COMPARATIVE STUDY OF PARTICLE BOARDS PRODUCED FROM USING VARIOUS AGRICULTURAL WASTES

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ANOSIKE, RITA NGOZI

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DEPARTMENT OF AGRICULTURAL ENGINEERING,
AHMADU BELLO UNIVERSITY,
ZARIA - NIGERIA.

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DECLARATION

I, Rita Ngozi Anosike, declare that this thesis is solely the result of my work and has never been submitted anywhere for any degree. All literature cited have been duly acknowledged, in the references.

R. N. Anosike

CERTIFICATION

This thesis entitled COMPARATIVE STUDY OF PARTICLE BOARDS PRODUCED FROM USING VARIOUS AGRICULTURAL WASTES by RITA NGOZI ANOSIKE meets the regulations governing the award of the degree of Master of Science (Agricultural Engineering).

Dr. C.N. Asota
Chairman, Supervisory Committee

25/6/93
Date

Prof. F.G. Braide
Member, Supervisory Committee
and Head of Department

25/6/93
Date

Prof. Dalhatu Mohammed
Dean, Postgraduate School

and Head of Department

18/1/96
Date

DEDICATION

To my parents, Mr. and Mrs. P.C. Anosike

ACKNOWLEDGEMENT

I am dearly indebted to my supervisor, Dr. C.N. Asota, who devotedly guided and patiently supervised this thesis. Indeed his supervisory acumen enabled me to complete this work on schedule.

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Above all, I thank God Almighty and our Blessed Mother Mary, who are the source of my strength and success.

ABSTRACT

Low density particle boards were produced locally from five different agricultural wastes, (rice husk, maize cob, sawdust, groundnut shell, and coconut shell) by the flat platen pressed method using gum arabic as the binding agent. The investigation aimed at establishing the optimal mass ratios of the components order to assess their potential for use as particle-boards.

Conditions for suitable processing of the waste products were investigated at a temperature range of 120°c to 160°c, pressure range of 3.ON/mm^2 to 4N/mm^2 and pressing time from 5 minutes to 15 minutes. The results show that the particle boards were very sensitive to the processing conditions. At pressing times above 5 minutes, increase in processing temperature beyond 160°c and pressure below 4N/mm , respectively, do not follow processing of the furnish into particle boards. Consequently, conditions for optimal processing of the waste furnishes into boards may be set at temperature range of 120°c to 160°c, pressing time ranging from 5 minutes to 15 minutes and pressure at 4N/mm^2.

Mechanical analysis of the boards shows that pure coconut shell boards had higher strength properties than its combinations, while maize cob and rice husk combinations were better than pure maize cob and rice husk boards respectively. Their mechanical properties compared favourably with the

literature values.

Further work on formulation is required to make the gum arabic bonded particle boards universally applicable and useful.

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CHAPTER ONE

1.0 INTRODUCTION

The family of crops producing wastes is dominated by rice, maize and groundnut. Whereas some agricultural wastes are useful, others present problems. Many farmers solve the problem in the field by burning the wastes. This is cheap, effective and creates few environmental problems when done in a controlled manner. When burning is either not possible or desirable, the residues usually have to be disposed off by allowing them to decay in the field.

Excess agricultural wastes also hinder traditional ploughing and their presence in the field can create an unfavourable soil environment for plant growth.

Much attention has been focussed recently on the uses of agricultural wastes at the series of conferences on agricultural wastes utilization organised by the Agricultural Development and Advisory Services of the Ministry of Agriculture, Fisheries and Food. The major use of agricultural wastes has been for animal feed and beddings. They can be used as raw material for paper, building board and as a starting point for production of chemicals.

Report by the United Nations Industrial Development Organisation (UNIDO, 1972) indicates that much research has been carried out on the use of baggasse (fibrous residues from sugarcane) in particle board manufacture and is now employed

in commercial production in some parts of the world.

The research for cheaper and readily available raw materials is in rapid progress. It is in this direction that different agricultural wastes are studied as a potential raw materials for particle board manufacture. The economic gains so derived will benefit the farmer in particular and the country at large.

Particle boards are "boards made from particles of wood and/or other lignocellulosic materials bonded with synthetic resin and/or other organic binders" (British Plastics Federation (BS, 1811), 1961). They include resin board wood chipboards, and the main non-timber particle board made from flax-shives, which are principally categorized into platen-pressed boards such as single layer boards, graded density boards and the three layer boards, and the extruded boards.

These materials which form one of the most important classes of industrial wood products are in large use in Nigeria. Particle boards have been industrial products of outstanding importance since their discovery in Switzerland (Desch, 1973). They are used by Timber Research and Development Institutes, Civil and construction Companies as well as the Federal Ministry of Works and Housing for house construction, as structural materials, wood veneers, hardboards or plastic laminates. They have also been used in fabricating countertops, cabinets, shelves, wall panellings and all types of doors.

In the past, many patents specified the use of metals as the essential structural materials for house construction, wood veneers, hard boards, shelves, and wall panellings. With advances in scientific discoveries, rising cost as well as shortage of critical metals, industries have been forced to develop particle boards as substitutes.

Gum arabic bonded particle boards are panels manufactured mainly of ligno-cellulosic materials primarily in the form of discrete pieces or particle of wood combined with gum arabic resin of 8-10 percent of the weight of wood particles. It is bonded together under heat and pressure in a hot press (Caleb, 1978). They are probably the newest of all the man-made sheet materials and are the cheapest type of particle boards.

Commercial chipboard production began in Switzerland and Germany as early as 1941, and in the United Kingdom in 1946. The growth of this industry in Europe has been phenomenal from 12,000 metric tonnes in 1950 to an estimated 5,060,000 metric tonnes in 1969 (Desch 1973). The major raw materials for this product are agricultural materials which are abundantly and cheaply available in these countries.

Most present day particle boards are manufactured either by platen pressing or extrusion techniques. Consequently, most chipboards, and all flax-boards are pressed between heated platens, the particles are in random or crisscross fashion, with their largest dimension parallel to the face of the board. This is typical of single layer boards, graded density

boards and three layer boards. Particle boards are also available as extruded between two parallel heated plates. This offers the advantage of continuous production and the ability to form thicker boards than are possible by means of platen-pressing. However, the process causes most of the particles to be perpendicular to the surfaces are the extruded boards are consequently weaker in bending than platen pressed boards. The distribution of the particles also leads to much greater moisture movement, particularly in the direction of extrusion. As a result of this, extruded boards are principally and singularly used as corestock for veneers. Therefore platen-pressed boards have some advantages over extruded boards. Their ease of processability requires minimum and simple machinery. Platen-pressed boards can be conveniently formed in mats and are reasonably strong with smooth high density surfaces.

The three main binders currently used in the production of particle boards are Urea resins, phenolic resins and gum arabic rasins (Powers, 1955). Urea melamine with formal dehyde to form aqueous amino resins, usually used in the impregnation of the wood or other cellulosic particles. All the urea formaldehyde (U.F) and urea melamine Formaldehyde (UMF) resins are imported and as there are no known local commercial sources of urea, melamine cum formaldehyde, home production appears uneconomical. The same expectation of economic predicament holds for phenolic resins which also, are not

locally available. However, gum arabic, naturally obtained as a water soluble, yellowish gum from certain varieties of acacia (economic tree) (Uvarov, 1979), are available in Northern part of Nigeria. These various reasons motivated this investigation on gum arabic bonded particle boards.

Some attempts have been made to determine the destructive and non-destructive properties of some gum arabic bonded particle boards, but there is still little done in the area of comparative study as well as the optimal processing conditions for the manufacture of particle boards from various agricultural wastes using gum arabic and paraffin wax or crotonaldehyde as the only binding agent and water repellents, respectively.

Available Markets for Particle Board

It is believed that there is a large internal market for particle board in Nigeria with intensive building construction. Nigeria has a population of over 88 million (FCOL, 1992) and shelter is needed for each member of this teeming population. The cost of building materials has risen sharply and a relatively cheap material as particle-board compared with plywood and fibre-board would readily be welcome by the consumers.

Particle board is not manufactured in Nigeria at present and it is estimated that about 8,000cm^3 was imported in 1973 at a cost of ₦190,000.00 (FAO, 1973). Now that low cost houses in many

cities and towns in Nigeria are being built by Federal and State Governments, demand for particle boards as construction and furniture materials will increase. The use of agricultural wastes for particle boards will reduce the need to import this vital commodity and lower their costs. Although agricultural waste particle boards will have to compete with fibre board and plywood, the high production envisaged as a result of cheap abundant raw materials will make the cost comparatively lower and in great demand.

Objectives of the Project

1. The primary purpose of this investigation is to conduct a comparative study of various particle boards produced from different agricultural wastes, namely, saw dust, coconut shells, groundnut shells, maize cobs and rice husks using the same binding agent (gum arabic).
2. Specifically, the investigations will aim at characterizing the various particle boards by defining their engineering properties and hence determine the best for a particular application.

It is hoped that achievement of these objectives will definitely open up new alternatives for consultants, researchers and particle-board manufacturers.

