PRODUCTION OF PARTICLE BOARD FROM AGRICULTURAL WASTE USING THE COMPOSITE OF COCONUT (*Cocos nucifera*) AND PALM KERNEL SHELLS (*Elaeis guineesis*) WITH GUM ARABIC AS BINDING RESINS

BY

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BEING A FINAL YEAR PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG) DEGREE IN AGRICULTURAL & BIORESOURCES ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE

FEBRUARY, 2010

DECLARATION

I hereby declare that this project work is a record of a research work that was undertaken and written by me .It has not been presented before for any degree or diploma or certificate at any university or institution. Information derived from personal communications, published and unpublished work were duly referenced in the text.

JAdOB. 1st March, 2010.

ADEGBEMI, JACOB OLUWASEYI DATE

CERTIFICATION

This project entitled, "Production of Particle Board from Agricultural Waste using Composite of Coconut *(Cocos nucifera)* and Palm kernel Shells *(Elaeis guineesis)* with Gum Arabic as Binding Resin" by Adegbemi Jacob Oluwaseyi, meets the regulations governing the award of the degree of Bachelor of Engineering (B.ENG.) of the Federal University of Technology, Minna, and it is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This project is dedicated to my entire family, the Adegbemi's for their encouragement, patience and support through out the period of my studies.

ACKNOWLEDGEMENTS

My greatest gratitude goes to God, for the enabling power, good health He granted me. Also for His provision that kept me going and favor on every side. I also want to acknowledge the guidance and supervision of my supervisor Engr. Dr. B.A Alabadan. My appreciation goes to all my lecturers and staff of the department, especially my H.O.D Engr. Dr. A.A Balami, the departmental examination officer, Engr. Mrs. H.I Mustapha and my level adviser Engr. M.A Sadeeq, for their contribution to the impartation of knowledge into me. I cannot but mention the loving support I enjoyed from my family, Pastor and Mrs. Adegbemi, Adura, Ope and Ruth Adegbemi and my Uncle Mr. Segun Adegbemi for their moral, spiritual and financial commitment to me, ensuring that my program in school was a success. To my fiancée Janet Ogunniran, I love you and will not forget your encouragement. And to all my class mates especially Afe Oluwasegun, and others I would not mention, I say thank you and God bless you all.

ABSTARCT

This project work was aimed at producing particle board from the composite of coconut and palm kernel shell using Gum Arabic as the binding resin in placed of the synthetic resins in use. These were achieved by making a composition of the material used in ratio of 70%: 30%, 30%: 70% and 50%:50% respectively and forming them into particle board using mat-form method. The result obtained from the project work shows that, the properties of the particle board depend on particle sizes of the shell, quality and quantity of the resin binder and method of forming. Also the presence of palm kernel shell further strengthen and increase the density of the board as reflected in the result of the different composition. The densities of the board formed are 1078.3kg/m^3, 803.03kg/m^3 and 1124.2kg/m^3 showing low density board, with compaction force of 3800N and pressure is 3313N/m^2. Therefore, resulting in a high quality and durable boards with good size requirement. A design and construction of production plant is hereby, recommended for further development.

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CHAPTER ONE

1.0 INTRODUCTION

Particle board, a wood product that was invented in the middle of the 19^{th} century, is defined generally as an engineered panel product, manufactured from wood particle which are by-product from the wood industry. These wood particles such as sawmills shavings, sawdust, wood chips that are bonded together using synthetic resin or other suitable binder, after which they are pressed and extruded.

Particle board is a composite material also known as chip board or grain-less wood board. The use of the particle board are enormous and this range from house accessories to factory and construction materials such as cabinet fittings, wall cladding, partitioning, floor table, tops, design furniture, carcass construction, ceiling board, chalk board, as well as in the art industry.

1.1 History and Development

Modern plywood, particle board as an alternative to natural wood were invented in the 19^{th} century, but by the end of the 1940s, there was no enough timber around to manufacture plywood affordably, particle board was then invented to be a replacement. The first commercial piece, were produced during world- war II at a factory in Bremen, Germany. It used waste material such as planner shavings, off-cuts or sawdust and hammer-milled them into chips, bonded together with a phenolic resin. Hammer milling involves smashing material into smaller pieces until they pass out through a screen, with the use of different resin for different manufacturers.

In recent development agricultural residues from many different regions of the world such as wheat straws, rice husks, bamboo, maize cob, sun flower stalks, palm kernel and coconut shell are used. Past development and research on particle board production showed that smaller particles decreased the static bending and modulus of elasticity. Also, low particle moisture content decreased the mechanical properties. This is however, corrected by well compacted particles to ensure no void, these increase the connection between particles, increasing the shelling ration and improved physical and mechanical properties of particle board.

1.2 Statement of the Problem

With the increasing demands for wood and wood product, one major ecosystem that has been greatly devastated is the forest reserves. Tress from forest are cut down to serve as source of energy (fuel), timber for furniture and paper industries, wood for construction and art (sculpture) e.t.c. This has lead to massive deforestation and change in the ecology, resulting in extinction of some animal species and alteration of the environmental climate that has cumulated into global warming. Therefore, the challenge of the modern world today, is to find alternatives to these one and only sources of raw material for wood and wood products.

In some of the developing countries environmental protection agencies have laws in place to protect forest reserves. And this has affected wood based industries and leading to unemployment. But as an Agric and Bio-resources undergraduate, what comes to mind is the use of recycling principle to find solution to these problem ravaging society and the world at large. Agricultural waste and by-product can be turned into useful recycled products. For example agricultural scrap such as rice husk, groundnut, coconut and palm kernel shells, corn curb can be transformed into useful product like, the production of particle board. Some of these by-products have alternative uses too, that have been neglected. But instead of forming a heavy biomass of these materials, we can begin to diversify them into job creating opportunities. As production of particle board can be made from these by-product.

1.3 Objectives

This project aims at utilizing the heavy biomass of coconut and palm kernel shell as waste generated in Nigeria, to be converted into effective raw material in the manufacturing of particle board:

1. To reduce the demands on timber and wood products by using agricultural waste, thereby effectively reducing the cost of production.
2. To produce particle boards from the composite combination of coconut and palm kernel shells in three different proportions.
3. To compare the physical and mechanical properties of the boards produced, with the view of identifying which of the boards is the best.
4. To encourage entrepreneur spirit, job creating opportunities in small and medium scale production of particle board which can be use in the construction and an art industries.

1.4 Justification of the Study

Particle board, also known as fiber-board in recent times has recorded increase in demand most especially in the furniture and construction industries. This is because of its characteristics; it is cheaper, denser and more uniform than conventional wood and plywood. And it serves as substitute for them, when appearance and strength are less important than cost. It is useful when value added wood product are needed especially in decorative designs. It is denser than conventional wood; it is the lightest and weakest type of fiber board.

