (2011) studied the potentials of foundry sand core binders made with composite of Nigerian gum Arabic and natural honey. Core specimens made with silica base sand bonded with composites of each of four grades of Nigerian gum Arabic and honey were classified and tested for tensile and compressive strength; permeability and shatter index to ascertain binder efficacy. Tensile strength specimens shaped like figure number eight were oven baked at 180°C and 200°C; cooled to room temperature and tested with universal strength testing machine. Cylindrically shaped permeability and

shatter index specimens were tested with permeability meter and shatter machine. Results showed that cores baked at 200°C attained higher strength at shorter baking periods than those baked at 180°C. Honey improved tensile strength by 15%, 17%, 16% and 17% over the plain gum Arabic grades 1, 2, 3, 4 bonded cores, respectively. It improved compressive strength by 7%; permeability and shatter index by 2%. Composites cores of 3% gum Arabic grade 2 - 4 with 0.5% honey baked at 200°C were suitable for magnesium, copper bronze, non-intricate aluminium, classes III, IV, V iron and steel castings. Cores made with composites of 1.5 - 3% honey and 3% gum Arabic grade 1 - 4 were suitable for intricate aluminium, copper brass, class II - V iron and steel castings.

Ademoh and Abdullahi (2009a) investigated the physical and chemical properties of Nigerian Acacia species to determine the melting point, optical rotation, specific gravity, water solubility, pH, Moisture/volatile matter, metal/sulphate ion and macro – structural composition of each of the four grades of Nigerian Acacia species. The study revealed that grade 1 has the highest melting temperature followed by grade 2, grade 3 and grade 4 with melting point average of 178 – 210°C, which fell within the range of most organic foundry binders like vegetable drying oil used extensively to bind core. The grade 4 species have positive optical rotation and with the least rotation, followed by grade 1, grade 2 and grade 3 with the value more than 200% greater than other grades. He stated that optical rotation inversely relates to specific gravity and adhesiveness, this means that grade 4 have higher bonding strength than grades, 1, 2 and 3. Specific gravity is directly related to viscosity and adhesiveness property, keeping all factors constant, grades 1 and 4 would likely exhibit similar adhesive properties and give stronger bonds than grades 2 and 3, since high specific gravity means high adhesives with sand.

The water solubility at temperature of 30° of each Nigerian Acacia species showed that the material has high solubility and forms clear solution in water. Acacia is insoluble in organic solvent, the result showed that grade 1 and 4 have equal solubility, followed by grades 3 and 2. Solubility relates directly with reactivity which determines bond strength, meaning that grade 1 and 4 of the Acacia species are better binders than grades 3 and 2. The average pH of the Acacia species ranged from 4.68 (grade 4) to 4.36 (grade 1), which are within weak acid range. Grade 4 is least acidic, followed by grade 2, grade 3 and then grade 1 most acidic in the group. The low acidity makes it chemically human friendly. He

also observed that grade 4 had the lowest moisture, implying that grade 4 will evolve least gas at high temperature.

Ademoh and Abdullahi (2008a) researched on the effect of kaolin clay addition on the mechanical properties of foundry moulding sand grade 3 and 4 Nigerian gum Arabic (*Acacia* species). They analysed the specimen for green, dry strength, permeability, hardness, shatter index, moisture content and comparison where made on plain grade 3 and 4 gum Arabic binders. Analyses of specimens bonded with 1-8% grade 3 Nigerian gum Arabic exudates mixed with 1% kaolin were found to contain moisture which decreased from 2.5 at 1% to 2 at 8% gum Arabic because more binder needed more water to dissolve it and wet the clay and sand for reaction. The green and dry compressive strength increased from 52/376 KN/m<sup>2</sup> at 1% acacia/1% kaolin to 102/436 kN/m<sup>2</sup> at 8% acacia/1% kaolin clay respectively. These compared with 71/349 kN/m<sup>2</sup>, for green/dry strength with 9% grade 3 acacia binder which showed that 1% added kaolin increased green/dry strength of grade 3 Nigerian gum Arabic bonded mould by about 45%/40%. Green/dry compressive strengths varied from 60/390 kN/m<sup>2</sup> at 1% acacia/1%kaolin to 120/502 kN/m<sup>2</sup> at 8% grade 4 acacia/1% kaolin. The hardness and shatter index for the tested moulds showed improvement over those bonded with plain grade 4 acacia and suitable for aluminium castings. A cross comparison of result for composites of grade 4 acacia/kaolin with grade 3 acacia/kaolin showed grade 4 acacia/kaolin is a better binder than grade 4 acacia/kaolin mix. Permeability, hardness and shatter index are higher for plain grade 4 gum Arabic bonded specimens. They reported that composite of 3% grade 4 acacia/kaolin binds better than that of 3% grade 3 acacia/kaolin and fixing kaolin at 1% with varied composition of gum Arabic gave higher benefits than otherwise.

Ademoh and Abdullahi (2008b) investigated the potential of composite combination of each of grades 1 and 2 Nigerian acacia species exudates and bentonite clay as sand mould binder. Core specimens were made with silica base sand bonded with bentonite clay and composites of each grades 1 and 2 of Nigerian acacia species exudates were classified and tested for moisture content, green and dry compressive strength, permeability and shatter index. The results of the study revealed that combination of bentonite clay and each of the grades 1 and 2 Nigerian acacia species as composite binders for moulding sand gave better performance than when each of the materials is used separately as plain binders in a foundry. Presence of bentonite clay in grades 1 and 2

Nigerian acacia species bonded moulds generally improved permeability, hardness, shatter index and particularly, green and dry compressive strength by about 12% and 25% respectively. The researcher further noted that though the peak values of bonding strength were not attained as shown by none sloping of the green and dry compressive strength curves, further addition of binder may cause decreases in values of some other critical foundry properties like permeability of moulds.

Wilson and Leaper (1999) determined the transverse strength of rubber seed oil for foundry core binders. Test samples were made of silica sand of BS standard size 30 – 50 mesh with sand binder ratio of 50 to 1 used; the samples were oven baked for 2 hours at 240°C. They observed that the average transverse strength of rubber seed oil was 45 kN/m<sup>2</sup> compared to that of linseed oil of 47.12 kN/m<sup>2</sup>.

Fayomi and Momoh (2011) investigated the effect of groundnut oil, palm oil and cotton seed oil contents on the tensile strength of core. Core sand mixtures comprises of sand, clay, cassava starch and water containing groundnut oil, palm oil and cotton seed oil in varying proportion. The oil level was varied between 1.5 and 10%, other additives were kept at 2.5% starch, 2.0% clay and 8% water. The mixtures were moulded into cores and baked at 200°C for 1 hour. The tensile strength, after baking were measured; they observed that increasing the oil content above 10% generates a lot of smoke, which burn off starch during baking. High baking temperature of 200°C increases the tensile strength of the cores, while strength values are lower for cores baked at 150°C. He suggested that high core oil level might not be safe for the workers and working environment due to danger of explosion and environmental pollution. Further investigation on the tensile strength of starch – free cores and the effect of increased starch on core strength, were carried out on cores mixtures, containing clay, water and oil as the primary binder, but had no starch addition.

The tensile strength was very low (306 kN/m<sup>2</sup>) for groundnut oil at baking temperature of 200°C and 274 kN/m<sup>2</sup> at baking temperature of 150°C, while the tensile strengths for cotton seed oil were 274 kN/m<sup>2</sup> and 271 kN/m<sup>2</sup> at baking temperature of 200°C and 150°C, respectively 99 kN/m<sup>2</sup> and 86 kN/m<sup>2</sup> at baking temperature of 200°C and 150°C for palm oil. The effect of increased starch on core strength revealed that the degree of bonding properties on the core strength is a function of starch level in the mixture of various oil content used in the study with other additives. At 3.5% starch, 10%

oil and 12% water, the tensile strength of the core using groundnut oil as core at 200°C baking temperature for 1 hour was 565 kN/m<sup>2</sup>. While cotton seed oil tensile strength, at the same level of starch, oil and water at the same baking temperature and time was 533 kN/m<sup>2</sup>, that of palm oil at the same level of starch, oil and water at the same baking temperature and time of 200°C and 1 hour was 486 kN/m<sup>2</sup>. But increasing the starch content to 4%, 3.5% clay and 12% water at baking temperature of 200°C for 1 hour, changed the tensile strength of cores made using groundnut oil to 534 kN/m<sup>2</sup>, cotton seed oil to 525 kN/m<sup>2</sup> and palm oil to 456 kN/m<sup>2</sup>, showing apparent deterioration in the properties of the core strength. This means that an increase in starch level beyond optimum level may cause unfavourable effect due to burning off of starch at temperature above 150°

#### ***2.3.4 Core – Binding Properties of Protein Binder for Aluminium Casting***

Shi *et al.* (2001) reported on a new protein based core binder for aluminium casting, with the aim of finding an alternative binder that is environmental friendly, easy to recycle and with reasonable cost for core making for aluminium casting. Standard China silica sand were collected, sieved, washed and oven dried to drive away moisture. The core sand were mixed with water, protein binder (a kind of natural amino acid ramification glue, with a relative molecular mass of range of 20000 to 250000) the mixtures were moulded into test cores of 50 mm height x 50 mm diameter cylindrical shape. The samples were heated to a certain temperature at different time for different mixtures of bonding sand, cooled to room temperature then tested for tensile strength and collapsibility of the sand core. The composition of the core sand mixtures were; Starch bonding sand: with composition of 100% sand, 2% starch and 5% water with baking temperature of 180°C for 30 minutes. Oil bonding sand: 100% sand, 2.5% oil, little water and dextrin with baking temperature of 210°C for 1 hour. Fat bonding sand: 100% sand, 2.5% fat and baking temperature of 210°C for 1 hour. Protein bonding sand: 100% sand, 1.4% protein binder, 7% water and baking temperature of 180°C for 30 minutes.