CHAPTER TWO

LITERATURE REVIEW

2.1 Boards-Overview:

To achieve the objective assessment of the properties and quality of particle board produced from rice husks, groundnut shells, coconut shells, maize cobs and saw dust it is necessary to review the characteristics of their allied products.

Board is defined as a flat or corrugated unit. In other words, boards are wood-based panel products. The word board covers three materials plywood (including block board and lamin board), fibre building board and particle board.

2.1.1 Plywood

This is an assembled thin sheets of wood panels called veneer which is made up of plies and adhesives. The sheets are glued together under pressure so that the grain of the central veneer runs at right angles to that of the outer sheets. An odd number of plies is normally used, since this enables symmetrical distribution of plies about the centre content changes, equal and opposite bending effects occur due to differential shrinkage of symmetrically opposed sheets. As a result, plywood can be used in situations with variable moisture content with minimum distortion. The flexural strength and stability of plywood increases with the number of

plies. Since the glue lines restrain surface cracking due to the stresses imposed by moisture changes, there is a limit to the thickness of surface plies that can be used. There is a wide variety of plywoods available, differing in thickness, strength durability and appearance. Plywood is used in areas where strength and lightness are of primary importance. Plywood is also very widely used for cladding as formwork, for concrete and for structural purposes.

Plywood is associated with blockboard and laminboard. they are manufactured by the same mills but construction differs. Blockboard and laminboard differed from plywood in that their centres or cores are composed of strips of softwood up to 25mm thick which are glued together. These materials compete greatly with particle board.

Plywood is manufactured in many countries in a very wide range of thicknesses, from 3 to 25mm but this range can be extended for special uses. The major producing countries include, United States, Soviet Union, United Kingdom, Nigeria and Gabon (Leigh, 1980).

2.1.2 Fibre Building Boards

These are produced by pulverising of wood down to individual fibres and then compressing them to form large sheets. Most fibre boards are made without any additional bonding material since wood fibres are self adhesives. Several different types of product are obtained according to the

degree of compression of the fibres. Almost all types are, however, very susceptible to moisture content change and to creep, especially in damp conditions.

The most densely compressed fibre boards are referred to as hardboards. These boards can have quite high bending strength (for example 30N/mm^2); though swelling and strength reductions occur on wetting (Taylor 1973). They have minimum density of 881kg/m^3. They are the most versatile of all the fibreboards. Hardboards are classified according to density as "standard", 'medium' and 'tempered'. Thickness ranges from 2mm to a maximum of 12mm and are used for lining low-cost doors, partitions and in sheeting and cladding in day situations. Nail and screw retention properties are poor. Oil-tempered grades have greater resistance to dampness and have been used for low-cost external cladding.

Hardboards are heavier than plywood but where lightness is not a pre-requisite, their cheapness and the ease with which they take surface finishes give them many advantages. They are used in furniture making in building construction. the major production areas of fibreboards include Europe, America, Australia and South Africa (Flemmich, 1959).

A number of medium fibreboards are now available which have moderate bending strength but better thermal insulation properties than hardboards. These are suitable for ceilings and claddings.

Low-density fibreboards (soft-boards) are made from

uncompressed wood or sugarcane fibre. They are used primarily for insulation purposes, having thermal conductivities of approximately 0.05w/m and densities of about 300kg/m^3. They are soft, porous and have relatively little strength. They are predominantly used for their excellent insulating and acoustic properties and they are ideal inexpensive building boards. They are obtained in a variety of thickness from 9mm to 25mm.

All types of board are inherently flammable, though fire retardants can be incorporated.

2.1.3 Particle board

Particle boards are defined by British Standard 1811 (BS 1811,1961) as "boards made from particles of wood and/or other ligno-cellulosic material bonded with synthetic resin and/or other organic binder". British Standard 2604: Part 2, 1970 defined particle boards as "Panel material manufactured under pressure essentially from particles of wood and/or other ligno-cellulosic fibrous materials (for example wood chips, sawdust, flax shives etc) with or without the addition of an adhesive, hydraulic binders being excluded". All particle boards generally conform to the requirements of BS 2604: Part 2. Resin-bonded wood chipboard" in which are given requirements for dimensions and tolerance, freedom from foreign particles moisture content, thermal conductivity, surface spread of flame and minimum strength properties.

Particle boards are manufactured by highly developed

mechanical techniques which ensures strict regularity of size, thickness, moisture content and other physical characteristics.

Particle boards are broadly classified into three basic types, according to density. they are low, medium and high density particle boards. The low density particle or insulation board has a density of 300-400kg/m^3 (FAO, 1963). The low density particle board is usually light. The medium density board is of 400-800kg/m density range while the high density is of 800-1200kg/m^3 range.

Particle board can be used for a wide variety of application such as roof decking, flooring, wall lining, partitioning, built-in figments and other joinery such as door cores. Within these application it is possible to obtain boards of specific nature and characteristics, for example, flooring grade boards of specific nature and characteristics, for example, flooring grade boards; ready-to-print grades, boards faced with wood, plastic and hardboard veneer, low-density panels (usually flaxboard) for roof-decking. In concrete form work linings, the board is normally sealed against water absorption.

In furniture industry, the board is faced with decorative wood veneers or plastic facings to provide panels of strength, stiffness and above all dimensional stability. It is used as core stock for desktops, drawer fronts, bed rails and shelves.

Report by Food and Agricultural Organisation (1958)

indicates that it is cheaper to build a particle board mill than a fibre board or plywood mill. Particle board being a manufactured material is not subject to grading for natural defects carried out for plywood or solid - timber. Particle board has some economic advantages over other wood based panels. it has been used in preference to other materials for sliding doors in closets and ward-robes because it is less affected by humidity changes. Delamination does not occur in particle board but plywood delaminates when in use. Generally, it is cheaper than other comparable materials on a cost per square meter (Ezra and Dip, 1971). The good dimensional stability and uniform strength properties of the board facilitate design and improved service performance in comparison to edge-glued timber panels (Bengston, 1963). Particle board is preferred in most construction to other board materials because of its freedom from warpage when veneering and due to the fact that it remains flatter in service (Garvvilor, 1962).

Particle board is also superior to other panel materials in machinability, screw-holding, gluing properties and dimensional stability (Leigh, 1980). Cabinets are being constructed of veneered particle board panels and in assembly are often joined together without frames.

Particle board has largely, supplanted plywood and block board in furniture panels in thickness greater than 9mm in the United Kingdom. The use of block board dominates for

horizontal surfaces and particle board is increasingly used in the side panels when flush panels replace solid rail panels with plywood inserts.

The disadvantage of particle board is that is not suitable for outside applications exposed to sun and rain. If particle board is applied to such area without a plastic covering, surface distortion will occur.

2.1.4 **Origin and Development of Particle board**

Some experimental work on particle board production as was reported by the Food and Agricultural Organisation (FAO, 1958) of the United Nationsl (UN) was carried out in both Europe and North America before 1940. Particle board (chip board) is the newest of all the man made sheet materials. According to Laidlaw and Hudson (1973), Commercial chipboard production began in Switzerland and Germany as early as 1941 and in the United Kingdom in 1946-47. The growth of the industry in Europe has been phenomenal, from 12,000 metric tonnes in 1950 to an estimated, 5,060,000 metric tonnes in 1969. Particle board consumption is now highest in West Germany, which has recently overtaken Switzerland, with Canada, United States of America and the United Kingdom very far behind the two leaders.

Particle board was first made both in the experimental and in commercial production in the flat presses. However, majority of plants operating today employs multi-platen presses. The extrusion process was developed in West Germany

between 1947 and 1949, and experience a rapid but short lived commercial expansion, for the product was unsatisfactory for many purposes because of its low strength characteristics.

The possibility of using some agricultural residues had been explored during the period from 1940-1946 in Switzerland and United Kingdom. The bulk of the raw material for particle board manufacture is wood, but flax or hemp-shives are also used. In addition to the wood particles, synthetic resin adhesives, typically to the extent of 8 to 10 percent of the weight of wood particles, water and a small proportion of wax 0.25 to 1.0% are used in the manufacture of particle board. The first plant based on flaxshives was put into operation in Belgium in 1947. Many researchers have reported their studies on the possibility of using agricultural residues for the particle board production. Staackman and Goodale (1970); Beagle and Beagle (1971) and Chittenden (1971) have suggested several uses of some agricultural residues among which are their uses for making particle boards.

Several attempts were also reported by various researchers (Staackman and Goodale 1970, Vasishth 1973, Lantin 1982 and Pablo 1983 in the past to develop a process for manufacturing boards from these agricultural residues but none was able to produce the board in commercial. A pilot plant under the guidance of vasishth 1973 of cor-Tech Research Limited, Canada, was set up in the Philippines for commercial production of rice husk particle boards. However, the final

product is yet to reach consumers as there are several draw back (such as high water absorption, thickness swelling and nail resistance properties) in the quality of the boards (Pablo, 1983).

Between 1966 and 1977 World production of particle board rose from 11 million to 37 million cubic meters (Leigh, 1980). The major producing areas include America, Belgium, Germany, Soviet Union, France and Italy.