However, the focus of the project is to explore the use of agricultural by-product (coconut and palm kernel shells) in place of the already drained forest resources (conventional wood) as source of the raw material for the production of particle board.

1.5 Scope of the Study

The particle board from this project is formed from a composite of coconut and palm kernel shells, both agricultural by-product using Gum Arabic (Acacia Senegal) as a natural binding resin, instead of the synthetic ones. The coconut and palm kernel are broken into smaller chips and particles mixed in the ratio 3:1 (70:30%), 1:3 (30:70%) and ratio of 1:1 (50:50 %) respectively. This is based on the physical and chemical properties of the three materials. They are then sieved and dried to uniform moisture content and mixed with resins. Using the mat-formed method, the mixed is spread in the wooden mould and cold-compressed on a flat rigid sheet or panel with specific thickness. Additive to improve the quality of the final product such as water proof, fire and insect resistance, resistance to fungal attack were not added. The sizes of the mat-formed panel are (0.37x 0.31x 0.019m). This method is in place of the existing extrusion method because of its convenience and viability for small scale and medium scale production.

The purpose of this project is to determine the suitability of particle board produced from the composite mixed of coconut and palm kernel shell with Gum Arabic as its binding resins as an alternative to the ever forest draining plywood and wood material for furniture and construction industries. This is achieved by testing and comparing their mechanical properties.

1.6 Limitation

This project work is restricted to laboratory research methods only. Although, both the industrial and laboratory methods share similar production process and steps, there is little variation in the final product obtained from the extrusion method and the cold/ hot mat-formed method, due to the technology involved. The method used in this project is the cold mat pressing method which eliminates high pressure and temperature involve in using other techniques.

The binding resins used in this research work are also agricultural by-product instead of the existing synthetic resins that are always used. Gum Arabic, a high holding and strong binder was used, although it is prone to fungi attack. This can be corrected by using additives that gives protection against fungi attack and painting. Thereby, making the composite of coconut and palm kernel shell a good alternative raw material in producing particle board.

CHAPTER TWO

2.0 LITERATURE REVIEW

Particle board production is as a result of an engineering innovation or discovery that occurred during the World War II and by the end of 1940, a wood product manufactured from natural fibrous material and wood particles such as saw-dust or flake, chips, shavings e.t.c. was invented. The advent of synthetic resins (urea Formaldehyde) aided the development of these product as it serve as adhesive which hold the particle together in form. These waste products are hammer milled into small particles of uniform sizes and a spray of the adhesive applied. After which certain amount of pressure is applied to mould the board into solid form.

The properties of the board formed depends on properties (both physical and chemical) of chips or waste material, the type and amount of adhesive (resins) used, the method of moulding and amount of pressure applied. Also the quality of the particle board is affected by the amount, nature and softness of the cellulose content present in the cell walls of the fibrous materials. Other characteristic of the board such as nail and screw holding properties are determined by the quality of the resin that glues the particle readily. Recommendation from existing manufacturers has shown that relatively long screws should be used, especially in grain edges. For higher or firm holding bore should be created in the faces rather than the edges. And shacks proof and twin fast screws are preferred for perfect fixing.

Classification of particle board in recent times are based or grouped into 3 major classes. The first classification set, is according to the density grades which put into consideration, the weight per cubic centimeter of the product. Basically, under this class we have the low density particle board (i.e. insulating type with density of $350kg/m^3$-$1400kg/m^3$) medium density (i.e.

decorating type with density of $1500kg/m^3$-$1700kg/m^3$) and the high density (i.e. hard board types for heavy construction with $1800kg/m^3$-$2100kg/m^3$ density). These different densities are achieved by varying the pressure applied during manufacturing process. (John, 1971)

The second classification is based on thickness or size under which exist the standard particle board (size 1.2 m x 2.4m x0.025m), common panel size (ranging from 0.0125-0.025m) and the three-player particle board (with the finer layer placed on the outside of the board with the central section composed of coarsed, cheaper chips). (Particle board output, Wikipedia 2009)

The third classification is based on the method of production used and there are basically two methods of producing the particle board which are the extrusion method and the mat-forming method. The extrusion method is a highly technologically advanced method that passes the raw chips through series of processes, sprays through jets and compressed under conditioned pressures and temperatures. The final set and hardened product of correct size, density and constituent board is then cooled, trimmed, and sanded. Finishing touches like paper lamination or covering with wood veneer can be done.

On the other hand, the mat-forming method is a more simpler method were the mixture of particle and synthetic resin are spread into sheets or mould after the particle have been grinded and dried into homogenous, uniform moisture particles. The mixture is then pressed together to a desired density (strength). The pressed board are allowed to cure and then trimmed to standard sizes using multiple saws and precision sanding on both sides to attain the required thickness.

2.1 Binding Resins

In the production of particle board especially when using agricultural material with high cellulose and lignin content in their fibers as in the case of composition of coconut and palm kernel, the choice of the type of binding resins to be use must be considered.

Binder are mainly chemical substance that under goes chemical reaction to form a solid bonds or structure with the material they react with, thereby serving as gluing medium or adhesive . Adhesive or binder are available in different type such as synthetic resins(e.g. Urea formaldehyde, Melamine formaldehyde and Phenol formaldehyde) gum resin (gum Arabic, sugar molasses from sugar cane) and timing adhesive e.t.c. The choice of this binding agent is greatly determined by cost, nature and quality of the product required, preservative to be added and safety of the chemical.

This project work considers Gum Arabic as the binding resin for the composition of coconut shell and palm kernel shell. This is because it is cheap, highly glossy, odorless and has good ink retention. However, it has the disadvantage of been prone to insect attack which can be corrected by addition of preservatives. But that is not within the scope of the project.

2.1.1 TYPES OF BINDERS OR ADHESIVES

(a) **Synthetic resin/ adhesive:** This is a combination of urea and formaldehyde that makes up the resins and it is the cheapest and easiest to use. It is use for most non-water resistant boards. Others are melamine formaldehyde resins which are more expensive and are use for moisture resistance, phenol formaldehyde also fairly expensive, dark colored and highly durable. But has been classified by WHO as human carcinogen, with 99.99% of this chemical contained in board curing process.(WHO2008)

(b) Vegetable-starch adhesive: Obtained from cassava, when the chips are grinded sieved and allowed to settle in water. It is then decanted and dried to prevent it from bacteria attack. Other adhesives liken casein adhesive made from curd of soured mill (FAO,1963)

(c) Animal adhesive: obtained from animal hides, skins, horns and bones by burning them in limited supply of air to form a gelatinous substance.

(d) Plant resin/ adhesive: These are substance obtained from plant back of trees through distilling wood, extract from plant body by solvent, e.g. sugar molasses from sugar cane. Most of which are soluble in water.