They reported that the protein bonding sand possesses higher strength, which is close to that of common resin sand, they also observed that protein core binder samples having 1% binder by mass are stronger than conventional core binder samples and less content of binder is needed to meet the core demand because of high specific strength. Similarly, the green compressive strength of protein sand core is higher than that of starch,

sand core, oil and fat sand cores. But the surface hardness of resin, oil and protein sand cores are higher than that of fat and starch sand cores. While the shakeout properties of starch core is better, next to protein sand cores that decomposes at 600°C, indicating that protein binder cores are very fit for aluminium casting.

Bender (1994) researched on pullulan as a binder for metal casting. He cultured a micro organism belonging to the genus pullularia, a strain of pullularia pullulans were inoculated into a culture medium comprising 10% of starch syrup, 0.5% of  $K_2 HPO_4$ , 0.1% of NaCl, 0.02% of  $MgSO_4 \cdot 7H_2O$ , 0.06% of  $(NH_4)_2 SO_4$  and 0.04% yeast extract, the culture was rotated at 24°C for 5 days. The cells were removed by centrifugation, the pullulan produced as an extracellular sticky substance were precipitated by addition of methanol and repeatedly dissolved in water to isolate white pullulan, washed with methanol and dried to obtain dry pullulan in a yield of 60% to 70% saccharides.

Sand samples were collected, mixed, washed and allowed to dry. Then 15% aqueous solutions of pullulan having a molecular weight of 185,000 were added to the silica sand. The mixture were milled for 3 minutes in a sand mill, and then moulded into test specimens of 50x50mm. The test specimens were dried in an explosion – proof constant temperature oven at 200°C for 15 minutes, cooled to room temperature. The specimens were tested for dry flexural strength and moisture content.

Bender (1994) noted that pullulan sand mould dries in a shorter period of time compared to oil sand mould, while the incorporation of bentonite in the linseed oil sand is effective for improving the green strength. He also used 60 kg of silica sand agitated in a whirl mixer (operating at 76 rpm), 3.0 kg of a 20% aqueous solution of pullulan having a molecular weight of 185,000, mix and milled for about 1 minute and 5 seconds then moulded into core A, no odour were detected. He reported that the mould produced were far superior to the shell mould and the furan – base self curing mould. Other moulds were prepared with 60 kg of silica sand, 1.875 kg of bentonite clay, 3.125 kg of a 20% aqueous solution of pullulan with molecular weight of 185000, mixed for 1minute and 5 seconds before moulding into mould and core B. The two cores A and B were set respectively into two master mould, malleable cast iron of 1450°C temperature were poured into the master mould, the pouring time were 15 seconds. During the pouring, almost no odours were detected except for a faint smell of scorched sweet potato. He observed that the core have distinctive superiority over the shell mould and oil sand cores. After the cast metals have

cooled to room temperature, the two cores (A and B) were broken down almost spontaneously, exhibiting very favourable knock – out behaviour. He also stated that the castings obtained were of high quality without showing no casting defect, in this respect the mould and cores made from the two different compositions and mixtures were far preferable to the water glass base mould.

Earl (2007) carried out a study on core oils (linseed oil, perrila oil, China wood oil and castor oil) to determine whether or not there is a relationship between the tensile strength of cores and the physical/chemical properties of core oils used as a binder and the effect of moisture on the tensile strength of the baked cores. Silica sand was sieved, washed and oven dried at 100°C for 10 minutes to drive away moisture. A ratio of 78% of sand to 4% of oil by weight, 10% bentonite by weight were used in preparing the core sand mixtures, 8% of water by weight were added to the mixture, mixed and moulded into sand cores. The cores were baked in an electric oven at 232°C for 45 minutes. Cores were carefully weighed to four decimal places on an analytical balance, placed in the moulds which were made from moulding sand containing 7 – 9% moisture, the cores were then suspended on wires instead of allowing them to come in contact with the moulding sand; otherwise the moulding sand will adhere to the core, which make it difficult to determine accurately the weight of the core. The cores were allowed to remain in the mould subjected to the moist atmosphere for a period of 24 hours.

The cores were removed from the mould, the inherent moisture was then determined by allowing the core to dry in an atmosphere of approximately 35% relative humidity until no further loss in weight occurred. He noted that the inherent or combined water were the difference between the initial weight of the core before placing it in the mould and the final weight after evaporation of the surface moisture, the amount of water absorbed by the cores were averaged.

Each core was tested for tensile strength after weighing and the average tensile strength of the cores were determined. The specific gravity, percentage of ash, flash point, iodine number and saponification number of the core oils were determined. Earl (2007) stated that the graphical correlation of the average original tensile strength of the cores with the specific gravity of the core oils showed that no definite relationship exist between these factors. He further stated that the specific gravity of the core oil should be used as a general test and in conjunction with the other tests, to predict the tensile strength of cores

made from oil and not independently, because of possible method used to produce the core oil. The flash point of the core oils varies directly with the original tensile strength of the cores, he stated that the relationship cannot be regarded as sufficient to justify judging the worth of oil on the basis of fire point alone. In a similar manner, the ash content of a core oils was high for a number of reasons, a relatively high percentage of ash was only a general way to indicate low tensile strength, and should not be used by itself to predict whether or not a core oil will produce cores with low or high original tensile strength. He also stated that it is not advisable to predict the strength – producing qualities of core oils on the result of a single test, but a complete analysis of all the physical and chemical properties of a core should be used to determine the quality or grade of oil. He further stated that the initial tensile strength of the baked cores made from the four oils by standard methods of mixing, ramming, baking time, and baking temperature were found to be directly proportional to the saponification and iodine numbers of the baked core oils. It is an evident that a linear equation may be used to calculate the approximate tensile strength of any core oil used, if either the saponification or the iodine number of the oil is known. Secondly the percentage loss in tensile strength of the baked cores made from the four oils were found to be proportional to the amount of water absorbed by cores, thirdly the amount of water absorbed by the baked cores made from the four oils varied inversely with original tensile strength of the cores or the oil that produce cores of low tensile strength also absorbed the greater amount of water.

Penko and Tom (1989) researched on Sodium Silicate Glass as an inorganic binder in foundry industries. Sodium silicate (65 g) was added to 35 ml water, the mixture was then heated to 75°C, while stirring. The solutions were kept under these conditions for 60 min until the dissolution was completed.

The concentrations of this solution were adjusted to 65% (w/w) in water, while stirring was continuous during the whole time. Adequate granular sugar were added to this solution in an amount of 1.0—2.0 weight percent with respect to sodium silicate used to achieve a concentrated silicate solution. The viscosities of this solution were controlled to 500 centipoises by addition of sugar. The solutions were cooled to room temperature and their apparent viscosities were measured at 25°C and then ready for use as an adhesive. The rheology study of polymer solution stated that the appropriate concentration variable for the particles is their volume fraction ( $\phi$ ), which is the ratio of the volume of the

particles to that of the entire dispersion. In prepared solutions the concentration is selected at a constant level, so volume fraction is constant and equal to  $\phi = 0.65$ . According to experimental results, the suitable concentration and viscosity of the silicate solution is 65 % (w/w) and 500 cp, respectively. Since viscosity is directly proportional to volume fraction of silicate solution, viscosity increases with increasing the concentration of solution. The viscosity studies on these silicate solutions indicate that the high viscosity of such concentrated solution which may even become syrupy, is not due to aggregation or polymerization, but due to the fact that the molecules are close to one another. Sodium silicate solution in presence of an ester acts as a binder in a two stage reaction; hydrolysis of the ester followed by gelling of the silicate at the lower pH. The bond strength and reaction velocity is dependent on the  $\text{SiO}_2/\text{Na}_2\text{O}$  ratio of the sodium silicate, the type and the amount of ester used.

The mixture of moulding sand, sodium silicate, hardener (an organic ester), and together with suitable additives were heated for about 10 minutes to produce the temporary mould. The flame causes the ester to decompose to produce acid and alcohol. The produced acid lowers the pH, thereby causing the silicate gel to bind the sand particles. Carbon (IV) oxide ( $\text{CO}_2$ ) was used as a hardener, the bond strength of the sand mixture depends on the  $\text{Na}_2\text{O}/\text{SiO}_2$  ratio of the sodium silicate, length of time spent and pressure of gasification rate step by carbon dioxide. The hardening process involving gassing of the sand mixture with carbon dioxide first established the importance of sodium silicate as binder. This process became of particular importance for core making on account of its rapid turn-around time (10–25s), and environmentally it is extremely beneficial.