2.2 Raw Material for Particle Board production

Particle board was first manufactured from wood of relatively low density, generally coniferous (FAO, 1955). However, there is an important difference between hardboard and particle board in that hardboard differs little in density, independent of the wood species used, whereas there is room for variation of density in the case of particle board.

Klauditz (1962) and Lirri (1963) studied and reported the relationship between wood density and properties of the material, such as board density, strength, dimensional stability and surface quality. The use of sawdust in particle board production and certain types of boards were also reported by Eisner (1962). Sawdust is being used in commercial production.

It is to some extent possible to compensate for the low quality of the raw material as in the case of fibre board by

increasing the percentage of binder. It has been found economically advantageous to use sawdust for general purpose boards and in one case where experiment was carried out, percentage of binder about 25% than normal have been utilized (Eisner, 1962).

It is agreed generally that the raw material requirements for extruded boards are less exacting and most kinds of wood residues constitute acceptable raw materials for this type of board. This is due to the orientation of particle in such boards, high bending or shear strength will not be reached, even with engineered particles. These boards are nearly always veneered, so that appearance is not a factor to be considered (Madoux, 1963).

A study was carried out by Peri (1950) on particle board production using cellulosic materials such as wood fibre, sawdust, straw, rice husks and nutshells with a hydraulic binder (Portland cement). These boards were stone like, durable, possessed light weight high insulation value and high value stability.

Othmer and Riccardi (1950) developed a process in which some cheap chemicals instead of resin binder are used for making boards from sawdust and other lignocellulosic wastes. A research on the possibility of preparing lignincarbohydrate wood-plastic from mixtures of larch and pine sawdust was carried out by Berseneva and Petri (1969). It was reported that the increase of moisture contents of particle boards made

of pine sawdust - larch sawdust mixtures increases the board homogeneity, but decreases strength and increases porosity. The optimum moisture concentration is 19-21% when the boards are made by compression at 170°C and 25kg/cm^2 pressure during one minute for each millimeter of the board thickness, lower temperatures require longer compression time. The production of particle board from arecanut hust and taioca stem have also been studied by Narayana Murti, (1951).

2.2.1 Use of agricultural wastes for particle board manufacture

The pattern of available raw material for particle board and almost all forest product is changing. The conifers (softwood) which are the preferred species in the manufacture of particle board are becoming scarce. The use of timbers for plywood, fibreboard, pulp and paper industries is now competitive and has resulted in higher costs of the raw material. These considerations have led to the use of wood and agricultural wastes. Research has also been carried out on the use of bagasse (fibrous residues from sugarcane) in particle board manufacture which is now employed in commercial production in some parts of the world (UNIDO, 1970).

The search for the cheapest and readily available raw materials is an on going process. It is against this background of finding alternatives that the five agricultural wastes are examined as potential raw materials for board manufacture.

The physical properties of such agricultural wastes as coconut shells, groundnut shells, maize cobs, and rice husks suggest the possibility that they could be used for the production of particle boards. Chemical analysis shows that coconut shell contains 26.6% cellulose, 29.4% lignin. Groundnut shell, maize cob and rice busk contain 70.9%, 45.0% and 35.68% crud fibre respectively (Chitternden, 1971).

2.2.2 Basic Processes in the Manufacture of Particle Board

Flat platen press and extrusion are the two main methods of particle board production. Flat platen press is more common and usually involves batch or continuous pressing while the extrusion process is continuous. the raw materials (for both types) are fed to cutters or shaving machines which produce the particles (splinters or shavings). The particles are screened, cooked and them dried to a controlled moisture content (5-6 percent) before being sprayed with 4-15 percent resin solution (Flemmich, 1959). Wax may be added to meet water soak requirement.

In the flat platen press method, the particles are next spread out on trays to a pre-determined thickness. The trays are then placed in hot press and subjected to a carefully controlled pressing schedule of 1.4-2.4 N/mm^2 at 100°C to 140°C for about 15 mins. In the continuous press method, the particles are spread continuously on a moving belt which passes through a pre-heater and then through the electrically

heated press.

In the extrusion method, the particles are forced through a horizontal or vertical heated extrusion die from which a continuous length of board emerges. This is carefully led onto horizontal table where it is cut to standard lengths. Extruded boards are always veneered before sale.

At the end of each process, the boards are trimmed to exact size, conditioned for about seven days and crated for shipment. The major characteristics of both types of boards as distinct from fibred board is that fibres are felted and held together by fibre to fibre bonding and their formulation from inorganic binder like cement.

2.2.3 Types of Particle Boards

Five types of particle board are recognised, namely: general purpose, interior-structural, interior-non-structural, exterior-structural and exterior-non-structural. The last two types are not yet available. There are three types of platen-pressed boards: single layer, multilayer and graded density. The density of single layer boards depends on the nature of the particles used. With wood particles the density is of the order of 600kg/m^3 or more, whereas boards made from flax shives are of 350kg/m^3 and above. Multilayer boards consist of thin relatively high density. Multilayer boards are inferior in strength properties to single layer boards and their screw holding qualities are lower. The merit of the multi layer

boards lies in the low density of the veneering and the saving in weight. The particle elements vary in size, and are distributed through the board in such a manner that they decrease in size from the centre thickness of the board to the outside.

2.3 Plants of Significance in Particle Board manufacture:

2.3.1 The Coconut Palm:

Coconuts (colos nucifera) are the most important of cultivated palms and the most widely distributed of all palms. They are stately trees of 12-30m tall and 0.2-0.6m in diameter (Popenoe, 1969). However, some trees are dwarf, some have branches and others have spiral trunks. They are monocotyledonous with no tap root; and have a swollen base. Every tree is different with millions of variations since they are propagated only by seed.

The coconut has fern-like pinnate leaves, with ribbon-like leaflets from 3.7-6m long and is one of the characteristic sights of tropical areas. The tree prefers a sandy soil, and are seldom found growing wild far from the sea. The fruit may be 0.3m long and consists of four parts: about 35% husk, 12% shell, 28% meat and 25% water (Aten 1958). The fruit is void in shape and, in the husk, is about the size of a football. They are widespread in warm regions, being most abundant in America and Asia, and less in Africa. Coconuts are now grown in all tropical regions around the world, where

the temperature humidity, soil, and elevation are suitable. The coconut crop of the world estimated at 16,914 million nuts comes out of an area of 8.7 million acres distributed over the tropical coasts of India, Indonesia, Ceylon and so on.

In Nigeria coconuts can be found more abundantly in the Eastern, western and southern parts of the country.

Coconuts are far more important to humanity than statistics show because millions of people in India and other tropical regions depend upon the coconut plantations for their livelihood (Popenoe, 1969). Coconuts are important: (a) as a source of food and shelter for millions of natives, (b) as raw materials for many small industries in the manufacture of products from the husks, shells, meat, leaves, stems and tree trunk and (c) for export in the form of fresh fruit, coir, copra coconut oil and desiccated coconut. In florida, the husked and unhusked nuts are sold as souvenirs, and are made into novelty items and speciality food products. It is also used in manufacture of Cosmetics such as face creams, shampoo and soaps.

The coconut palm tree affords, a variety of useful products. These include food of many varieties, house building materials, wearing apparel, tools and others.

Products of Coconut Origin

Coconut husks: coconut fibres is used in making carpets, brush (fibre from the husk of coconut) mat, matting, rugs, carpets of a wide range of qualities and attractive colours

and designs are well known throughout the world for durability, sound-proofing and damp-proofing qualities which are largely used for floor covering in offices, factories and residential places.

Coir fibre of inferior quality, may be used for manufacturing hard board when low grade coir fibre (100kg) is mixed with fossil resin (10kg) melted at a high temperature and suitably pressed into boards of suitable size. The boards are durable, smooth on both sides, inherently insect proof, fire retarding and water repellant. They may be sawed, nailed, glued and finished into any type of board according to requirements.

Coconut Shells: The Coconut Palm, perhaps yields more products of use to mankind than any other plant. In supplying food, drink and shelter it not only caters for some of the primary needs of mankind, but also provides raw materials for a number of important industries.

The weight of shells varies with nuts of tall palms over the normal range of size, but averages about 25% of the husked nuts. Much is used for domestic fuel in copra kiln. Although the lignin content lower, coconut shells are similar in chemical composition to hardwoods. The following discussion reviews its status as potentially valuable industrial raw material.

Coconut Shell flour: This is the preparation of powdered coconut shell in the form of coconut shell flour. It is

extensively used as a compound filler for synthetic resin glues and extruder for phenolic moulding powers. This unique filler is also being used successfully with specialised surface finishes liquid products (as an absorbent), mastic adhesives, resin casting, mild abrasive products, hand cleaners, polyester type laminates, bituminous products and potent insecticides. Coconut shell flour gives a smooth lustrous finish to moulded articles and also improves their resistance to moisture and heat.

Furfural from Shells: An important product that can be derived from coconut shells is furfural. Furfural is useful as a chemical intermediate in the manufacture of nylon, in the preparation of pharmaceuticals, fungicides, insecticides, preservatives, herbicides and other chemicals, in the preparation of wood resin and for refining lubrication oils. Shell Charcoal: A considerable portion of the available supplies of shells is used for preparing shell charcoal. it is prepared by burning the shells in a limited supply of air in suitable kilns (coconut Research Institutes, Ceylon, leaflet (1970) No.6). Shell charcoal is used in laundry, smithy, bakery, for gas masks, and as fuel for automobile gas generators.