(e) Cement: These are inorganic type made from calcium trioxocarbonate IV clay, sand and other materials.

In the classes of adhesive discoursed above, it's only the starch adhesive that can be compared with Gum Arabic in terms of availability and cost as both are available in commercial quantities in Nigeria and can be readily processed.

2.1.2 Characteristics of Adhesive

Adhesive can be used if it has the following characteristics

a) Have low moisture content

b) Resistant to creep at high temperature

c) Easy to apply and require as special fixing equipment

d) Dehydration of binding area

e) Fast grab attack

f) Flexibility on application

The selection of an adhesive depends on the following

a) Heat and safety factors

b) Economic factors

c) Its life span

d) Effect on materials to be bonded

e) Flammable and toxic nature to the materials chosen

f) Availability in commercial quantities (Galdius,1977)

2.2 Botanical consideration of Gum Arabic or Gum Acacia

Gum Arabic or Gum Acacia source and predominant supply have been linked with Kordafan on the East and Senegal on the West of Africa. History has also linked the commodities transfer to Europe through Arabian traders, from where its name may have been originated from. The Gum appears on the stem and branches during the prevalence of dry desert winds, which blows in the winter or harmattan after the close of the raining season, and the flow is aided by certain methods of treatment.

The small tree Acacia Arabic, one of the sources of Gum Arabic is recognized by the triple spine at the base of the branch chalets. Similar to it is the Acacia dungeon with occasional third spine meeting within Acacia latex. The gum exudates from this acacia tree and other species of acacia trees containing Arabin. The finest quality of this gum is obtained from acacia Senegal also found in Southern Mozambique, Acacia Arabica found in the red dry region of North-west Africa and in some Northern part of Nigeria e.g. (Maiduguri, Zamfara, Bida-Niger state) e.t.c.

2.3 Chemical composition and structure of Gum Arabic

Gum Arabic is an odorless, colorless and tasty gum and quite soluble in water. The best quality ones take, one and half times their weight of water to form thick viscous mucilage. Like other resins, Gum Arabic is a gelatinous substance with a chemical composition which is highly branched polymer of gelatos, rhamose, arabinose and glucoronic acids.

These complex organic acids also called gum acids, when hydrolyzed it forms galactose, xylose, and simple acids which are useful polysaccharides or their derivatives that hydrates in hot or cold water to form viscous solutions that harden when dry. Classified as natural gums, Gum Arabic serves as base for mucilage in cloth finishing, calico printing and emulsifying constituents in medicines and cosmetics it is used also as adhesives for thickening inks in textile industries, stabilizer and binder in low calories food stuff.

They are found in certain calcium, magnesium and potassium salt with molecular weight of 240,000. Highly soluble in water and insoluble in alcohol and hydrates to form viscous solution. (Peter,1985).

2.4 Botanical consideration of coconut

Coconut palm (*Cocos nucifera*) is one of nature's greatest gifts to mankind. Practically all part of the plants is useful in one way or the other. The leaves, are woven into mats, baskets, and roof for housing; their fruits serve as food drink, provide oil, medicine; fibers for ropes and wood for construction of houses and boat. But the focus this time is on coconut shell, important use of this shell in the past has shown that the shells are used for gas mask, they are also used in manufacturing high quality activated carbon obtained from the charcoal, which are used in producing military and industrial gas mask, gold dust recovery, solvent recovery plant e.t.c.

The target of this research or project work is to use this highly fibrous material in composition with palm kernel shell in producing particle boards.

2.4.1 Fibre characteristics of coconut

Coconut fiber strands are up to 0.3m in length, the surface of the fiber bundle being occasionally covered with small lens-shaped silicified stegmats about 15μ in diameter. Each fibrovacular bundle consists of a thick walled sclerenchymatous sheath with individual fiber cells up to 0.3 – 1.0mm long and 0.01 - 0.02mm in diameter forming a polygonal to round cross-section. The fiber has a natural resistance durability and resistance to water which makes it useful in manufacturing of marine cables and hawers for ship and sailing, craft. Resent researches has shown that it can be used in producing packing material to protection against shock, and heat as well as water proof, sound proof and fine proof boards and thermal insulation (Kochhar,1998).

2.4.2 Origin and commercial utilization coconut shell

The true geographical area of the origin of coconut is much debated subject. It was believed at one time, to be a native of the Pacific Coast of Tropical America, Carried westward by oceanic current to Polynesia and Asia. But available evidence now indicated that the place origin of coconut is somewhere in the Indo-Pacific region from where it has been scattered throughout the coastal region of the world by sea current without the aid of man.

Recent estimate show that 90 percent of production of the coastal grown plant comes from the Philippine (1,780,000t), Indonesia (1,365,00t), India (455,000t), Vietnam (230,000t), Mexico (170,000t), New Guinea (100,000t), Malaysia (70,000t), and Syria Lanka (60,000t). With United States of America as the biggest importer of coconut (KOCHAR,1998).

Commercial utilization is in the area of confectionery and bakery product, its oil are classified as edible oil and due to its higher content of lauric and myristic acid, they are used in saponification process. Also it occupies very important place in the Hindu Rituals.

The development of coconut shell into particle board is another area of its utilization, which can be explore to it fullest. Due to the nature of this fibrous material, with the presence of cellulose in the cell-wall, along side pectin or lignin in combination of resins, high quality particleboard can be produced. In Nigeria, coconut is available in large commercial quantities in the earthen and Southern parts of the country. And the focus of the project work is to use the waste material generated along side another predominant fiber plant, the oil palm (palm kernel shell) in place of wood product.

2.5 Botanical Consideration of Oil Palm (Focus on Palm Kernel)

The African oil palm (*Eleas guinessis*) is of the same botanical family with the coconut (Arecacea) and they give the highest yield of oil per acre than any other oil seed crop. This plant, oil palm product, palm oil from the fleshy mesocarp of the fruit and palm kernel oil from the seeds.

History has shown that the oil palm is a nature of West Africa and is grown in the coastal areas. but its plantation has spread to the Southeast Asia the American tropics and the west Indies, with world statistics showing the leading producers as Malaysia (7,220 410t), Indonesia (3,890,00t), Nigeria (950,00t), Columbus , Thailand, Brazil and other countries in the west African zone. And Nigeria as the largest exporter of palm oil and palm kernel oil to the United Kingdom, Germany, the Netherlands, France and the Middle East countries. The heavy biomass of waste generated, is the concern of this project work, converting these raw materials into useful production of particle board in composition of coconut shell.(KOCHAR,1998)

2.5.1 FIBRE CHARACTERISTICS OF PALM KERNEL SHELL

There are four varieties of the palm and they can be distinguished on the basis of their morphological nature and fruit structure, especially the thickness of the endocarp. Var macrocarpa, 40-60 percent shell; var dura 20-40 percent shell, var tenera 5-20 percent shell and var pisifera a shell-less form. The best considerations are the first two with higher percentage of shell and their fibre characteristics are similar to the coconut (family Arecacae) as shown in table 2.0 below. The palm kernel oil is the widely known use, but little is known of the shell, that it can also be used in the wood industry.