The concentrated 3:3 ratio ( $\text{SiO}_2:\text{Na}_2\text{O}$ ) sodium silicate solution, the moulding sands, and pitches or sugar with suitable additive and cross-link agent are composed to make a temporary mould. The 3:3 ratio sodium silicate solution with a suitable viscosity, as an inorganic binder is responsible for binding the different sand particles, in presence of an organic ester (by using flame) or carbon dioxide. The viscosity study indicates that the high concentrated silicate solution is used to wet the sand grains. Since a suitable viscosity is necessary for improving wettability of sand particles and consequently for increasing the temporary mould stability, the sugar is used as a thickening agent, to concentrate the binder solution at a desirable limit. The suitable limits of viscosity for sand moulding were

about 500 centipoise. The produced concentrated silicate solution forms a thin film around the sand particles. The sand particles, when they come into contact with each other form a rigid network rapidly, due to gellation in presence of a suitable curing agent.

Nigeria foundries largely depend on imported core binders like linseed oil and other sophisticated binders which are based around phenol formaldehyde resins. According to O.Apondiede cited by Ademoh (2009), revealed that some indigenous vegetable oils are suitable for foundry cores but with each suffering from certain technical limitation.

A search through the literature on locally available core oils in Nigeria indicates that extensive investigation on rubber seed and shea butter oils as foundry core binders has not been carried out. Therefore there is need to investigate the functional properties of rubber seed and shea butter oils and to test for suitability as core binder. Rubber seed and shea butter oils are cheap, humanly and environmentally friendly, there are also abundantly available in Nigerian. Their use will practically lower the production cost of casting aluminium products.

## CHAPTER THREE

### MATERIALS AND METHODS

#### 3.1 Materials

The materials for this study were rubber seed oil, shea butter oil, clay sand and water. The materials were selected based on the fact that they are widely available in the southern part of Nigeria. The rubber seed oil is dark red in colour and was free from sediment and the shea butter oil is milky in colour and was also free from sediment.

##### *3.1.1 Rubber Seed Oil*

Raw rubber oil (RSO) was bought from Rubber Seed Research Institute Benin City, Edo state, with chemical composition containing 19.0% saturated acids made up of - Palmitic acid (10.6 %) and Stearic acid (8.4 %) and 81.0% unsaturated acids made up of Oleic acid (24.6 %), Linoleic acid (39.4 %) and Linolenic acid (17.0 %).

##### *3.1.2 Shea Butter Oil*

Shea butter oil (SBO) was bought from a local market in Idumuje Unor, Aniocha south local government area of Delta state, with chemical composition of Oleic acid 60%, Stearic acid 30%, Linolenic acid 7%, Palmitic acid 2%, Linoleic acid 0.6% and Arachidic acid 0.4% as its major active ingredients. Fatty acid composition of Shea butter oil was determined using gas chromatography. An oil quantity of 0.1 ml oil was converted to methyl ester using 1 ml of Sodium methoxide ( $\text{NaOCH}_3$ ) in 1 ml hexane before being injected into the gas chromatograph. A gas chromatograph analysis was performed on a Shimadzu gas chromatograph equipped with flame ionization detector and capillary column (30 mm  $\times$  0.25 mm  $\times$  0.25  $\mu\text{m}$  films). The detector temperature was programmed for 280°C with flow rate of 0.3 ml/min. The injector temperature was set at 250°C. Nitrogen was used as the carrier gas. Identification of the peaks was performed by comparing retention times with those of genuine standards analyzed under the same conditions

### ***3.1.3 Clay and Silica Sand***

The clay was collected from clay depot in Ebu in Oshomili north local government area of Delta state, while the silica sand was collected from Federal Institute of Industrial Research Oshodi Lagos state (FIIRO). Sieved sand, representing sample of the dried sand was taken by the cone and quartering sampling method for experimentation as described by American Foundry men Society (AFS) Mould and Core Test Handbook (1963)

## **3.2 Methods**

### ***3.2.1 Physical and Chemical Properties Determination***

Specific gravity of the formulated core oil at different composition and linseed oil was carried out by placing 100 ml of core oil in a 500 ml beaker and hydrometer was introduced into the oil. The specific gravity was read directly from the hydrometer, the process was repeated for linseed oil.

Flash point of the formulated core oil at different composition and linseed oil was determined by placing the oil to be analysed in a beaker after which a thermometer was introduced into the oil, heat was applied and the flash point temperature was noted.

Iodine number was determined by weighing 2 g of formulated RSO-SBO into iodine flask and dissolved in 10ml of chloroform. Then 25 ml of Hanus iodine solution was prepared by dissolving iodine (13.3 g) in glacial acetic acid (1liter) with the help of heat. The Hanus iodine solution was added using pipette to drain the solution within 5 minutes. The solution was mixed well in the dark for exactly 30 minutes by shaking occasionally, 10 ml of Potassium iodide (KI) was added and shaken thoroughly. Thereafter 100 ml of freshly boiled and cooled water was added to wash down any free iodine on the stopper. The mixed solution was titrated against 0.1N sodium thiosulphate until yellow solution turns almost colourless. A few drop of starch was added as indicator and titration continued until the blue colour disappeared completely. Towards the end of the titration the flask was shaken vigorously so that the remaining iodine solution in  $\text{CHCl}_3$  was taken up by potassium iodide solution. The process was repeated for linseed oil and also without the formulated RSO-SBO and linseed oil ( i.e. Blank, was run without the sample).The quantity of Blank minus the quantity of sodium thiosulphate solution

gives the thiouslphate equivalent of Iodide absorbed by the formulated RSO-SBO and linseed oil. The iodine number for the formulated RSO-SBO and linseed oil was calculated using the equation. 2 (Omuja, 2009)

$$\text{Iodine number} = \frac{(B-S) \times N \times 12.69}{\text{weight of sample (g)}} \quad (2)$$

B = ml thiosulphate for blank

S = ml thiosulphate for formulated RSO-SBO and linseed oil

N= normality of thiosulphate solution

pH of the formulated core oil at different composition and linseed oil was determined by weighing out 10 g of RSO-SBO into a clean dry analysis cup and manually adding 50 ml of (TAN) solvent per ASTM D 664-89 Isopropyl Alcohol, Toluene and water, the TAN solution was to make oil to take hydrophobic organic form, in order to introduce water to oil, since oils are not water soluble (to solvate the carboxylic acid), which oxidized the oil. Mixing of the solution was done by agitation in the analysis cup after which a pH electrode linked to Denver titrator was placed in the analysis cup and the pH of the RSO-SBO was read out directly from the screen of the Denver titrating machine. The process was repeated for linseed oil.

Refractive index of the formulated core oil at different composition and linseed oil was determined with digital Abbe refractometer (DR194B) by placing two drops of the oil to be tested in the well by pressing a button on the key pad. The custom designed microprocessor gave out instantaneous readout of the refractive index.

### ***3.2.2 Test Specimen Preparation***

The experimental raw materials were core oil, water; silica sand washed and oven dried at 110°C to remove water. The silica sand was classified with BS sieve of size range 40 - 72 mesh. Mixes were comprised of 6% clay, 5% water and 3% cereal binder (alkama). The proportion of sand in each of the mixture was 85.5, 85, 84.5, 84, 83.5 and 83% for 0.5, 1, 1.5, 2, 2.5 and 3% core oil binders, respectively.

Using a digital scale, measured quantities of silica sand, clay, cereal binder and water were mixed in a roller mill for 10 min and moulded into test cores as shown in Plates I(a) and I(b) which were oven baked at 200°C for 1 hr, and then oven cooled to room temperature before the tests for compression strength, tensile strength, permeability and collapsibility. Specimen for green compression, permeability and collapsibility was cylindrical in shape, 2 inches diameter, 2 inches height and weighed 130 g after compacting with a standard rammer with 3 blows each of 6.5 kg from a height of 50 mm in a standard ram. The tensile strength test specimen was in accordance with standard foundry practice shaped like figure number eight dimensioned as shown in Figure 3 and Plate I(a), while compression strength, permeability and collapsibility specimen were made into 50 mm diameter by 50 mm height cylindrical shape according to AFS as shown in Plate IB. Each of the mixture weighed 800 g and then was further subdivided into five portions of 160 g each.

All test specimens were prepared by subjecting a weighed quantity of sand core mixes to three blows adjusted to produce a close tolerance specimens. Which was expelled from the tube on a striping post, freshly prepared unbaked specimens were used for green properties testing such as green tensile, green compressive, permeability and collapsibility. The whole of the procedure was repeated, 3 times, for mixes containing varying amount of rubber seed oil while the linseed oil was used as standard (control oil).

### ***3.2.3 Experimental Design***

The experimental design for core oil formulation was 5×6 (two factor randomized complete block design) as given in Table 2.