Shell Ash: Ash in coconut shell has been reported to be useful in native medicine and it is used in pottasic manure.

Coconut shell is hard and takes a high polish. It can be carved decorated with lacquer, inlaid with silver or other

metals and generally used with ornamental effect. Local craftsmanship has produced articles such as lamps, goblets, flower vases, combs, ladles, bowls, stands, buttons, cufflinks, tea sets, ashtrays, trinket-dishes, paper weight, musical instruments, spoons, sugar-ports and bangles of very attractive appearance and characteristics of the native art of the various countries of origin. Coconut shells are also used in making cups which are used for setting jaggery, for collecting rubber latex and as measures for many types of liquids.

2.3.1.2 **Suitability of Coconut Shells in Board production**

The suitability of the raw materials to be used in particle-board production is of paramount importance. A knowledge of their physical and chemical characteristics is therefore, useful. This will assist in knowing the constituents of the raw materials and the extent to which it can be used for the intended purpose. The physical and chemical compositions of the coconut shells were studied by Popenoe, (1969). Coconut shells are similar in composition to hardwood, though lower in cellulose and higher in lignin. Chemical composition of coconut shell is shown in Table 2.1

Table 2.1 Chemical Composition of coconut shell

Composition	Percent
Moisture	8.0
Ash	0.6

Solvent extractives	4.2
Lignin	29.4
Cellulose	26.6
Pentosans	27.7
Uronic Anhydrides	3.5

Source: Popenoe, (1969)

Celulose and lignin are usually good for board manufacture (Leigh, 1980). The small quantity of acid and extractive content shows that the board properties may not be affected. These contents (lignin 29.4%, Cellulose 26.6%, moisture 8.0% and pentosans 27.7%) according to Foster (1967) affect the board quality. It was assumed that coconut shells might be a suitable raw material for particle board production.

2.3.2 **Rice Plant**

Rice is grass (Gramineae) belonging to the genus Oryza linn of which two species are cultivated, oryza Sativalinn and Oryza glaberrima Steud. The former is by far the more important, oryza glaberrima being confined to small areas in West Africa. In Nigeria rice is grown mainly in Eastern, Western and Northern parts of the country.

Oryza Sativa is widely grown in tropical and subtropical region either as a dry land (upland) crop but more usually in water. The ripe seed is the staple food in many Eastern

countries. The height of the paddy rice is usually 1.20 to 1.80m. Rice is mainly used as a good. It is used in making wines, cakes, starch, flour, vinegar, sugar,salted bean paste, soya sauce, medicine.

The hulls are valueless as food, not only because of their low nutritive value but because their high silicon content renders them harmful to the digestive and respiratory organs of animals. Hulls are used as packing for fragile materials and for manufacture of furfural. The chief use of hulls is as a fuel to supply power for the mill. It is also used for insulating materials, cardboard, rayon, linoleum and sometimes for polishing metal castings, soil mulches as well as in the manufacture of certain gases.

The outstanding properties of rice hulls namely their abrasive character, high ash and crude fibre content offer the best opportunities for developing industries which will use large quantities of hulls. Hulls are used in building materials. Some success has attended the employment of hulls for making paper and hardboard. Rice hulls are used to make valuable building materials by the stranit process, and waxes, lignins and pentosans appear to liguify to some extent at the process and no other binding agent is needed (Jensen, 1975). It has been calculated (Jensen, 1975) that the manufacture of particle board from rice hulls will become economically attractive when the cost of rice hulls is 85% of the price of wood at the factory or less. The chemical composition of the

Rice hull is shown in Table 2.2.

Table 2.2: Composition of Rice hull

Composition	Percent
Moisture content	9.02
Crude proteins	3.27
Fat	1.18
Carbohydrates	33.1
Ash	17.14
Crude fibre	35.68

Source: Jensen, (1975)

2.3.3 Groundnut Plant

Groundnut is an annual crop and is grown over a considerable area of the Northern Part of Nigeria. Groundnut is of leguminosae family. Its cultivated variety is Arachis hypogea linne. Its origin is south America, but it is now widely cultivated in warm countries throughout the world. it is suitable for tropics, subtropics and warm temperate regions.

Groundnut seeds yield a non drying edible oil, used in cooking pastry, for deefrying, shortening, making bread, margarines, salads and in canning. It is used in the manufacture of soap cold creams pomades, lubricants, emulsions for insect control, vegetable ghee, and in pharmaceutical industry.

The cake is a high-protein livestock feed and may be used as flour for human consumption. Seeds are used whole roasted

and salted or chopped in confectionaries, or ground into groundnut butter.

The composition of groundnut shells is fairly variable. all contains a high content of woody matter and carbohydrate. Biochemicals composition of groundnut shell is shown in Table 2.3.

Table 2.3 Chemical Composition of Groundnut shell

Composition	Percent
Moisture	6.85
Protein	5.2
Ashes	2.05
Non-nitrogenous extract	3.7
Hydrolysable sugars	11.7
Cellulose	70.9

Source: Adrian and Jacouot (1968)

Shells are used mainly as industrial fuel in oil-mills processing shell nuts. In non-producing countries, the shells may be compressed into cylinder blocks with a density of about 0.7/0.8kg/m^3, which can be sold as house hold fuel. through another process, the shells are burnt to obtain charcoal which can be compressed and sold in blocks.

Another secondary use is the mixing of shells with various products to produce building mud. After grinding, the shells may be mixed into feed for ruminants; the energy giving value is, however, low and the shells are used mainly to provide roughage (Ultery, 1973.

The shells, either in natural or in composit form may be incorporated in the soil to provide a considerable increase in the organic matter content. They also serve to improve the structure and increase the moisture content retention of the soil.

Groundnut shells are used in the manufacture of agglomerate board. After grinding, drying and addition of gum, a product inferior in quality to that made with wood may be obtained.

The pentosan contained in the shells make it possible, after hydrolitic cleavage to obtain furural. This is produced on a large scale in United States of america, Using oat straw, with an excellent output, groundnut shells therefore do not appear to be competitive in this field.

2.3.4 The Maize Plant

Maize (Zea Mays), known also as corn is one of the main subsistence crops cultivated by man. It originated in america continent and was first introduced to West Africa by Portuguese in the sixteenth century (Irvine, 1974). The plant grows in the temperate, tropical and sub-tropical regions of the world. it is an erect annual plant with fitrous roots, large stalk, long arching leaves with evenly ruffled edges and big seed. the corn seed grows in concentric rows around a cylindrical cob forming the "ear". The cob is about 15-20cm long and 2.5cm in diameter. it is covered by several leaf-like husks which are heavier and tougher than the leaves.

Botanically, maize belongs to the Graminae family which has only one species. There are many different varieties that grow up to a height of 3 meters. But cultivated maize, normally grows to 1.5-2.5m (Mantell, 1975). The plant grows in most soils except pure clay or sand. It requires an annual rainfall of 750 to 1500mm but substantially good at 375 to 500m, provided it is evenly distributed over the growing season. it will not grow well in areas with excessive rainfall; 2500 to 50,000mm or more (Irvine, 1974).

Maize is primarily grown for its seeds. The stalk has been used in making paper, building boards and other products before Nineteenth century (Mantell, 1975). The seeds have been used for human food and livestock feed. the yield of maize per hectare is about 250kg on average, but the yield may be up to 425kg.hectare (Livestock Feeds, 1986).

Corn is a cereal crop in Nigeria. It is second in importance to sorghum. Production is however, increasing at much wider areas as many more people prefer it to sorghum. It gives a greater yield per hectare Livestock feed producers also use a lot of maize, hence increasing demand for the crop. It is grown in almost every part of Nigeria. This ranges from the forest zones in the south where it can be cultivated twice in the year to the Savannah zone where it is believed to have the greatest production potentials with less diseases and pests. Other areas will require better management and facilities for good cropping.

The crop could be harvested and cooked as a vegetable or roasted when green but mature. It could also be processed when dried into flour use for many dishes in Nigeria houses. It can be used both locally and industrially for alcohol production. The yield of maize in Nigeria is about 2.5 million tonnes annually (Miracle, 1966). Major problems associated with corn production in Nigeria include weed, pest and disease.

Maize is used for three main purposes:

As a human food: Maize is processed in many forms, from primitive trampling and grinding (or boiling) to the modern maize mill. It is roasted (corn-on-the-cob) and eaten by most people. Modern human food made from maize include hominy grits, corn flakes, malt syrup, corn sugar, corn oil, corn bread and other bakery products. It is also used in alcohol production.

As a livestock feed: As a feed for livestock, it is the grain that is of most importance, but stalks, leaves and mature ears are also used as feeder for domestic animals. The corn is provided in ground form (Miracle, 1966).

By-products of corn industries used for livestock feed include gluten feed and meal, oilcake or meal, corn sugar molasses, germ cake or meal, dried distillers grained and dried brewers grains. Corn is an important ingredient in mixed manufactured feeds.