Table 2.0 Average composition of palm kernel

Composition	Percentage
Carbohydrate	48.00
Oil	5.00
Proteins	19.00
Fibre	13.00
Ash	4.00
Water	11.00

(Opeke,2005).

2.6 MANUFACTURING STEP OF PARTICLE BOARD

The production or manufacturing of particle board starts by sourcing for the raw materials to be used and taking them through the process of size reduction into chips and splits. The broken chips are sieved into uniform sizes and dried to form uniform moisture content, before mixing with binder (adhesives). The mixture are then compressed to proper density and cured under heat and pressure. The curing process that results into the particle boards can be achieved through two major methods;

(a) Extrusion method (which is highly technical and expensive)

(b) Cold/ hot mat- formed method (simple and less sophisticated)

In the extrusion method, the extruded board is homogeneous (single layer) in structure and manufactured by mixing wood particles or flakes together with resin and forming the mixture into sheets. The raw material to be used is fed into disc chipper with radially arranged blades and resin in liquid form is sprayed through nozzles into the particles, the flakes are then spread by an air jet which throws finer particles further than coarse one. Two such jet, reversed, allow the particle to build up from fine to coarse and back to fine. The mixture is made into sheets by an oil heated metal plate serving as a weighing device, that compresses the spread of the mixed particle on a continuous sheet of moving belt into sized thickness and width. This is done at a pressure of 2-3 megapascal and temperature between 140c-220c. The process sets and hardens the glue. All aspects of the entire process are done carefully controlled machines. The final boards are then cooled, trimmed and then sanded and they can also be covered with wood veneer or laminated with paper for quality finishes.

The mat- formed particle board method on the other hand, consolidate and formed as flat panel consisting of building particle of wood together with synthetic resin. Lignins are treated from the particle by digestion which gives an advantage of protection against bingo- celluloses attack. In this method, a layer structure and three layer structure can be made. The single layer board has the advantage of forming a solid structure when great pressure is applied while the three layer structure increase the bending strength and stiffness of the board.

The fibre in the above method can be processed by mechanical or chemical means.

(a)Mechanical processing

This method, involves blending and applying pressure up of about 6.9Mpa at a temperature of 200°C. The blended finished mats become very loose particles, as its thickness are gradually reduced by the applied pressure until the final density is achieved.

(b) Chemical processing

In this processing method, lignin are removed from fibre mixture by adding pulping chemicals which greatly reduce them (i.e the three dimensional polymer formed from cyclic alcohol to protect cellulose from hydrolysis) and hemi celluloses in the fibre. This as an advantage of lesser application of pressure on the mixture and disadvantage of cost of production than the mechanical method.

2.6.1 Properties of Particle Board

The properties of particle boards produced have greatly depend on the morphological nature and structure of the raw material used, amount of adhesive and method of forming . For high quality board, some properties must be possessed by these boards which invariably will depend on properties of the raw material and they include;

(a) Tensile strength

Tensile strength is the resistance of a body to tensile forces that tend to pull it apart. It can also be referred to as maximum tensile strength which is the force per unit cross –sectional area that a body can resist before it ruptures. The relationship between stress and strain in particular material, this determined by means of tensile test (Shukar,1977).

(b) Hardness

This is the ability of a solid substance to resist surface deformation or abrasion. It can be measured by the capacity for bending through a definite angle. One or more time without fracture. The hardness of a material does not relate to the strength, durability and toughness of that material, rather it is the material ability to resist fracture by bending.

(c) Abrasion Test

This is the measure of scratch that a material can withstand. This is alone by scratching the smooth surface of the material to be tested, by comparing the result with reference to hardness scale, the relative hardness is found. A better test is by means of a level attacked to a vertical pillar and taking the pillar by bond, to make a scratch. The weight in grams required to produce a scratch of standard depth gives a measure of hardness. (Gladius,1977).

(d) Plastic limit

The moisture content at which a board become too dry to be in a plastic condition as determined by the plastic limit test.

(e) Nailing Test

Nailing on a particle board is the ability of the material to withstand nailing or stretching without splitting or disintegration of the binder used. Nailing test is done in order to ascertain the bonding strength of the material. Particle board should have a minimum holding force of not less than 178N (40 pa)

(f) Moisture content

This is the weight of water contained in a given sample of a particle. It is expressed in percentage. It is the ratio of weight of wet sample minus weight of dry sample divided by weight of dry sample minus weight of container all multiplied by hundred.

(g) Density

This is a measure of strength of material, depending on the pressure applied per unit, volume expressed in kilogram per cubic meter or in the ratio of the mass of a body to its volume. Relative density is obtained by dividing the weight in air by the loss of weight when the body is immersed in water. There are recommended density for particle board .(Low density 350 kg / m^3- 1400 kg/ m^3 and high density 1600kg/m^3 -2100kg/m^3)

(h) Fire resistance

This is the ability of material to withstand the effect of fire for a particular period of time before it starts burning. This varies in different materials and it depends large on the composition of the materials. Some additives have been known to increase the fire resistance of particle board, hence can be added in the mixing process.

(i) Compressive strength

This is the ability of a material to resist compressive force before collapsing. And is the ratio of the failure under compressive load to the multiple of the length of the breath of the material and its thickness measured in kg /cm^2.

(j) Static Bending

This is ability of a material to withstand a static load. The static bending of a material results either from a purely dead load from a variable load. It is very important test enabling one to ascertain the maximum allowable load on materials. The bending can be achieved if density of the materials satisfied (Gladius, 1977).

2.6.2 Finishing processes of particle board and uses

Particle board products are used in various forms and in different places. The furniture industries account for a large use, in lumber core plywood, strips of solid wood, cabinet, drawer bottoms, kitchen cabinets, notice board e.t.c. Summing up to about 20-25%. But also particle board are used along side metal products in the automobiles, refrigerators and trucks, exteriors television cases and in the construction industry. Therefore a high quality finished and semi-finished product is needed for different industrial uses. Some of the processes are as follows;

(a) Sanding

The quality of particle board is such that surface sanding is not normally required. However sawed edges, machined surface scratches can be dressed up by normal wood sandy procedures. Also precision sanding to close tolerance can be done.

(b) Machining

Machining can be achieved the same way as other wood products such operation as shaping, routing and planning gives best result if tools are kept sharp. Absence of grain In particle board allows uniformly fine machining without splintering.