### ***3.2.4 Core specimen testing***

In this work the following tests were carried out on the core specimen:

- (i) Tensile
- (ii) Compressive
- (iii) Collapsibility
- (iv) Permeability



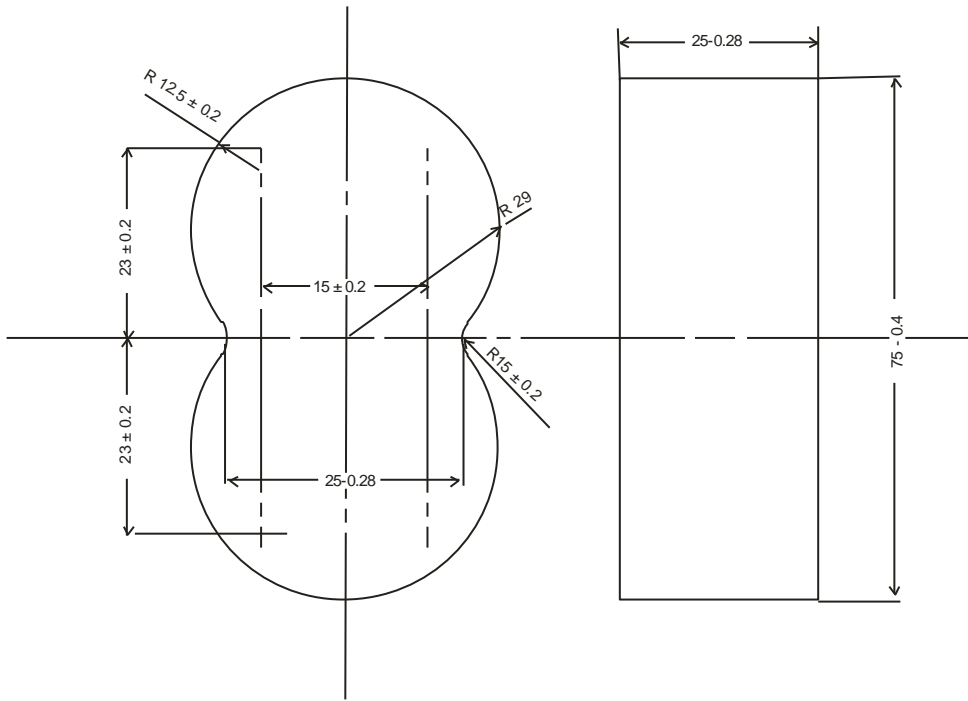
(a)



(b)

*Plate I. Moulded oil core Test specimens.*

*(a) Tensile specimens (b) Compression strength, Permeability and collapsibility Test specimens.*



*Figure 3: Designed shape of the cores for tensile strength*

*(Dimensions are in millimetres)*

Table 2: Percentage of Core Oil in the Core Sand and the Proportion of RSO-SBO in Percentage.

% of core oil in the core sand	Proportion of RSO-SBO,%
0.5	0, 25, 50, 75, 100
1.0	0, 25, 50, 75, 100
1.5	0, 25, 50, 75, 100
2.0	0, 25, 50, 75, 100
2.5	0, 25, 50, 75, 100
3.0	0, 25, 50, 75, 100

#### ***3.2.4.1 Tensile Test***

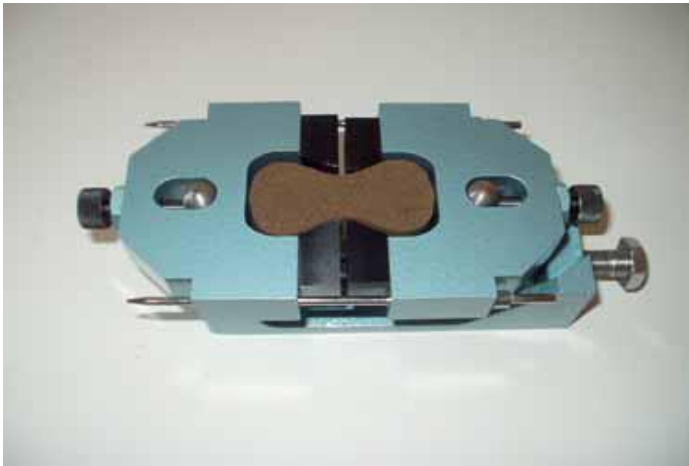
The tensile strength specimens were oven baked at 200°C for 1 hour and then oven cooled to room temperature before the tests. The dry tensile strength (DTS) specimen was inserted in the Tensile Core Strength Accessory, fitted with self-aligning contoured grips (AFS (imperial)). The guide pins line up both left and right hand jaws for insertion of the specimen. The guide pins were removed during the test allowing self-alignment of the jaws. This provides a means of uniformly pulling and breaking the test specimen on the Universal Sand Strength Machine as shown in Plate II. A steadily increasing tensile force was applied on specimen by turning the hand wheel of the universal strength machine until failure occurred and a magnetic rider on the scale recorded the position at which the specimen fractured, and the strength of the sand was read direct from the scale. The test procedure for green tensile strength (GTS) was similar except that the specimens were not baked.

#### ***3.2.4.2 Compressive Test***

The compressive strength specimen were oven baked at 200°C for 1 hour and then oven cooled to room temperature before the tests. A dry compressive strength (DCS) specimen was inserted in the upper hole where the breaking force is increased by a factor of five on the universal sand strength machine. A steadily increasing compressive force was applied on specimen by turning the hand wheel of the universal sand strength machine until failure occurred and a magnetic rider on the scale recorded the position at which the specimen collapsed, and the strength of the sand was read direct from the scale. Similarly the specimens for green compressive strength (GCS) was not oven baked, and was tested but in green state in the lower hole.

#### ***3.2.4.3 Collapsibility Test***

The baked collapsibility was determined by loading standard AFS specimens into the collapsibility testing machine with an in-built furnace, in which the specimen was heated to 600°C and soaked at that temperature. The time it took for the specimen to collapse was recorded (AFS, 1963).



*Plate II: Tensile Core Strength Accessory*

#### 3.2.4.4 Permeability Test

The permeability specimens were made and tested in the green state with the permeameter. In the permeability tests, a steady and standard air pressure of  $9.8 \times 10^2 \text{N/m}^2$  was passed through specimen in sample tube placed in the meter and after  $2000 \text{cm}^3$  of air had passed through, the time it took for  $2000 \text{cm}^3$  of air to pass the sample tube was then recorded. Permeability was calculated using standard equation 3 (Gupta and Kaushish, 1996).

$$P = \frac{3007}{T(\text{sec})} \quad (3)$$

P = permeability

T = time

## CHAPTER FOUR

### RESULTS

#### 4.0 Introduction

This chapter presents the properties of the produced core using formulated core oil and core made using the control oil (linseed oil). Such properties include, green tensile strength, dry tensile strength, green compressive strength, dry compressive strength, permeability and collapsibility. The chemical properties of the formulated and the control oil are also presented in this chapter.

#### 4.1 Physio - Chemical Properties of the Formulated Core Oil and Linseed Oil

Six different mixes made up of RSO – SBO containing 0, 25, 50, 75, and 100% of SBO and linseed oil were considered for the study. The physio - chemical properties of the oil are given in Table 3.

Average p.H ranges from 4.5 to 6.1 for RSO-SBO. These are within weak acid range, 0% RSO-SBO is the least acidic, followed by linseed oil, 25% RSO-SBO, 50% RSO-SBO, 75% RSO-SBO and 100% RSO-SBO is the most acidic in the group.

Iodine value ranges from 85 to 170 for linseed oil and RSO-SBO, linseed oil has the highest iodine level, followed by 100% RSO-SBO, 75% RSO-SBO, 50% RSO-SBO and 25% RSO-SBO while 0% RSO-SBO has the least iodine level.

Refractive index value ranges from 1.46 to 1.60 for linseed oil and RSO-SBO, 0% RSO-SBO has the highest refractive index value, followed by 25% RSO-SBO, 50% RSO-SBO, 75% RSO-SBO, linseed oil while 0% RSO-SBO has the least refractive index value.

Specific gravity value ranges from 0.930 to 0.935 for linseed oil and RSO-SBO, 0% RSO-SBO has the highest specific gravity value followed by 25% RSO-SBO, 50% RSO-SBO, 75% RSO-SBO, linseed oil while 0% RSO-SBO has the least specific gravity.

Table 3: Physio - Chemical Properties of Linseed Oil and RSO-SBO at Different Proportions.