As a raw material for many industrial products: Maize is industrially important chiefly as starch, oil and alcohol.

These are obtained by "wet milling" process. the starch, when dried can be converted into dextrins, if not dried, it can be further processed into syrups and sugars.

Oil obtained from the germ goes into soaps and glycerines. it is also refined for cooking and salad making.

The protein in maize (zein) is used in producing synthetic fibre which is reportedly comparable in quality with other protein fibres (Mirade, 1966).

Maize is used extensively for the production of alcohols. Whisky, ethyl, butyl and acetone are also derived from maize.

Report by Boyd and Brevik (1952) indicates that concrete made from corn cob fragments, sand and cement may be successfully used for farm building construction. The high moisture absorption of such concrete necessitates some method of water proofing the wall surfaces. The cobs are also used for a cork substitute, fuel furfural, pipe bowls, xylose and many other products.

Corn stalks or leaves have been used for manufacturing paper, paper board and wall board.

Maize cob which is the product of interest in this research, is part of the maize plant. the cobs of the common varieties of maize generally are 17-20cm long and 2-4cm in diameter at the butt (Mantell, 1975). The cob tappers to about 2mm near the opposite end.

The cobs consist of three main portion; cortical layer, wood blast and pith.

The cortical layer is the outer layer of the cob on which corn grains are arranged. it consists of fine and coarse chaff. it is yellowish in colour and is good for making fibres.

The wood blast is the main part of the cob. it is a hard tough woody layer surrounding a centre of pith. It is good for board making. Its proportion increases from top to the bottom.

The pith is the central portion of the cob. It is composed of soft tissues. it easily becomes powdered during grinding process.

The physical and chemical composition of the cob, by weight, as shown in Table 2.4.

Table 2.4 Composition of Maize Cob

(a) Physical composition:

Constituent	Average (%)
Cortical layer	24.97
Wood blast	73.35
Pith	1.67

(b) Chemical composition:

Constituent	Average (%)
Ash	3.2
Pentosan	20.6
Lignin	31.2
Cellulose	45.0

Source: (Zubairu, 1989)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The agricultural wastes used for the production of particle board were coconut shells, maize cobs, rice husks, groundnut shells, and sawdust. Rice husks and coconut shells were bought from the Samaru market while groundnut shells, maize cobs and sawdust were collected from the Institute of Agricultural Research (I.A.R), A.B.U., Zaria and Timber shade, Sabo-gari, Zaria. Gum arabic used as a binder was obtained from Sokoto.

3.2 Preparation and Processing of Particle board

The production of the boards was carried out as follows:

3.2.1 Grinding and seiving of agricultural wastes

Each of the materials was screened to remove the dust, sand particles and other foreign bodies. The agricultural wastes were reduced in size in a hammer mill fitted with a 2mm screen and subsequently further screened to remove fines. The moisture contents of materials was determined on dry basis.

The ground materials were sieved into different particle sizes using sieves of varying meshes. The ground groundnut shell, sawdust, maize cob, rice husk and coconut shell particles were each sieved through 500μm and 300μm sieve sizes, (BS 812).

3.2.2 Preparation of resin

The gum arabic was reduced in size in a hammer mill fitted with a 6mm screen and subsequently ground into particle sizes of 300μm with an electric grinder. 40 percent of gum arabic (33.6gm) was added to 60 percent of water (66.4gm), (Zubairu, 1989) in 500cm^3 beaker on the weight basis of the material. The mixture was vigorously stirred to mix and form a homogenous solution. The freshly prepared resin was used immediately to impregnate the ground agricultural wastes.

3.2.3 Preparation of particle boards

In this investigation, two types of formulation of the components (agricultural wastes), namely; maize cob, coconut shell, sawdust, groundnut shell and rice husk into particle board with pure individual component as well as the blending of three components (rice husk, maize cob and coconut shell, both at controlled processing condition of temperature, pressure and time.

(a) **Formulation of particle boards with pure components**

The particles used were sizes of 500μm and 300μm. According to Chittenden and Flaw (1972), standard size ranges from 500×10^{-6} mm to 0.9mm.

Seventy percent of ground individual agricultural waste was impregnated with 30 percent of gum arabic resin as the binding agent (Nagasawa et al, 1981). 0.25 percent paraffin wax on the weight basis of the material was incorporated into

the mixture as the water repellent/water resistance. The components were mixed manually using pestle and mortar until they were thoroughly blended and homogenized. This was pressed at controlled processing conditions of temperature, 140°C and pressure 3.5N/mm^2 for 10 minutes.

(b) **Formulation of particle boards by blending three components**

The ground agricultural wastes i.e maize cob, rice husk and coconut shell were blended and impregnated with 30 percent gum arabic resin as the binding agent 0.25 percent paraffin wax on the weight of the material was incorporated as the water repellent.

The mixture components were formulated using simplex Lattice design which contained ten blended mixtures as shown in Table 3.2. The formulations were processed at three processing factors of temperature, pressure and time, using two level factorial design (2^{nn}). The values of resin and water repellent were fixed. The mixtures were pressed at 120°C and 160°C, pressing pressure of 3N/mm^2 and 4N/mm^2 for 5 minutes and 15 minutes. These conditions were selected based on experimental trials of ± 20°C to the original temperature of 140°C, ± 5 minutes to the original pressing time of 10 minutes and ± 0.5N/mm^2 to the original pressing of 3.5N/mm^2.

3.2.4 Mat Formation and Processing

A mat was produced by positioning a steel plate (200 by 200mm) on a horizontal surface and sheet of aluminium foil (200 by 200mm) was spread on the top of the steep plate base to prevent the blended specimen from sticking to the steel plate. A square metal mould was placed on the steel plate.

After blending, the particles were transferred to a 150mm metal board former (mould) (whose surface were covered with aluminium foils) through a 500μm screen to ensure a uniform distribution of the particles. Another aluminium foil was placed on top of the mat and a second steel plate was placed on top of the aluminium foil on the mat. The dimensions of the plates were slightly larger than the mat formed inorder to cater for the loss at the sides.

The mat was placed carefully on an electrically heated oil press (Plate 1) and pressed to a thickness of 10mm and cured for a total of 10 minutes. The platen temperature was pre-adjusted to a value (80°c) that would allow the mat core to reach the curing temperature of 140°c in 8 to 10 minutes.

Table 3.1: Pariticle size analysis for the materials

Components	Modulus (FM)
Groundnut shell	1,74
Coconut shell	1.43
Rice husk	2.86
Maize cob	2.61
Sawdust	2.03

Plate 1: Hydraulic Pressing machine



Table 3.2: **Experimental Design for blending of Components**

The Process Variables			Ratio of Mixture Compositions by weight									
Temp. (°c)	Pressure (N/mm^2)	Time (min)	(ABC)	(ABC)	(ABC)	(ABC)	(ABC)	(BC)	(ABC)	(ABC)	(ABC)	(ABC)
120	3	5	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
160	3	5	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
120	4	5	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
160	4	5	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
120	3	15	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
160	3	15	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/1,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
120	4	15	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
160	4	15	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)

A - Maize B - Coconut C - Rice 1 = 84g; 1/3 = 28g; 2/3 = 56g

Tale 3.2: **Experimental Design for blending of Components**

The Process Variables			Ratio of Mixture Compositions by weight									
Temp. (°c)	Pressure (N/mm²)	Time (min)	(ABC)	(ABC)	(ABC)	(ABC)	(ABC)	(BC)	(ABC)	(ABC)	(ABC)	(ABC)
120	3	5	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
160	3	5	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
120	4	5	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
160	4	5	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
120	3	15	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
160	3	15	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
120	4	15	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
160	4	15	(1,0,0)	(0,1,0)	(0,0,1)	(2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)

A - Maize B - Coconut C - Rice 1 = 8[illegible]g; 1/3 = 28[illegible]g; 2/3 = 56[illegible]g

3.2.5 **Conditioning**:

The board produced was removed from the hot plates of the press and left in an open air to cool to room temperature. A weight containing water was placed on it so as to allow to cool down under pressure. The steel plates were then removed and the board was left to age at room temp. (27°c) for 24 hrs after which it was trimmed with sharp saw. The board was then conditioned at the same room temperature for several days before any test was carried out to determine its physical and mechanical properties. The purpose for conditioning is to equalise the moisture content throughout the board and minimise warpage that might otherwise occur.

3.3 Characterization of the Boards

The boards were tested for their physical and mechanical properties. The tests carried out were basically of destructive and non-destructive nature. The low-density boards were tested for their wood working properties.

Owing to the more recent origin of the low-density particle boards, there is no stnadard yet for its comparison. The standard used in this work is that for "Plywood and other wood-based panels" by the FAO, (1963). The standard is based mainly on experience in the use of flax shives for the production of this type of board. The deflection limit was from BS 1142, part 3, 1972.

To determine the efficiency of the boards made from the

five different agricultural wastes, it was necessary to establish if the minimum standard of bending and tensile strength in particular and other properties in general as specified in BS 2604, part 2, 1970 could be attained. The test and test procedures carried out are briefly described below.