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(c) Laminating

This process is done to give particle board resistance against dampness and change in color as a result of fungi attack. The board is laminated with paper or covered with veneer. This gives the board an esthetic look, and other times no need for painting.

(d) Sawing

Sawing the particle board can be achieved with the use of hand or power saw. But for high quality product the second option should be used to avoid edge cut and saw must be carbide-tipped.

(e) Screwing and Bolting

Special fasteners are designed for particle board; ordinary screw and nails will not provide the correct holding power over time. Threads may strip, portions of the particle board may blow out when stressed. Therefore holes smaller than the screws diameter should be drilled to accommodate shake of screw or bolts

(f) Drilling

The process of drilling particle board is same as other wood products. Only that, to achieve good holding capacity the drilled holes should be smaller in diameter to that of the fastener to be used along side with solid backing to attain clear and smooth edges.

(g) Fastening

Particle board may be hold together with other common wood fasteners such as nails, staples, automatic saver, bolts, adhesives and rivets.

(h) Painting the particle board

To paint the particle board required no much sophistication as any method could be used to achieving the finishing touches using brushes, spray or rollers. Also interior – wall panels require no special sealer, however if sealer are to be applied, rubber or vinyl- base whiter sealer are good choice oil base paint. Clear varnish or resin sealers should not be used as first coat. Instead transparent filler-scaler, natural paste wood filler or clear-drying white vinyl- glue can be used.

(i) Staples of particle board

Best stapling is achieved through a narrow screw and divergent point (branding out in different direction) along side a hammer - types stapler or air gum spacing of 3.5″ or as recommended. The length of staplers should be at least 1″ plans the thickness of the board.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Materials /Equipment: used for the production and characterization of particle board from agricultural by- products are given in table 3.0 and 3.1 below. This is to give the material use and source of the materials as well as their botanical names and comments

Table 3.0 Materials used for the project.

Materials	Sources	Botanical name	Comments
Coconut shell	Gwadabe Market Minna	*Cocos nucifera*	Dried and crushed into smaller particles
Palm kernel shell	Minna central Market	*Elaesis guinieensis*	Dried and crushed into smaller particles
Gum Arabic	Gombe Central Market	*Arabino gelactan*	Shredded, crushed sieved and dissolved
Water	Soil lab Fut Minna	Tap water	Washing items

Table 3.1 Equipment used for the project

Material	Sources	Research code
Manual square press shaped with steel pallet cover and bottom steel plate size 0.37x0.31x0.019	Mallam Billiaminu processing workshop Minna	
Electronic weighing balance	Saunter England	Digital calibration in (g)
Stop clock	Made in Nigeria	
Measuring cylinder	Eit England	BS 410/ 1986
Cylindrical steel container	Eit England	Metal
Grinding Machine	Made in Nigeria	
Mortal and Pestle	Made in Minna	Wooden frame
Oven	Eit England	BS 410 /1988
Local sieve	Made in Minna	Wooden frame
British standard sieve	Eit England	BS 410 /1986
Milk can	Soil and water lab	C1,C2, C3
Rammer	Eit England	BS 410 / 1986
Nails and screw	Made in Nigeria	

3.2 Preparation of composite of coconut and palm kernel shell particle core (mould) and gum Arabic (binder)

The composite of coconut and palm kernel shells sample used in production of the particle board were taken through some series of processes to obtain a particular particle size before being moulded into a particle board. The shells of both coconut and palm kernel were obtained from the coconut fruit sellers at the Saturday Gwadabe market and kernel from the native women who sell oil palm, and palm kernel seed at Central market all in Minna. These raw materials are dried daily under the sun to appreciable moisture content (dryness). The dried materials are pounded using mortar and pestle to break into size of splinter flakes and saw dusts. And it was further reduced using grinding machines. These particles are again sun dried for several days to further reduce moisture content to about 5%m.c. an experiment to determine the moisture content of the sample were taken (See table 4.0and 4.1)

The summary of the final preparation of these raw- material are given below;

1. The coconut and palm kernel shells were sun dried separately for some days to aid easy pounding and serving.
2. The coconut and Palm kernel shells were reduce into particle sizes of flakes, chips, splincters and saw dusts using the manual pounding method of mortar and pestle to achieve the particle of both coconut and palm kernel shell.
3. The particles were sieved using British standard sieve to determine particle size to be used to form a homogenous mixture. N.B. The finer the particles size the better the quality of the particle board produced.

4. The retained particle sizes were sun dried for several days to reduce the moisture content to about 5%
5. A moisture content test was conducted in the laboratory to keep the particle below or within the 5% M.c after sun drying.
6. The solidified acacia and other foreign bodies were stocked to the extract.
7. About 50g of the treated acacia extract was mixed with about 0.5Lit of hot water at temperature of 100°C for 30 minutes. To obtain homogeneity, the mixture was agitated until a stable viscosity was obtained. It is then cooled in a water bath until the temperature drop to about 27°C. And was mixed base on cmpositive mixtures as given in the appendices
8. The sample of coconut and palm kernel shells particle sizes were weighed using electronic saunter balance into 3 (three) separate samples "A, B and C" each and keep labeled.
9. The wooden mould and flat steel sheets were greased with oil on sides, bottom, surface and cover to obtain reduced frictional resistance created during forming operation.
10. A separate sample "D, E and" F" of the composites of the both coconut and palm kernel shell at a mixed ratio of 70:30,30:70 and 50:50 in percentage respectively was prepared from the samples "A, B and C" above.

3.3 Manufacturing process of particle board

The sample D of the composite of both coconut and palm kernel shell particle were poured into an opened steel container in damped condition.

The liquid Gum Arabic at 27°C hot condition was added to the composite particles and mixed thoroughly for about 5 minutes to form thick slurry of flares called "stuck'. This loose but damped material (particle mixture) was forces spread to achieve a uniform compaction into a greased mould of internal size 0.37mx 0.31 x 0.019m (thickness). The board was shaped to the required size as the stuck was compacted several times using a standard rammer on top of steel pallet cover in strokes to achieve a particular pressure (3333.3 N $/m^2$) in the British standard (BS) 2604 part 2 codes of manufacturing particle board. The formed particle board was left to dry under atmospheric condition for several days. The mould was removed, 30 min after placing and compacting process. The same procedure was repeated for sample E and F. N.B. coloring, anti-fungi agent and fire- resistance additives were not add due to scope of the laboratory work

3.3.1 Conditioning (Curing).

The production of the particle board was done after mixing and compacting were due to pressure. The wooden mould was removed leaving behind the formed board to dry in open air at room temperature for several days. The purpose of the conditioning is to equalize the moisture content through out the board and to minimize warpage that might other wise occur due to uneven shrinkage.