Properties	Linseed Oil	0%RSO-100%SBO	25%RSO-75%SBO	50%RSO-50%SBO	75%RSO-25%SBO	100%RSO-0%SBO
Refractive index	1.48	1.60	1.57	1.53	1.50	1.46
Specific gravity	0.931	0.935	0.934	0.933	0.932	0.930
pH value	5.8	6.1	5.7	5.4	4.9	4.5
Iodine value	170	85	101	117	134	145
Flash point	226° C	120° C	145° C	169° C	194° C	218° C

## **4.2 Mechanical Properties of the Cores**

### ***4.2.1 Green Compression Strength***

The results of the green compressive strength of the produced core using formulated core oils are presented in Figure 4. Figure 4 shows the effect of core oil binder content on the green compression strength of the core sand mix containing RSO-SBO and linseed oil as control. The green compressive strength of the core ranges from 20.33 kN/m<sup>2</sup> in 0.5% core oil in sand with 0% RSO-SBO to 40.00 kN/m<sup>2</sup> in 3% core oil in sand with 50% RSO-SBO. While for linseed oil used as control, the green strength of the core ranges from 21.6 kN/m<sup>2</sup> in 0.5% core oil in sand to 38.00 kN/m<sup>2</sup> in 3% core oil in sand.

### ***4.2.2 Dry Compression Strength***

The results of the dry compressive strength of the produced core using formulated core oils are presented in Figure 5. Figure 5 shows the effect of core oil binder content on the dry compression strength of the core sand mix containing RSO-SBO and linseed oil as control. The dry compressive strength of the cores ranges from 570.30 kN/m<sup>2</sup> in 0.5% core oil in sand with 0% RSO-SBO to 633.00 kN/m<sup>2</sup> in 3% core oil in sand with 50% RSO-SBO. While for linseed oil used as control the dry compressive strength of the cores ranges from 579.00 kN/m<sup>2</sup> in 0.5% core oil in sand to 634.00 kN/m<sup>2</sup> in 3% core oil in sand.

### ***4.2.3 Green Tensile Strength***

The results of green tensile strength of the produced core are presented in Figures 6. Figure 6 shows the effect of core oil binder content on the green tensile strength of the core sand mix containing RSO-SBO and linseed oil as control.

The green tensile strength of the core ranges from 18.00 kN/m<sup>2</sup> in 0.5% core oil in sand with 0% RSO-SBO, to 36.33 kN/m<sup>2</sup> in 3% core oil in sand with 50% RSO-SBO. While for linseed oil used as control the green tensile strength ranges from 20.33 kN/m<sup>2</sup> in 0.5% core oil in sand to 35.00 kN/m<sup>2</sup> in 3% core oil in sand.

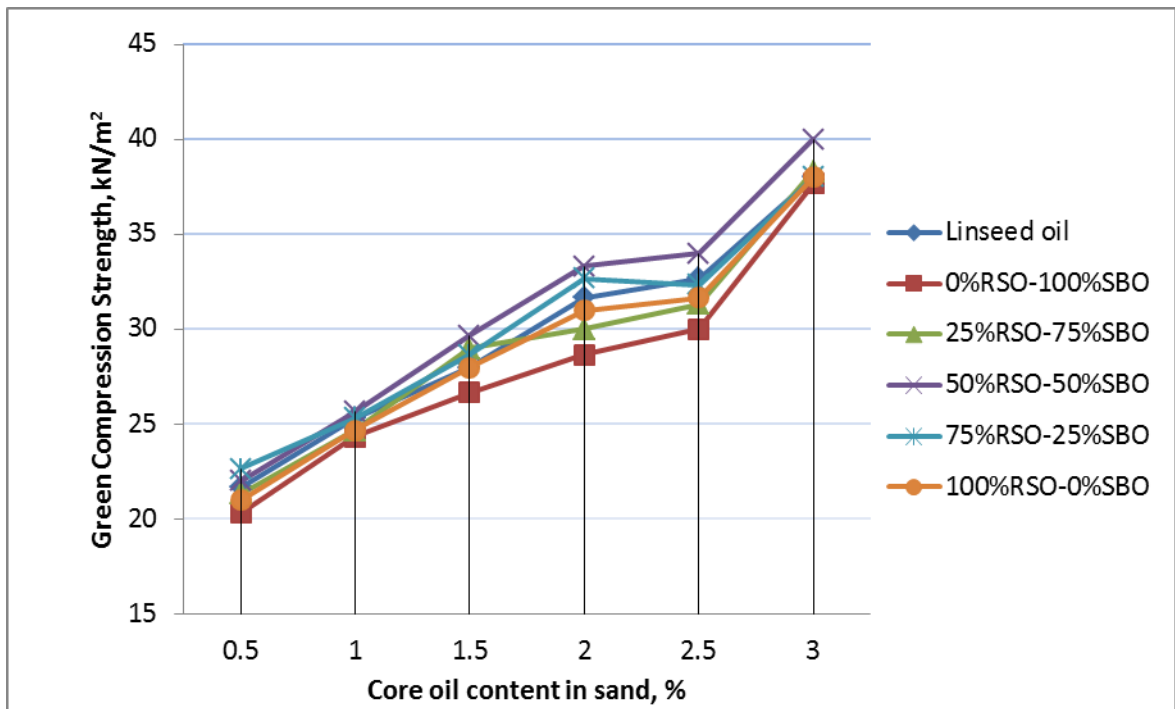


Figure 4: Green compression test graph for RSO-SBO and linseed oil

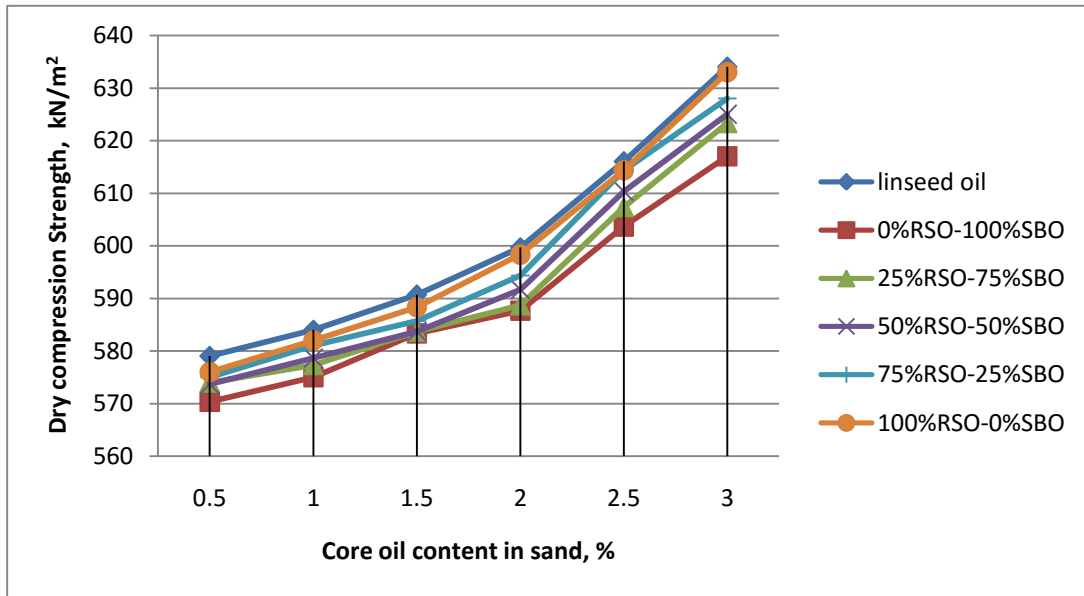


Figure 5: Dry compression test graph for RSO-SBO and Linseed oil

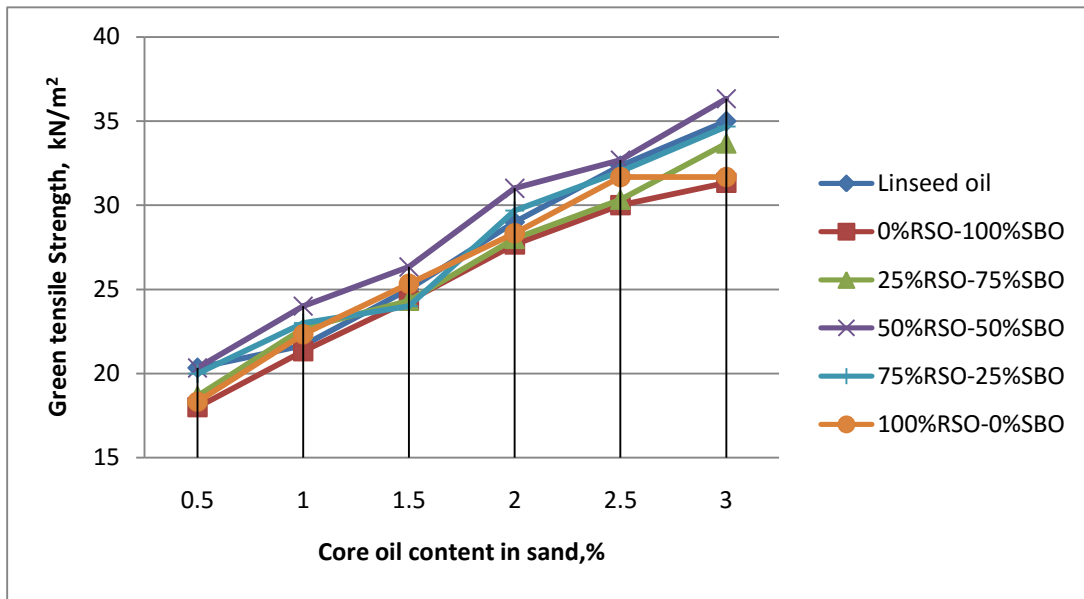


Figure 6: Green tensile Strength test graph for RSO-SBO and Linseed oil

#### ***4.2.4 Dry Tensile Strength***

The results of dry tensile strength of the produced core are presented in Figures 7. Figure 7 shows the effect of core oil binder content on the dry tensile strength of the core sand mix containing RSO-SBO and linseed oil as control. The dry tensile strength of the core ranges from 518.33 kN/m<sup>2</sup> in 0.5% core oil in sand with 0% RSO-SBO, to 601.67 kN/m<sup>2</sup> in 3% core oil in sand with 50% RSO-SBO. While the dry tensile strength of core made from linseed oil ranges from 541.33 kN/m<sup>2</sup> in 0.5% core oil in sand to 604.67 kN/m<sup>2</sup> in 3% core oil in sand.