Plate II: Hounsfield Tensometer with the samples produced.

3.3 Density

Density is one of the most important physical properties of the boards which affects the other engineering properties. The density of the test piece was determined by weighing the test specimen and measuring its dimensions (length, width and thickness) for the calculation of volume. the density of each test piece was calculated as follows:

$$Density = \frac{Mass}{Volume}$$

3.3.2 Tensile Strength Parallel to Surface Test

Three Specimens from each sample were tested for tensile strength. The effective dimensions of each speciment were 150mm x 35mm x 10mm. The test was performed on Dension Testing machine. The tensile strength was calculated by the formula

$$T = P/A$$

where T = Tensile Strength in N/mm^2

P =load in Newtons (N)

A = Cross-sectional area (mm^2)

3.3.3 Tensile Strength Perpendicular to the Surface Test

Test pieces 35mm x 35mm x 10mm were glued between two pieces of wood with glue line on the top and bottom faces of test pieces. A 36mm wood screw has earlier been inserted into

each wood to facilitate easy gripping by the split chucks of the machine. The whole assembly was inserted in the Hounsfield Tensometer using the split chucks and pins. (Plate II). The alignment of the speciment was ensured by the spherically mounted attachments with no load applied to the specimen, adjustments were made to ensure that the mercury column was at zero.

The drive system was also adjusted until all the slacks had been taken up. The load handle was turned continously while the mercury movement was followed with the perspex indicator. A tensile load was in this way applied to the sample until it failed. No heat was applied during the gluing.

3.3.4 Compressive Stength Test

This test was made on specimens with load applied parallel and perpendicular to the long dimensions of the board. The dimensions were:

Length - 4t (mm)

Width - t (mm)

Thickness - t (mm)

The load was applied using the Denson Testing Machine.
The Compressive Strength was obtained using the formula.

$$C = P/A$$

where, C = Compressive Strength (N/mm^2)

P = Rupture load (N)

A = Cross-Sectional Area (mm^2)

For parallel load, A = 4t x t

For perpendicular load, A = t^2

3.3.5 **Bending Strength (Modulus of Rupture) Test**

Three specimens of 150mm x 35mm x 10mm cut from each sample were tested on rollers of 85mm x 20mm diameter. The rollers were kept at 120mm apart and load applied at the centre by the Denson Machine (Plate III). The speed of tests on this machine was 2mm/min. The data were obtained using the formular given by

$$S = \frac{3Pd_L}{2bt^2}$$

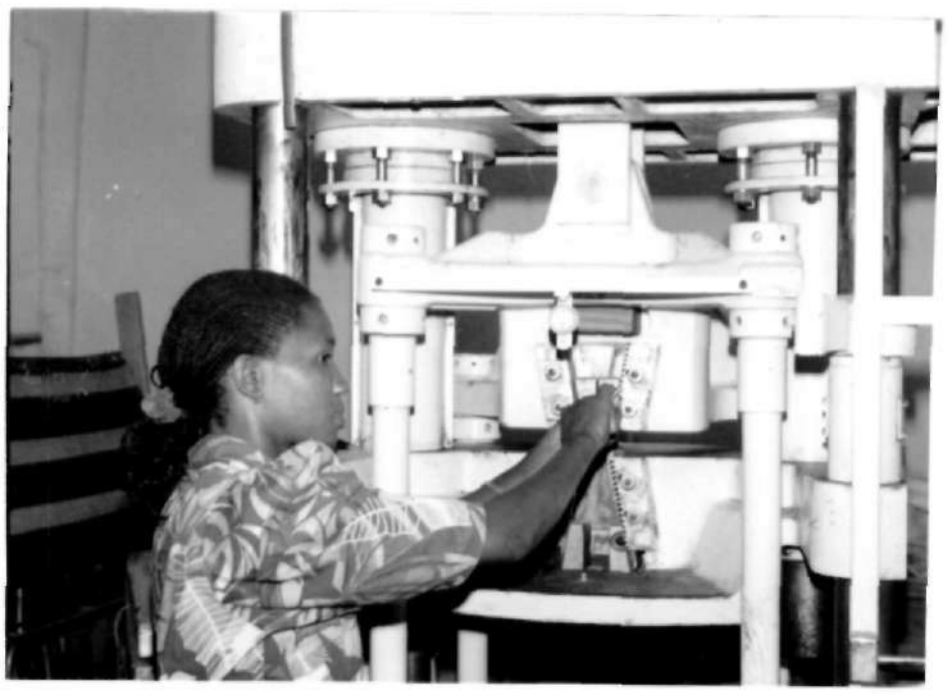


Plate III: Dension Testing Machine

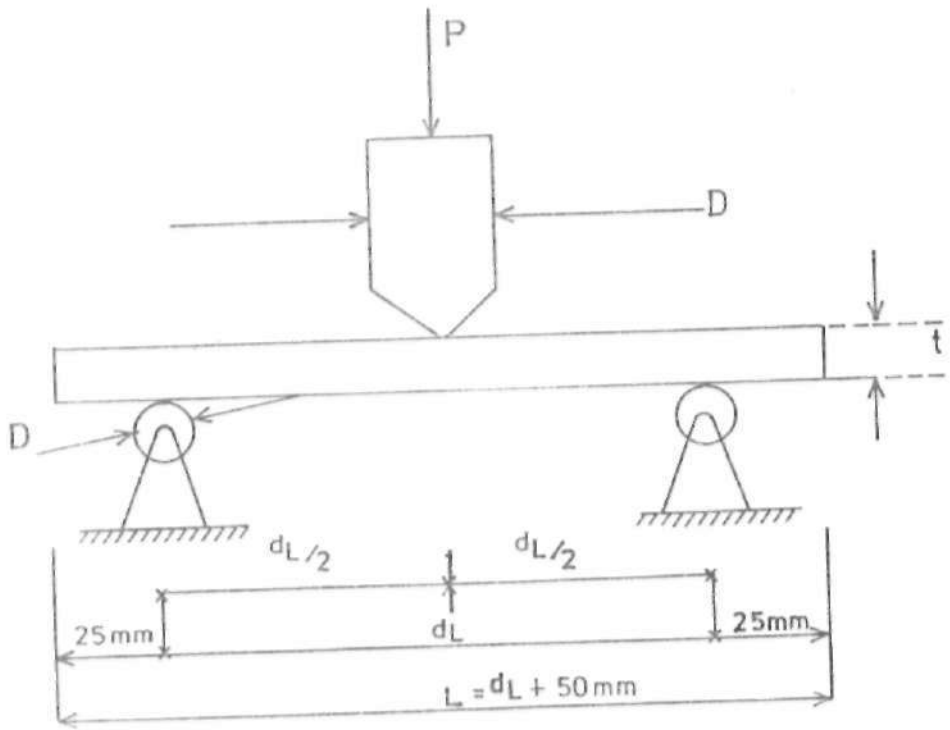


Figure 3·1 Bending Strength Apparatus

Where, S = Bending Strength in N/mm^2

P = Load at rupture in Newtons

d_L = Distance between support in mm

b = Width of the test specimen in mm

t = Thickness of the test specimen in mm.

3.3.6 Nail Resistance Test

The nail resistance test was done for both parallel and perpendicular directions. The load required to push the nail through the test specimen as applied with Denson Testing machine. The length and diameter of the nail was 57mm and 3mm.

3.3.7 Screw Withdrawal Test

Two test piece 35mm x 35mm x 10mm were prepared. In each test piece a 36mm wood screw was inserted at the mid point of the surface into a preboared hole, 2mm diameter and 5mm deep. Care was taken to ensure that the piece was perpendicular to the appropriate surface of the test piece and was inserted into board to a depth of 9mm as specified. The test pice was put in a Hounsfied tensometer as described above and the load required to withdraw the screw was obtained.

3.3.8 Surface Soundness

This is the force that will tear-off the surface layer. In order to determine the surface soundness of the boards produced, two boards were tested. For each test specimen, two

diagonals were drawn on the face and back of each test piece of 35mm x 35mm x 10mm. A block of wood 20mm x 20mm x 10mm was glued without the application of heat centrally to each face of the test piece, making use of diagonals for accurate location. Two screw eyes of nominal length of 50mm complying with the requirements for screw guage 14 in Table 6 of BS 1494, Part 21 were inserted into the centres of the wood blocks, opposite each other and perpendicular to the plane of the test specimen. the load handle was turned continuously while the mercury movement was followed with the perplex indicator. The load was applied to the sample until it failed.

Here fracture took place at the surface of the board unlike in the tensile case where fracture was at the centre.

3.2.9 Moisture content Test

The moisture content of the boards was determined by weighing the board on an analytical balance, drying in an oven for a period of 24 hours at a temperature of 100°c to a constant mass and then cooling in a desicator and weighing for the second time. Two specimens (35mm x 35mm) from each board were used, and the results were obtained using the formula.

$$MC = \frac{Mi-Mo}{Mo} \; X \; 100\% \quad (dry\ basis)$$

where, MC = Moisture content of the board (%)

M_i = Initial mass of the test specimen (g)

M_o = Oven dry mass of test piece specimen (g)

3.3.10 Deflection Test

Two specimens of 150mm x 35mm x 10mm were cut from each board and tested on two parrallel rollers 75mm x 25mm diameter. The rollers were kept 150mm apart and the load was applied at the centre continuously at a speed of 2mm per minute until a load of 30N was reached by the Denson testing machine. The deflection was then read directly from a dial guage. This test was performed in accordance with BS 1141, part 2, 1972.