3.3.2 Characterization of the board

The produced particle board attained the required pressure and density which is with in he range of 350 kg $/m^3$ - 1400kg$/m^3$ for low density board. The standard requirements are based on plywood and wood- based panels provided by F.A.O. (1963). To determine the efficiency of the boards made from the composite of coconut and palm kernel shells with Gum Arabic, it is necessary to establish the minimum standard of blending and tensile strength and other properties specified in BS 609 part 211970.

3.3.3 Observation of formed board

In this project, three particle boards were produced given Sample A with 70%:30% composition of coconut and palm kernel shell sample B with 30%:70% composition sample C with 50%:50 % composition respectively. With the same particle size 200μm and 600μm.The finish product differ in color slightly, weight and density.

The curing steps are as follows:

1. The particle board was left to cure at room, temperature (27^0C) for 30minutes to set after which the mould was remove and the board was then conditioned at the same room temperature for several days
2. The board was then trimmed and shaped to finish

CHAPTER FOUR

4.0 LABORATORY EXPERIMENT/ TESTS, RESULTS& DISCUSSION

Laboratory experiment and tests were carried out following method and step prescribed scientifically. This is to ensure that results obtain are based on provable principles which originate from facts and figures which guide engineering principles.

The experiment conducted were on the coconut and palm kernel shell sample to determine , the moisture content of the sample and reduced it to appropriate required standard of 5%Mc. Also a sieve analysis experiment was conducted to know the size distribution of the particle, obtain homogenous size particle for proper mixture. To ascertain the suitability of the particle to be used.

The experiment procedure, test, observation and results are observed as follows.

Experiment 1

Federal University of Technology, Minna

Department of Agric & Bioresource Engineering

Material testing Laboratory (food and processing section)

Percentage Moisture contents Determination

Assignment: Project Research

Title: Moisture content determination

Aim: To determine the percentage moisture content of the experimental sample of coconut and palm kernel shell particles.

Apparatus: (i) Sample of coconut and palm kernel shell particles

(ii) Electronic weighing balance.

(iii) Cylindrical steel tin or container labeled A and B

(iv) Electrical oven.

Procedure: The weights of the empty containers were taking as (W_1) in each case A and B. Dry sample of coconut and palm kernel were put in each can with coconut and palm kernel labeled A and B respectively. The weight of the can and wet sample were weighed and recorded as (W_2). The samples were then placed in the oven at 105°C for several hours. The oven dry sample and container were weighed and recorded as (W_3). The obtained data were used to calculate the percentage of moisture content of the samples based on BS 1377 of 1975 which is given as follows:

$$\frac{W_2 - W_3}{W_3 - W_1} \times \frac{100}{1}$$

Precautions

1. The container was cleaned with dry cloth.
2. Moisture or water was avoided from coming in contact with dried sample before and during weighing.
3. Error due to parallax was avoided during reading of weighing balance.
4. Dried sample were allowed to cool before taking their weight to avoid expansion and contraction effect.
5. Results were fastly and carefully collected as stated in Table 4.0

Table 4.0 Moisture content Analysis

% Moisture content	Test 1 (sample A)	Test 2 (sample B)
Weight of container (W_1) g	24.46	22.09
Weight of wet sample + container (W_2) g	50.78	53.00
Weight of dried sample + container (W_3) g	49.56	51.55
Weight of moisture (W_2- W_3) g	1.22	1.45
Weight of dried sample (W_3- W_1) g	25.10	29.46
Moisture content $W = \frac{W_2-W_3}{W_3-W_1} \times \frac{100}{1}$	4.86	4.92

Uses of the Test

In forming a standard particle board the required moisture content is 5%. Therefore, the test, enable the determination of the moisture content in the samples. And if high than 5%, through the oven drying, it is further reduced to the required moisture content which affects the properties of the formed particle board.

Experiment 2

Federal University of Technology, Minna.

Department of Agric & Bioresource Engineering.

Material Testing Laboratory (soil and water section)

Assignment: Project Research

Title: sieve analysis of coconut & palm kernel shell particles

Aim: to determine the distribution of particle size of coconut and palm kernel shells using the British standard sieve (BS 410), with the aim of selecting the medium, less medium (small) and finest test particle for board production.

Apparatus: (i) Weighing balance

(ii) Wire brush

(iii) Stopwatch

(iv) British standard SIEVE

(v) Sieving machine (vibrator machine)

Procedure: The sieves of the British standard sieve were weighed on the weighing balance each. 1kg of the particle samples of coconut and palm kernel shell each was poured into the top sieve and set on the vibrator machine respectively. The set were set into vibration for 10 minutes for each of the sample respectively. The sieve were arranged in descending order in sizes of 6.70mm, 4.75mm, 2.00mm, 1.18mm, 8.50µm, 600µm, 300µm, 180µm, 150µm, and the bottom pan. After the vibration each sieve and the retained particle were weighed. The result is shown in the table below.

The result of sieve analysis conducted on the coconut shell particles is given below showing the weight and percentage retained.

Table 4.1 SIEVE ANALYSIS DATA OF SAMPLE A (COCONUT SHELL)

No	Bs/sieve mesh size	Wt of sieve (Kg)	Wt of sieve + sample (Kg)	Wt of retained sample (Kg)	% Retained	Cumulative % retained
1	6.70 mm	0.50	0.51	0.01	1.00	1.00
2	4.75 mm	0.51	0.52	0.01	1.00	2.00
3	2.00 mm	0.50	1.15	0.65	65.00	67.00
4	1.18 mm	0.40	0.56	0.16	16.00	83.00
5	850 μm	0.40	0.45	0.05	5.00	88.00
6	600 μm	0.35	0.36	0.01	1.00	89.00
7	300 μm	0.36	0.44	0.08	8.00	97.00
8	180 μm	0.39	0.40	0.01	1.00	98.00
9	150 μm	0.36	0.37	0.01	1.00	99.00
10	Pan	0.30	0.31	0.01	1.00	100.00
	Total			1.00		724.00

Fineness modulus = cumulative 724/100% = 7.24

The result of the sieve analysis conducted on the palm kernel shell particles is given below showing the weight and percentage retained.

Table 4.2 SIEVE ANALYSIS DATA OF SMAPLE B (Palm kernel shell)

No	Bs/sieve mesh size	Wt of sieve (Kg)	Wt of sieve + sample (Kg)	Wt of retained sample (Kg)	% Retained	Cumulative % retained
1	6.70 mm	0.50	0.51	0.01	1.00	1.00
2	4.75 mm	0.51	0.53	0.02	2.00	3.00
3	2.00 mm	0.50	1.00	0.70	70.00	73.00
4	1.18 mm	0.40	0.48	0.08	8.00	81.00
5	850 μm	0.40	0.45	0.04	4.00	85.00
6	600 μm	0.35	0.37	0.02	2.00	87.00
7	300 μm	0.36	0.43	0.07	7.00	94.00
8	180 μm	0.39	0.40	0.01	1.00	95.00
9	150 μm	0.36	0.39	0.03	3.00	98.00
10	Pan	0.30	0.32	0.02	2.00	100.00
	Total			1.00(Kg)		717.00

Fineness modulus = cumulation 717/1000% = 7.17

Precaution

1. Before the sieve analysis was carried out, the samples were dried for adequate moisture content to have correct weight of samples.
2. Error due to parallax was avoided during reading.