#### ***4.2.5 Permeability Properties***

The results of the permeability of the produced core are presented in Figure 8. Figure 8 shows the effect of core oil binder content on the permeability of the core sand mix containing RSO-SBO and linseed oil as control. The permeability of the core ranges from 410.67 No in 3.0% core oil in sand with 50% RSO-SBO to 442.00 No in 0.5% core oil in sand with 100% RSO-SBO. While for linseed oil used as control the permeability ranges from 421.67 No in 3.0% core oil in sand to 432.65 No in 0.5% core oil in sand.

#### ***4.2.6 Collapsibility Properties***

The results of the collapsibility of the produced cores are presented in Figure 9. Figure 9 shows the effect of core oil binder content on the collapsibility of the core sand mix containing RSO-SBO and linseed oil as control. The collapsibility of the core ranges from 166.67 seconds in 3% core oil in sand with 50% RSO-SBO to 291.33 seconds in 0.5% core oil in sand with 0% RSO-SBO. While for linseed oil used as control the collapsibility ranges from 170.00 seconds in 3% core oil in sand to 288.00 seconds in 0.5% core oil in sand.

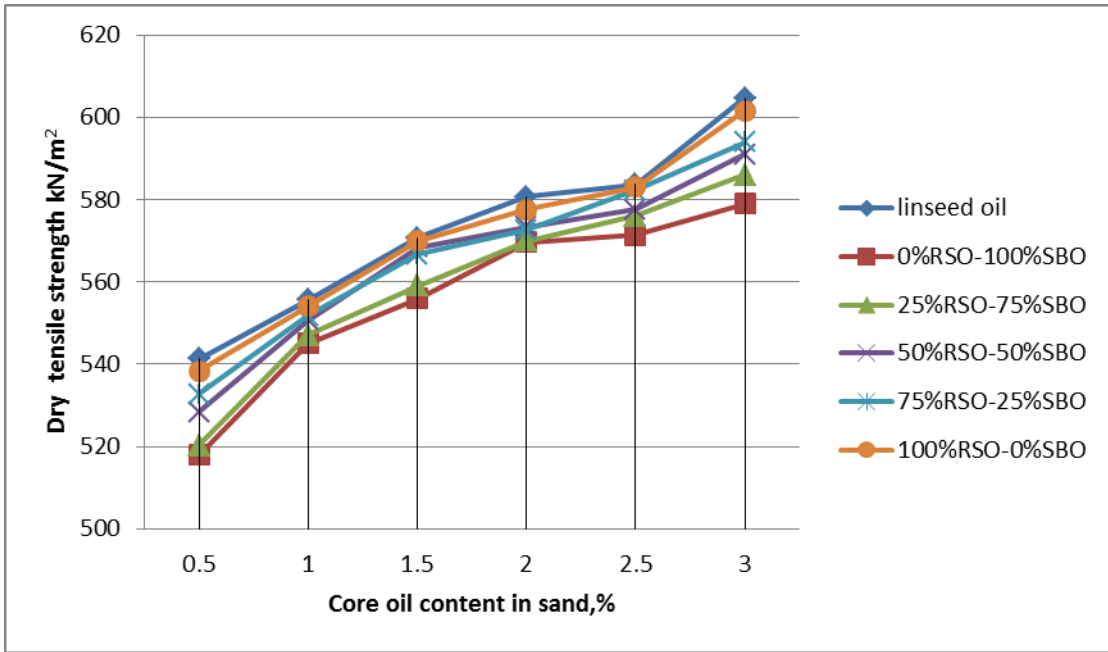


Figure 7: Dry tensile strength test graph for RSO-SBO and Linseed oil

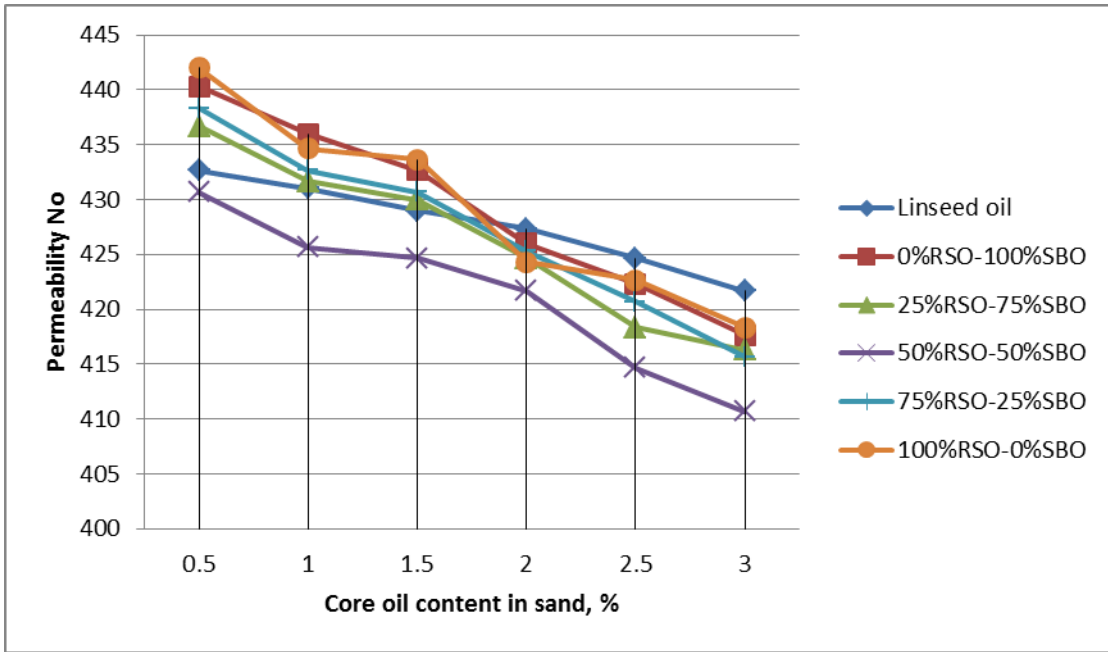


Figure 8: Permeability test graph for RSO-SBO and Linseed oil

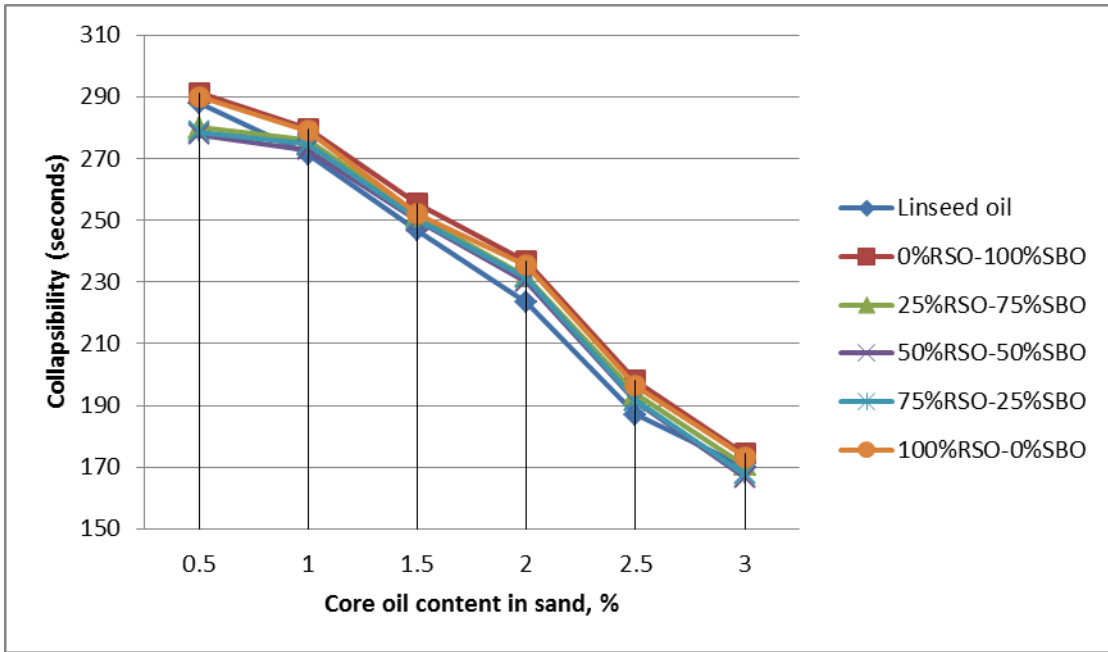


Figure 9: Collapsibility test graph for RSO-SBO and linseed oil

## CHAPTER FIVE

### DISCUSSION

#### 5.1.0 Physio - Chemical Properties of Core Oil

Average p.H ranges from 6.1 to 4.5 for both linseed oil and RSO-SBO. These are within weak acid range, 0% rubber RSO-SBO is the least acidic, followed by linseed oil, 25% RSO-SBO, 50% RSO-SBO, 75% RSO-SBO and 100% RSO-SBO. Since linseed oil and formulated RSO-SBO fall within weak acid range making it chemically, human friendly and non corrosive to tools and equipment, and they thus satisfy another critical attribute of foundry binder.