3.3.11 Water Absorption and thickness Swelling Tests

Two weighed specimens from each board 35mm x 35mm were used. The original thickness (10mm) of each of the test piece was measured by a vernier caliper at various points. Specimens were then submerged completely in water at temperature of 28°c specimens were removed and wiped with a damp cloth to get rid off the excess water on them. the weight and dimensions of the specimens were taken again and the water absorption of each board was calculated from the formula:

$$A = \frac{M_2 - M_1}{M_1} \; X \; 100\%$$

where, A = Water absorption (%)

M_1 = Mass of the Specimen before immersion (g)

M_2 = Mass of the specimen after immersion (g)

The swelling thickness of each specimen was obtained from:

$$T = \frac{t_2 - t_1}{t_1} \; X \; 100\%$$

where, T = Thickness swelling of the specimen (%)

t_1 = Thickness before immersion (mm)

t_2 = Thickness after immersion (mm)

In this work water repellent (paraffin wax) was added to all the boards produced.

3.4.0 **Screening the Components**

In the experimental runs, baords were produced from ten pure samples (Components) and tested for mechanical and physical properties. A reduction in the number of necessary components is sought not only from the standpoint that it is easier to understand a system that contains only a small number of components but also for reasons of economy, so that only the most important components are considered further. This was done by selecting the products which gave the best results from the size of their effects (Strengths) after the tests.

These are maize cob (300 μm), coconut shell (300μm) and Rice husk (300μm). The results of the experimental runs are used to design the board for the mixture of the three components.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Board Density

Table 4.1 shows the tensile strength of the particle boards (particle sizes of 500μm and 300μm) produced from five different agricultural wastes.

It can be seen from the table that the densities of all the boards produced are within the range 300-400kg/m^3 recommended in BS 2604, Part 2 (1970) for low density particle board. Coconut shell board (300μm) has the highest density of 400kg/m^3 while groundnut shell and sawdust boards (500μm) have the lowest densities of 300kg/m^3 and 310kg/m^3 respectively. This may be due to the fact that coconut shell particles have higher bulk density than groundnut shell and sawdust particles.

It was generally observed that as the board density increased, there was an increase in values in most of the mechanical properties and a reduction in tensile strength parallel to the boards surface. The probable reason for this decrease in tensile strength parallel to the board's surface was that high pressing temperature (160°c) and long pressing time (15 minutes) tended to make the boards brittle.

ble 4.1: Tensile Strength of the Particle boards produced from five different agricultural wastes.

Property	Units	Low Density Particle boards										FAO, 1963
	Particle Size μm	Grounnut Shell 500μm	Grounnut Shell 300μm	Rice husk 500μm	Rice husk 300μm	Maize cob 500μm	Maize cob 300μm	Sawdust 500μm	Sawdust 300μm	Coconut shell 500μm	Coconut shell 300μm	Recommended
Board density	kg/m^3	300	340	330	380	320	390	310	350	370	400	300-400
Thickness mm		10	10	10	10	10	10	10	10	10	10	12max
Tensile Strength Parallel to the surface of the board	N/mm^2	1.6	1.38	1.54	1.1	1.48	1.05	1.58	1.3	1.18	0.8	
Tensile strength pendicular to the surface of the board	N/mm^2	0.16	0.18	0.26	0.34	0.1	0.37	0.14	0.33	0.29	0.38	0.1-0.3

Max - maximum

4.2.1 **Tensile Strength**

Tables 4.1 and 4.2 show the tensile strength of the boards produced from five different (pure) agricultural wastes and the mixtures of the wastes.

The tensile strength varied from 0.1 N/mm^2 for boards produced from 500 microns sized maize cob to 0.38 N/mm^2 for boards produced from 300 micron sized coconut shell as depicted in Table 4.1.

From the Table 4.1, it suggests the order of tensile strength of the particle boards can be deduced as coconut shell > maize cob > rice husk > sawdust > groundnut shell for the boards produced from the above mentioned wastes.

The tensile strength parallel to the surface of the board decreased with increase in density. On the other hand, the tensile strength perpendicular to the surface of the board increased with increase in density. These results are in agreement with literature values (FAO, 1963). Since tensile

strength is a measure of the internal bond of a board the comparatively, low tensile strength value (0.38N/mm^2, relative to the high bending strength 24.4N/mm^2) indicate that a satisfactory binding of the particles was attained.

From Table 4.2, it can seen that by the proportion of the components. The calculated F-values of the mixture components were higher than reference statistical value of 3.996. Generally, the tensile strength of the boards produced from the mixture of the different agricultural wastes proved superior to the tensile strength of the boards produced from pure component wastes, with exception of boards produced from pure coconut shell. This information implies that there was a significant difference on the tensile strength of the boards due to the effect of the component of proportions.

In decreasing order of tensile strength, the particle boards from the mixture components can be written as coconut shell and rice husk (1:2); maize cob and coconut shell (2:1); pure maize cob; maize cob and coconut shell (1:2); maize cob, coconut shell and rice husk (1:1:1) and coconut shell and rice husk (2:1).

As can be deduced from Table 4.2 the interaction between temperature and time was highly significant. The interactions compared with least significant different (LSD), indicated that low temperature and long pressing time is most sensitive to tensile strength of the boards.

Table 4.2: Tensile Strength of the Mixture boards (N/mm^2)

The Process Variables			Mixture Proportions									
Temp. (°c)	Pressure (N/mm^2)	Time (min)	(1,0,0)	(0,1,0)	(0,0,1)	2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
120	3	5	0.63	0.86	0.46	0.59	0.32	0.29	0.64	0.34	0.29	0.24
160	3	5	0.61	0.84	0.54	0.82	0.51	0.47	0.58	0.39	0.27	0.55
120	4	5	0.86	0.97	0.40	0.57	0.41	0.57	0.32	0.51	0.32	0.80
160	4	5	0.33	0.86	0.21	0.22	0.37	0.29	0.34	0.33	0.44	0.57
120	3	15	0.31	0.74	0.24	0.55	0.36	0.39	0.34	0.29	0.29	0.55
160	3	15	0.54	1.07	0.51	1.14	0.86	0.76	0.65	0.60	0.46	0.87
120	4	15	0.32	1.91	0.29	0.30	0.57	0.56	0.59	0.66	0.69	0.85
160	4	15	0.29	1.14	0.26	0.23	0.31	0.31	0.25	0.29	0.31	0.27

From Table 4.2, it is seen that a temperature of 120°c, pressure of 4N/mm^2 and pressing time of 15 minutes were suitable for producing boards if high tensile strength. It was observed that at high and time the boards became burnt and brittle while at short time and low temperature, the resin in the boards were not completely cured. These process conditions resulted in warpage and significant reduction in the strength property of the boards.

Consequently, the tensile strength of all boards produced were greater than the minimum value of 0.1 N/mm^2 specified in literature (Azeez, 1989).

4.2.2 Bending Strength

Tables 4.3 and 4.4 show the bending strength of the boards produced from five different (pure) agricultural wastes and the mixture of the wastes, respectively. It can be seen from Table 4.3 that the bending strength increased with increase in density. The strength values ranged from 7.61N/mm^2 for boards with lower density (300kg/m^3) to 24.4N/mm^2 for boards with highest density (400kg/m^3). These compared favourably with the literature report on wood particle board with minimum strength of 13.8 N/mm^2 (FAO, 1963).

The bending strength of 24.4N/mm^2 is far above the minimum value of 13.8 N/mm^2 specified in the literature report.

Table 4.4 depicts the effect of component proportions,

pressure, temperature and time on the bending strength of the boards. They have high significant effect on the bending strength of the board. It can be seen from Table 4.4 that the bending strength of the boards was affected by the proportion of the components. The bending strength of the boards produced from the mixture of different agricultural wastes proved superior to the bending strength of the boards produced from pure components.

The bending strength of the boards produced from the mixed components compared favourably with the reference minimum literature value of 13.8 N/mm^2.