3. The sieve was cleaned with wire brush to avoid retention of the first sample before the second was introduced.
4. The samples were allowed to settle after vibration to avoid loses.
5. Error due to computation was also avoided.

Uses of the Test

The test is important in separating the particle sample of both coconut and palm kernel shells into flake, chips and dust. And hence the determination of the suitability of the sizes to be used. The particles retained in sieves 200mm and those in 600μm and below were selected for homogeneity of the particle board.

4.1 CONSIDERATION OF MECHANICAL PROPERTIES

4.1.1 Particle board density

Table 4.3 shows the density of the particle board based on test and calculation carried out on the particle board formed as shown in the appendices, for different composition of coconut and palm kernel shells at 70:30%, 30%:70% and 50:50% composition respectively. Also putting the sieve size analysis of the particle into consideration. It shows that the density of the particle board formed falls with the range of low density of 350Kg/m^3 – 1400Kg/m^3, which has a wide variety of use in insulation and decoration.

4.1.2 Hardness

The particle board was subjected to surface deformation and abrasion but show high resistance, which automatically means the board, has high strength and durability.

4.1.3 Optimum concentration of the binder

The concentration of the Gum Arabic used is of high viscosity and the result show good retention or adhesion. Therefore, a good binding resins base of this mix composition shown in the appendices

4.1.4 Nail/Screw withdrawal test

The particle board of sizes 0.37 x 0.31 x 0.019m and composition of coconut and palm kernel shell in ratio of 70:30%,30%:70% and 50:50% formed were passed through nail/screw withdrawal test. The three samples A,B and C particle board were subjected to nailing using a 15" nail and hammer. The nail was driven to a depth of 10mm.the particle board had a firm grip of the nails which shows that the board satisfied the minimum holding force as specified by (Madoux, 1963). To remove the nail a considerable force was applied.

4.1.5 Tensile strength

Which is based on the maximum tensile stress which is the force per unit cross sectional area a body can resist before it ruptures. This shows that particle board has high tensile strength as these is always inversely proportional to density which is low in the formed board. (ASTM, 1988)

4.1.6 Moisture content

From the moisture content experiment, the moisture content of the board is at 5% M.C. required standard for a good particle board.

4.1.7 Fire test

The samples were subject to fire test without additive, to determine the level of their resistance. With all condition keep constant use was observed that sample C has the highest resistance as it took some time to burn. Sample A burn a little earlier than sample B. it might have been affected by the compositional ratio. Sample B burns a little earlier than C, but much later than A.

Table 4.3 Summary of Comparative Material Composition and Test Results

al composite	Types of resin binder	Volume of coconut & palm kernel (m^3)	Weight of formed particle (Kg)	Density (Kg/m^3)	Grade of particle board	Pressure	Comment on properties of Gum Arabic	General remarks or comments	Curing conditio
e A 70% ut 30% palm shell particle .00mm and below).	Gum Arabic	2.1793×10^{-3}	2.35	1078.3	Low density	3313.00	High	Slow dehydra- -tion	Room tempera- -ture at 27°C
e B 30% ut 70% palm shell particle 00μm below)	Gum Arabic	2.1793×10^{-5}	1.75	803.0	Low density	3313.00	Low	Fast dehydra- -tion	Room tempera- -ture at 27°C
e C 50% ut 50% palm shell particle .00mm and below)	Gum Arabic	2.1793×10^{-5}	2.45	1124.2	Low density	3313.00	High	Slow dehydra- -tion	Room tempera- -ture at 27°C

4.2 DISCUSSION OF RESULT

Based on the result obtained from the three samples of the board formed. It is shown that composite particle board has higher quality due to combination of properties. And the 50%:50% and 30%:70% show greater qualities with little differences. But with that of 50%:50% composition preferred. Although with good Gum Arabic mixture and under hot compression with oven dry method the 30%:70% will give best properties. These two samples are good for different uses based on the properties required. Table 4.4 below show a breakdown of the compound properties

Table 4.4 Comparism of Properties against Particle Board Samples

No	Properties	Sample A 70:30%	Sample B 30:70%	Sample C 50:50%
1.	Fastener holding	Low	High	Moderate
2.	Smoothness	High	Low	High
3.	Shrinkage	High	Low	Moderate
4.	Abrasion resistance	Low	High	Moderate
5.	Swelling	Moderate	Moderate	Moderate
6.	Bending	Moderate	Low	Moderate
7.	Rate of burning	Fastest	Fast	Slow
8.	Density	1078.3 Kg/m^3	803.0 Kg/m^3	1124.2 Kg/m^3

4.3 POSSIBLE FACTORS LEADING TO THE LOSS IN STRENGTH OF PARTICLE BOARD

Loss of strength in particle board could results based on some factors mentioned below

1. **Nature and Structure of Method:** The morphological nature which is based on both Chemical and physical properties of the material used can caused structural deformation leading to loss of strength which can result into warping, bending, fracture and less inter -particle bond e.g. acid content of the material.
2. **Type of Adhesive used:** Improper choice or selection of adhesive and amount used can affect the strength of a particle board.
3. **Method of forming or mould used**: The method or mould used may bring about loss of strength, if the process is not effectively applied and design of mould not properly used during composition which can result in variation In shape.
4. **Particle sizes:** The particle sizes selected to form a particle board affect the density and invariably affects the strength of the board formed. Previous experiment formed in test has show that the smaller the particle sizes the more effective the inter-particle board. As its provide larger surface areas for the binder to reach with and penetrates to form a solid mould
5. **Drying effect:** The strength of a particle board is directly proportional to its drying effect. The presence of oily surface, very high viscose and oily binder, tend to prevent effective drying. Thereby, reducing the strength of the particle board, producing a gummy surface during the drying process. (Saydi, 2007)

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion:

Since the advent of particle board, different material has been used in production of the board. The use of Agricultural by-products is a new innovation that is used in recent time, as particle board have been produced from rice husk, rice straw, groundnut shell , coconut shell e.t.c. But the newest innovation being explore is the use of compatible composite of agricultural waste. The composite of coconut and palm kernel shells at different composition or proportion has brought about new properties and characteristics of the board produced in terms of strength and usability. The agro-based raw material needed are sufficiently available to support particle board manufacturing has coconut and palm kernel are produced in large quantities in southern part of the country especially palm kernel shell from oil palm. Although some of these material may not be suitable for some geographical zone thereby, affecting the economical variability.