Iodine value expresses the degree of unsaturation of oil; the higher the iodine number the higher the rate of absorption of air at room temperature. The absorption of oxygen causes core oils in sand to polymerise after application to form tough, adherent, impervious and resistance films. From the result, it means that linseed oil will absorb more oxygen than any other formulation of RSO-SBO, causing green sand core to polymerise and form tough green sand core (Ademoh and Abdullahi, 2009b).

#### 5.2.0 Mechanical Properties of Core

##### 5.2.1 Green Compression Strength (GCS)

The result of the green compression strength of the produced core show that green compression strength of the core ranges from 20.33 kN/m<sup>2</sup> to 40.00 kN/m<sup>2</sup>. GCS of the core sand mixes containing RSO-SBO and linseed oil continue to increase as content of core oil binder in the core sand mixes increases, from the range of 20.33 kN/m<sup>2</sup> in 0.5% core oil in sand to 40.00 kN/m<sup>2</sup> in 3.0% core oil in sand.

The result show that the cores made using the formulated core with composition of 50% and 25% RSO-SBO, have GCS of 40.00 kN/m<sup>2</sup> and 38.33 kN/m<sup>2</sup>, respectively which is higher than the core made from linseed oil (control) with maximum GCS of 38.00 kN/m<sup>2</sup> at 3.0% of core oil in sand. The result also reveals that cores made with formulated core oil of 75% and 100% RSO-SBO oil have the same GCS with linseed oil (control).

The maximum GCS of 40.00 kN/m<sup>2</sup> was obtained for cores made at the composition of 50% RSO-SBO and at 3.0% core oil in sand.

At all same proportion of RSO-SBO, there is no significant difference in the GCS of cores produced using various core oil contents in sand ( $P > 0.05$ ).

The results of this study on green compression strength are within the range of findings of Olakanmi and Arome (2009) on the functional properties of cores made with varying proportion of beniseed and melon oils. Among the functional properties was GCS which ranges from 34.00 kN/m<sup>2</sup> to 43.00 kN/m<sup>2</sup> for beniseed.

The development of the GCS in the core sand mixes could be attributed to the effective bonding mechanism of the formulated RSO-SBO binder which promotes formulation of binder film which surround the core sand particles. The absorption of oxygen causes core oils in sand to polymerise after application to form tough, impervious and resistant film, causing green sand core to polymerise and form tough green sand core (Ademoh and Abdullahi, 2009b).

The results of the GCS of the formulated 50% RSO-SBO falls within the range required for casting aluminium alloy (Titov and Stepanov, 1982).

### ***5.2.2 Dry Compression Strength (DCS)***

The result of DCS of the produced cores reveal that addition of each of the RSO-SBO and linseed oils to the core sand mixes resulted in DCS with the range of 570.33 kN/m<sup>2</sup> and 634.00 kN/m<sup>2</sup>. The DCS of the core sand continue to increase as content of core oil binders in the core sand mixes increases from 0.5% to 3.0%. The maximum DCS of produced core was observed to be 634.00 kN/m<sup>2</sup> and 633.00 kN/m<sup>2</sup>, for the RSO-SBO and linseed oils respectively.

General comparison of the values of the DCS of the produced cores using formulated RSO-SBO and linseed oil suggests that linseed core oil binder imparts slightly better DCS than all the composition of formulated RSO-SBO core binder. The formulated RSO-SBO gave rise to cores with DCS of 570.33 kN/m<sup>2</sup> for 0% RSO-SBO and 633.00 kN/m<sup>2</sup> for 100% RSO-SBO. At the same proportion of RSO-SBO, there is no significant difference in the DCS of cores for all various core oil contents in sand ( $P > 0.05$ ).

Similar observation was made by Ademoh and Abdullahi (2009a) on the development of dry compression strength for sand binder mixes. They observed that dry compression strength of the sand core continue to increase as content of binders in the sand mixes increases within the range of 114.00 kN/m<sup>2</sup> to 327.00 kN/m<sup>2</sup> in sand. This could be explained by the organic nature of binder and the cereal binder which are combustible at temperature which the tests specimen for dry compression was baked.

### **5.2.3 Green Tensile Strength**

The results of GTS of the produced cores show that addition of each of the formulated RSO-SBO and linseed oils to the core sand mixes produced cores with GTS which ranges from 18.00 kN/m<sup>2</sup> to 36.33 kN/m<sup>2</sup>. The GTS of the core sand mixes continue to increase as content of core oil binder increases from 0.5% to 3.0%. The maximum GTS of produced core using the RSO-SBO and linseed oils was observed to be 36.33 kN/m<sup>2</sup> and 35.00 kN/m<sup>2</sup>, respectively.

General comparison of the values of the GTS of the produced cores suggests that 50% RSO-SBO at 3.0% core oil in sand impact a better GTS than linseed oil and all other composition of RSO-SBO. The result also shows that 50% RSO-SBO have slightly better GTS at 2% of RSO-SBO.

The obtained green tensile strength is similar to that obtained by Shi *et al*, (2001) who studied the mechanism of protein based core sand for aluminium castings and obtained maximum green tensile strengths of 40.00 kPa for the cores. The development of the GTS of the produced cores, is as a result of the binder film surrounding each particle of the core sand is sufficiently thinner such that the inter – particles distance between neighbouring particle closes up leading to strong bonds within the matrix of the core sand (Shi, Hung, Shi, and He, 2001).

### **5.2.4 Dry Tensile Strength**

The results of DTS of the produced cores, reveal that addition of each of the RSO-SBO to the core sand mixes resulted in cores with tensile strength varying from 518.00 kN/m<sup>2</sup> to 604.67 kN/m<sup>2</sup>. The DTS of the core sand mixes continue to increase as content of core oil binders in the core sand mixes increases from 0.5% to 3.0%. The maximum

DTS of the produced cores using the formulated RSO-SBO and linseed oils was observed to be 601.60 kN/m<sup>2</sup> and 604.67 kN/m<sup>2</sup>, respectively.

General comparison of the values of the DTS of the produced core suggests that linseed oil at 3.0% core oil in sand gave a better DTS than all other compositions. The result also shows that 100% RSO-SBO have a better dry tensile strength than any of RSO-SBO composition.

At 0.5% core oil in sand, there is significant difference in the DTS of cores produced using 25%RSO-SBO and DTS of cores produced using 100%RSO-SBO and linseed oil. While there is no significant difference in DTS of cores produced using other proportions of RSO-SBO.

At 1.0% and 1.5% core oil in sand, there is no significant difference in the DTS of cores produced using various core oil contents in sand.

At 2.0% core oil in sand, there is significant difference in DTS of cores produced using 0%RSO-SBO and DTS of cores produced using linseed oil, while there is no significant difference in the DTS of cores produced using other proportion of RSO-SBO (P>0.05)

At 2.5% core oil in sand, there is significant difference in DTS of cores produced using 0%RSO-SBO and DTS of cores produced using 50%RSO-SBO, 75%RSO-SBO and 100%RSO-SBO. While there is no significant difference in the DTS of cores produced using other proportion of RSO-SBO (P>0.05).

At 3.0% core oil in sand, there is significant difference in DTS of cores produced using 0%RSO-SBO and DTS of cores produced using 50%RSO-SBO, 75%RSO-SBO and 100%RSO-SBO linseed oil. While there is no significant difference in the DTS of cores produced using other proportion of RSO-SBO (P>0.05).

The strength values obtained for this study fall within the range obtained by Ademoh (2009) on the effect of addition of linseed oil to Nigerian gum Arabic grade 2 and 4 on baked tensile strength of sand cores used as implants in foundry moulds, his result shows that the dry tensile strength of the baked core at 200°C for 3.0% gum Arabic grade 2 at varied amount of linseed oil for 1 hour to 3 hours ranges from 400.00 kN/m<sup>2</sup> to 700.00

kN/m<sup>2</sup> and for 3% gum Arabic grade 4 at varied amount of linseed oil for 1 to 3 hours ranges from 455.00 kN/m<sup>2</sup> to 770.00 kN/m<sup>2</sup>.

The dry tensile increased at 200°C baking temperature which enabled more sand and binder molecules to acquire higher reaction energies needed for strong bonding. The increasing percentage of core oil in sand mixes also provided more binder molecules that reacted with more sand grain for higher bond strengths. Strength increased without dropping at 100% rubber seed to shea butter oil because the baking temperature is below flash point of core oil composition of about 218°C (Ademoh and Abdullahi, 2009b) above which burning of some of its molecules and reduction of strength could have occurred. The results of the dry tensile strength of the formulated 50% rubber seed – shea butter oil falls within the range required for casting aluminium alloy (Titov and Stepanov, 1982).

#### ***5.2.5 Permeability***

The result of permeability test of the produced core with the same quantity of rubber seed to shea butter oil shows that addition of 0.5wt% of each of the rubber seed - shea butter and linseed oils to the core sand mixes led to cores with permeability between 410.67 No and 442.00 No.

The permeability of the core sand mixes containing formulated rubber seed - shea butter and linseed oils continue to decrease as content of core oil binders increases from 0.5% to 3.0%. The maximum permeability of the produced core was observed to be 442.00 No and 432.65 No respectively.

General comparison of the permeability of the produced cores shows that cores made from formulated 50% rubber seed - shea butter oil at 0.5% core oil in sand have a permeability which is in the range obtained for linseed oil. In all other cases, cores made using formulated oil with 0.5 – 1.0% core oil in sand have a better permeability than those made by linseed oil. The formulated rubber seed - shea butter oil gave rise to cores with permeability of 410.00 No at 50% rubber seed to shea butter oil and 442.00 No at 100% rubber seed to shea butter oil.

Similar observation was made by Ademoh (2009) on the beneficial effect of addition of linseed oil to foundry sand cores with Nigerian gum Arabic grade 2 and 4. He

stated that permeability of the sand core continue to decrease as content of core oil binders in the core sand mixes increases within the range of 185 No to 155 No in cores bonded with grade 2 gum Arabic/linseed oil, while the range for core bonded with grade 4 gum Arabic/linseed oil were within 155 No to 121 No.

In addition, the results show that pure materials have better permeability (no significant difference between 100% RSO and 100%SBO) which indicate that gases and vapour can easily permeate the pores of the core made with these oils, thereby minimising the incidence of defect formations in the casting (Olakanmi and Arome, 2009).

### ***5.2.6 Collapsibility***

The results of collapsibility test of the produced core at same amount of rubber seed to shea butter oil show that addition of each of the formulated rubber seed to shea butter and linseed oils to the core sand mixes gave collapsibility of 166.67 - 291.33 seconds. The collapsibility of the core sand mixes containing formulated rubber seed to shea butter and linseed oils continue to improve (i.e. decrease in time required to break the core ) as content of core oil in the core sand mixes increases from 0.5% to 3.0%. The best collapsibility of the produced core using the formulated rubber seed - shea butter and linseed oils was observed to be between 165.00 and 170.00 seconds.

General comparison of the collapsibility of the produced cores using formulated rubber seed - shea butter and linseed oils values suggests that 50% rubber seed to shea butter oil at 3.0% core oil in sand have a better collapsibility than linseed oil and all other composition of rubber seed to shea butter oil, the result also reveals that 50% rubber seed to shea butter oil have a slight better collapsibility than 75% rubber seed to shea butter oil. The formulated rubber seed to shea butter oil collapsibility is within the range of 166.67 seconds at 3% oil in sand for 50% rubber seed to shea butter oil and 291.33 seconds at 0% rubber seed to shea butter oil at 0.5% oil in sand.

At 0.5% core oil in sand, there is no significant difference in the collapsibility of cores produced using 0% RSO-SBO and collapsibility of cores produced using 100%RSO-SBO and linseed oil. There is also no significant difference in the collapsibility of cores produced using 25% RSO-SBO and collapsibility cores produced using 50% RSO-SBO

and 75%RSO-SBO. While there is significant difference in the collapsibility of cores produced using other proportion of RSO-SBO.

At 1.0%, 1.5% and 3.0% core oil in sand, there is no significant difference in the collapsibility of cores produced using various core oil contents in sand.

At 2.0% and 2.5% core oil in sand, there is significant difference in the collapsibility of cores produced using 0%RSO-SBO and collapsibility of cores produced using linseed oil. While there is no significant difference in the collapsibility of cores produced using other proportion of RSO-SBO ( $P>0.05$ )

This behaviour occurred possibly because at experimental temperature of 600°C at which collapsibility was measured, core oil and cereal binders (starch) were burnt off, thereby making it easier for the cores to collapse more readily after they had solidified. According to H.W Dietert in Mathew and Wainko (1983), collapsibility within the range of 60 and 150 seconds are considered as fast with the consequence of the production of cracks and warpage in castings whereas those greater than 480 seconds are regarded to be slow, this resulting in metal penetration in castings. However, moderate collapsibility which is between fast and slow, recorded for core sand mixes containing the formulated rubber seed - shea butter oil and core oil binder in this research is considered to be suitable for aluminium casting.

## CHAPTER SIX

### SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 Summary

The primary aim of this research was to formulate a core oil from rubber seed and shea butter oils for Aluminium casting, as an alternative to the imported foundry core oils. Rubber seed oil was bought from Rubber Research Institute, Benin City, Edo state. While the shea butter oil was bought from a local market in Idumuje Unor, Aniocha south local government area of Delta state. The physical and chemical properties of the formulated RSO-SBO oils and existing core oil (linseed oil) were also carried out. These physical and chemical properties include refractive index, specific gravity, Ph value, iodine value and flash point of the core oils.

Sand samples were collected from two different points and were mixed thoroughly, washed and allowed to dry. The experimental design was 5×6 (two factors randomized complete block design). During the experiment, the dried sand sample were weighed and placed in a mixing container where a known quantity of clay, water, cereal binder (alkama) and formulated rubber seed - shea butter oil were added. A fairly homogenous mixture was obtained by mulling the mixture.

Core sand mixtures (sand, clay, cereal binder and water) containing varying proportion of formulated rubber seed to shea butter oil were prepared. Using AFS standard procedures, various specimens were prepared and tested for green compression strength, dry compression strength, green tensile strength, dry tensile strength, green permeability and collapsibility. Freshly prepared unbaked specimens were used for green properties testing such as green compression, green tensile strength and green permeability test, which was made into 50 mm diameter by 50 mm height cylindrical shape according to AFS. The specimens for dry tensile strength were made into figure eight shape according to AFS and were oven baked at 200<sup>0</sup>C for 1 hr. Analysis of variance was used to evaluate the mean variance, at constant core oil in sand with the variation of percentage of RSO-SBO for different mechanical properties and at constant percentage of RSO-SBO with the variation of core oil in sand for different mechanical properties at P>0.05 level.

## 6.2 Conclusions

The following conclusion can be drawn from the study.

1 Cores made using 50% RSO-SBO have higher green compression strengths than those made using the control oil (linseed oil).

2 Cores produced using 100% rubber seed oil have higher dry compression strengths than those made using any of the formulated RSO-SBO. Cores made using 100% rubber seed oil have equivalent dry compression strength with those made using control oil (linseed oil).

3 Cores made using 50% rubber seed and 50% shea butter oil have higher or equivalent green tensile strength compared to these produced using control oil (linseed oil).

4 Cores produced using linseed oil have higher dry tensile strengths than those made using any of the formulated RSO-SBO, but dry tensile strengths of cores made using 100% rubber seed oil have equivalent dry tensile strengths with the cores made using the control oil (linseed oil). An increase in core oil in sand increases the dry tensile strength of the core.

5 Cores oil made using 100% rubber seed oil have higher permeability than those made using any of the formulated RSO-SBO and control oil (linseed oil). Increasing the core oil in sand decreases the green permeability of the produced sand core.

6 Cores made using 50% shea butter and 50% rubber seed oils have better collapsibility than those made using the control oil (linseed oil) and all other formulated RSO-SBO

7 Generally, the produced cores using formulated core oil have very good mechanical properties required for foundry core meant for aluminium castings.

8. The green and dry compression strengths and green and dry tensile strengths of the core made using the formulated oils increase with increase in the amount of oils in sand while permeability and collapsibility decrease with increase in the amount of oil in sand.

9. Generally, the properties of cores produced from the formulated oil are statistically equal and are within the accepted standard values. However, in many cases those produced from 50% RSO-SBO gave the individual maximum properties.

### **6.3 Recommendations**

Based on the research, the following recommendations suffice for implementation and for further investigation.

1. Foundry shops should utilise the formulated core oil, particularly the 50% rubber seed – 50% shea butter oil for production of cores for aluminium castings to reduce reliance on foreign organisations for linseed oil.
2. Further investigation should be carried out on increasing core oil in sand above the maximum 3.0% core oil in sand as used in this study.
3. Further study on the impact of increasing the baking temperature and time above 200°C and 1 hr respectively should be carried out.
4. Further investigations should be carried out on the chemical and mechanical properties of starch free and increased starch on core strength.

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