Coconut and palm kernel shells are good alternative source of bio-material with good physical, mechanical and chemical properties that can be used in production of particle board. In addition they possess good handling properties and are environmentally friendly. Gum Arabic is another agro-based product that is used in place of the very expensive and chemically based synthetic resin as a binder to form the particle board.

The properties of particle board produced in terms of strengths are dependent mostly on board densities this is a very important point to note when selecting the design process, type of agricultural by-products and binder to be used in developing the board.

The uses of the board formed can be applied in the following areas:

1. **General furniture:** - Low density boards are widely used in place of woods, this is because they are less expensive; therefore reduce cost and weight of material. They are use in light furniture, like TV, cabinet, shelves, wardrobe, partitioning, ceilings board, chalk board as well in the arts industry.
2. **Acaustic paneling:** - Low densities boards are used in construction were sound proof is desired, like in studios, auditorium, and theatre halls e.t.c. (Madoux, 1963).
3. **Insulation:** - Based on the nature and structure of the material used in particle board production and their low density properties. They are very good insulators use in lagging heating materials were heat loss is not require, also in electronic casing to prevent shock and maintain required environmental temperature.
4. **Floor underlay:** - Engineered panel or particle board can be used as floor underlay, to serve as resilient floor covering.

5.2 Recommendation

On the basis of the result obtain from this project; the following recommendations can be made for further development. The development of a local production plant for the manufacturing of particle boards based on the design recommended should include; drying process → milling → mixture processing → delignification → blending building (core mould) → oven drying → finishing process. Thereby, enhancing the recycling of the agricultural by-product and Gum Arabic. This will be a cheap and mass local production of the boards. Thereby reducing the dependence on the forest based product that are use in construction and building industries in Nigeria.

The building industries in the country should be encourage to use the waste generated from agricultural by-product and products formed from them to reduce cost of production, as a result of high cost of raw materials.

Also, further environmental studies should be done to show the effect of agricultural waste on the environment such as dumping and burning of palm kernel shells, rice husk, groundnut shells and the burning of these wastes.

The use of Gum Arabic should be further developed in industries, encouraging them to go into the production and improvement of its properties for it to effectively replace synthetic resins or adhesive like the urea formaldehyde which are imported at very high cost into the country. For effective drying, curing in the oven can be employed.

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APPENDICES

Appendix I Density Determined

In calculating the density of the dried particle board, the weight of the formed board per unit volume is very important.

$$\text{Density} = \frac{\text{mass}}{\text{Volume}}$$

Sample A (70%: 30% composition)

Weight of particle board = 2.35Kg

Volume of particle board = 0.37 x 0.31 x 0.019 = 2.1793 x 10 $^{-3}$ m^3

$$\text{Density of board A} = \frac{2.35}{2.1793 \times 10^{-3}} = 1078.3 \text{ Kg/ m}^3$$

Sample B (30%:70% composition)

Weight of particle board= 1.75Kg

Volume of particle board= 0.37 × 0.31 × 0.019 = 2.1793 × 10^{-3}

$$\text{Density of board B} = \frac{1.75}{2.1793 \times 10^{-3}} = 803.0 \text{ Kg/m}^3$$

Sample C (50%: 50% composition)

Weight of the particle board = 2.45 kg

Volume of particle board = 0.37 x 0.31 x 0.019 = 2.1793 x 10^{-3} m^3

$$\text{Density of board C} = \frac{2.45}{2.1793 \times 10^{-3}} = 1124.2 \text{ Kg /m}^3$$

Appendix II Compaction

Using a 38Kg standard rammer, with a applied distance 0.10m iron mould pallet to compact particle board mixture. The force of application can be computed as:

$$\text{Compaction Force} = \frac{\text{Mass}}{\text{Applied distance}} \text{(Kg) x acceleration due to gravity} = 380 \text{ Kg x } 10 = 3800 \text{ N}$$

Pressure

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \quad \text{N/m}^2$$

$$= \frac{3800}{(0.37 \times 0.31)} \quad = \quad 3313.00 \text{ N/m}^2$$

Appendix III Mixture Composition

The composition mixture of the composite of coconut and palm kernel shells particles with the Gum Arabic is given as:

50 Kg of Gum Acacia dissolves in 0.5lit hot water

Let volume of Gum Arabic be denoted with G = 500ml = 0.5lit

Volume of the composite shall be denoted as $S = 0.37 \times 0.31 \times 0.019 = 2.1793 \times 10^{-3}\text{m}^3$

But $1000\text{ml} = 1\text{lit} = 1\text{m}^3$

$$\text{Composition Mixture} = \frac{G}{S} = \frac{0.5}{2.1793 \times 10^{-3}} = 229.4$$

$$G = 229.4S$$

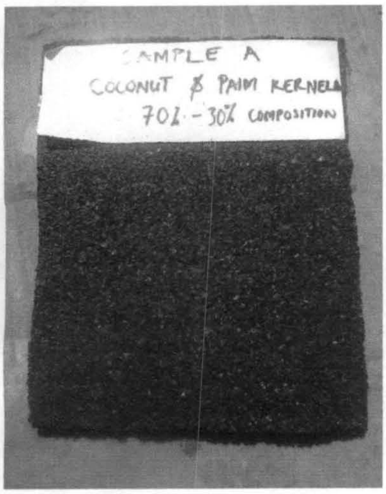

Plate 1: Sample A 70%:30% Particle Board Developed

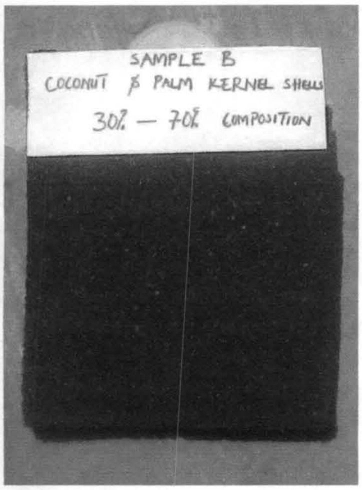

Plate 2: Sample B 30%:70% Particle Board Developed

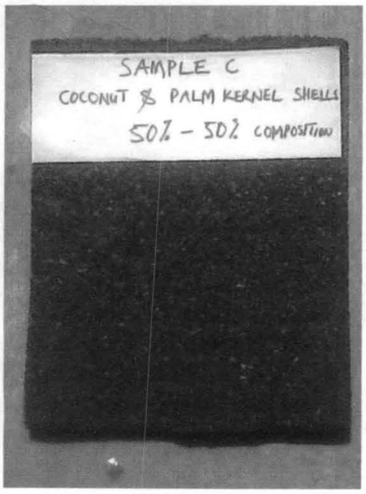

Plate 3: Sample C 50%:50% Particle Board Developed