Table 4.3: **The bending strength of the boards produced from five different pure agricultural waste**

Property		Low Density				Particle boards						FAO, 1963
	Particle Size μm	Grounnut Shell 500μm	300μm	Rice husk 500μm	300μm	Maize cob 500μm	300μm	Sawdust 500μm	300μm	Coconut shell 500μm	300μm	Recommended
Board density	kg/m^3	300	340	330	380	320	390	310	350	370	400	300-400
Thickness	mm	10	10	10	10	10	10	10	10	10	10	12max
Nail Resistance	N	170	360	295	430	250	545	210	370	480	580	360min
Bending Strength	N/mm^2	8	14.4	12.8	20.8	11.2	22.4	9.6	16.4	14.8	24.4	13.8min

Min - minimum, max - maximum

Tale 4.4: **Bending Strength of the mixture boards**

The Process Variables			Mixture Proportions									
Temp. (°c)	Pressure (N/mm^2)	Time (min)	(1,0,0)	(0,1,0)	(0,0,1)	2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
120	3	5	13.7	33.77	7.54	19.20	13.6	14.20	18.8	14.29	14.29	10.79
160	3	5	27.03	31.71	14.00	17.71	20.29	20.29	22.51	13.60	17.14	10.29
120	4	5	21.26	33.77	24.29	20.86	24.97	29.77	16.34	8.14	6.86	21.14
160	4	5	29.09	34.86	13.31	14.61	29.49	29.77	13.57	24.29	22.23	9.60
120	3	15	25.66	28.57	22.91	22.63	14.29	22.23	13.60	24.29	14.97	16.06
160	3	15	22.11	35.43	21.43	22.11	21.14	34.86	30.34	35.66	31.71	23.31
120	4	15	31.14	30.0	15.66	35.14	18.40	23.43	21.43	18.0	26.63	23.60
160	4	15	14.77	15.43	13.9	14.29	13.94	16.60	17.91	14.29	15.57	14.29

4.2.3 **Compressive strength**

Tables 4.5 and 4.6 show the compressive strength of the boards produced from five different (pure) agricultural wastes and the mixtures of the wastes, respectively.

From Table 4.5, it can be seen that the compressive strength increased with increase in the density of the boards. However, no standard results in the literature exist for appropriate comparison.

Table 4.6 depicts the effects of the process variables and mixture components proportion on the compressive strength of the boards.

The compressive strength of the boards were significantly affected by the components mixture proportions in that it increased well above the values obtained from pure components.

Moreso, it was observed that pressure exerted a highly significant effect on the compressive strength. When the average effects of the combined process variables were compared using least significant difference it was also deduced that using high pressure ($4N/mm^2$) yielded better boards than a low pressure of $3N/mm^2$).

Table 4.5: The compressive Strength of the boards produced from five different pure agricultural wastes.

	Particle Size μm	Grounnut Shell 500μm	Grounnut Shell 300μm	Rice husk 500μm	Rice husk 300μm	Maize cob 500μm	Maize cob 300μm	Sawdust 500μm	Sawdust 300μm	Coconut shell 500μm	Coconut shell 300μm	Recommended
Board density	kg/m^3	300	340	330	380	320	390	310	350	370	400	300-400
Thickness	mm	10	10	10	10	10	10	10	10	10	10	12max
Compressive strength parallel to the length length of the board	mm	1.1	1.5	1.4	1.9	1.3	2	1.2	1.6	1.7	2	12max
Compressive Strength perpendicular to the length of the board	N/mm^2	2.5	3.4	3.2	4.3	2.9	4.5	2.7	3.5	3.8	4.7	

Tale 4.6: Comprehensive Stength of the mixture boards

The Process Variables			Mixture Proportions									
Temp. (°c)	Pressure (N/mm^2)	Time (min)	(1,0,0)	(0,1,0)	(0,0,1)	2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
120	3	5	0.29	3.7	0.29	2.4	2.2	2.0	4.8	1.7	0.27	2.4
160	3	5	1.7	4.2	6.0	4.4	3.2	3.0	1.6	6.0	2.6	1.8
120	4	5	3.0	4.2	3.8	4.0	2.4	3.0	1.6	6.0	2.6	1.8
160	4	5	0.22	1.8	1.4	2.29	1.57	1.62	2.2	1.87	2.4	0.96
120	3	15	1.6	1.14	3.2	2.0	1.30	3.0	1.50	4.3	3.6	7.0
160	3	15	6.2	7.6	13.8	7.0	6.8	3.9	8.0	3.4	6.0	3.5
120	4	15	5.0	8.7	13.7	7.8	5.0	6.2	3.0	2.8	3.9	1.2
160	4	15	1.20	1.14	0.26	0.23	0.31	0.27	0.25	0.29	0.31	0.55

4.2.4 Screw withdrawal and Nail Resistance

Tables 4.7 and 4.8 show the resistance to screw withdrawal and nail resistance of boards prepared from pure components (agric-wastes) and the effect of the component proportions and process variables on the screw withdrawal, respectively.

The resistance to screw withdrawal of the boards (pure) depicted an increase from 80N to 570N with increase in density of the boards. It can be seen from the Table 4.7 that a satisfactory board would have a minimum density 360kg/m^3. The above boards would meet the required minimum value of 360N as specified in FAO (1963). The resistance to screw withdrawal of board densities from the range of 300-330kg/m^3 are below the specified range of 360N. This is attributable to too large pre-bore hole drilled on the boards before inserting the screw.

The results of the effects of the component proportions and process variables are presented in Table 4.8. The table depicts that the screw withdrawal resistance of the boards were affected by these variables. When the effects of temperature and pressure were compared using least significant difference, it was observed that use of high temperature, high pressure result in better quality boards interaction between temperature and time was also significant. The three factor interaction between temperature, pressure and time increased the screw withdrawal resistance.

The results showed that pure coconut shall boards had highest screw withdrawal resistance, while its combinations improved the screw withdrawal resistance in rice husk and maize cob, respectively. Generally, the boards possessed screw withdrawal resistance that exceeded the minimum specified screw withdrawal value of 360N.

The nail resistance test on the boards produced from pure agricultural wastes followed the same trends as the results of the screw withdrawal test. It was generally observed that a satisfactory board should posses a minimum density of 346 kg/m^3. Since tensile strength is related to screw withdrawal and nail push through the edge of the board, the low density boards (300 - 330kg/m^3 i.e groundnuts= shell, maize cob (500μm) and sawdust (500μm) boards would be less suited as ceiling boards where a lot of edge nailing occurs, unless battens are used. For the boards produced from component proportions, the effects of pressure, mixture proportions, temperature and interaction between temperature and time; pressure and time increased the nail resistance of the boards. When the average effects of the process variables were compared using LSD, it was observed that high pressure increased the nail resistance. It was also observed that use of low temperature and time resulted in low nail resistance.

Table 4.7: Screw withdrawal and Nail resistance of the pure five different agricultural wastes.

Property Components		Low Density				Particle boards						FAO, 1963
	Particle Size	Grounnut Shell 500µm	300µm	Rice husk 500µm	300µm	Maize cob 500µm	300µm	Sawdust 500µm	300µm	Coconut shell 500µm	300µm	Recommended
Board density	kg/m^3	300	340	330	380	320	390	310	350	370	400	300-400
Thickness	mm	10	10	10	10	10	10	10	10	10	10	12max
Nail Resistance	N	170	360	295	430	250	545	210	370	480	580	360min
Screw withdrawal	N	80	370	230	450	180	500	130	350	360	550	360min

Max - maximum

Tale 4.8: **Screw withdrawal and Nail resistance of the mixture boards**

The Process Variables			Mixture Proportions									
Temp. (°c)	Pressure (N/mm^2)	Time (min)	(1,0,0)	(0,1,0)	(0,0,1)	2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
						SCREW WITHDRAWAL (N)						
120	3	5	387	390	372	364	484	422	544	460	430	486
160	3	5	365	794	275	490	440	500	475	460	350	590
120	4	5	530	789	417	500	480	670	515	520	520	620
160	4	5	412	550	356	270	480	370	460	390	370	375
120	3	15	484	720	356	480	390	496	680	506	510	690
160	3	15	600	800	550	800	515	768	792	635	530	740
120	4	15	675	775	700	505	580	830	620	535	785	715
160	4	15	300	650	270	467	549	215	325	330	240	495
						Nail Resistance (N)						
120	3	5	410	700	500	250	200	520	750	640	650	760
160	3	5	740	490	500	630	740	620	810	825	660	590
120	4	5	400	390	340	550	860	720	800	800	720	520
160	4	5	420	600	500	300	520	720	800	690	500	750
120	3	15	500	540	370	250	840	560	800	630	530	620
160	3	15	480	800	580	850	820	840	810	830	780	850
120	4	15	800	770	690	700	690	770	850	840	770	760
160	4	15	530	500	510	500	680	520	770	560	560	550

4.2.5 Deflection

Tables 4-9 and 4.10 show the deflection results of the boards produced from the five different agricultural wastes and their component proportions, respectively.

The deflection result of Table 4-9 shows that the deflection property of the boards produced from the five different agricultural wastes is satisfactory as it decreased from 3.1 t0 1.2mm. This result is in conformity with the reference value of 4mm maximum. It was also observed that as the density of the boards increased, there was a decreased in deflection property.

Based on the above results these boards can be very useful for ceilings.

Table 4.10 shows the analysis of variance for deflection from the effects of the process variables, pressure, interaction between temperature and time. Effects of pressure, and temperature and time combined showed a highly significant deflection. When their averages were compared using least significant difference, it was observed that boards pressed at high pressure had better deflection property then those pressed at low pressure. The best deflection was obtained by using high temperature at short pressing time.

Table 4.9: **Deflection results of the boards produced from the five different agricultural wastes.**

Property Units		Low Density Particle boards										FAO, 1963
	Particle Size μm	Grounnut Shell 500μm	Grounnut Shell 300μm	Rice husk 500μm	Rice husk 300μm	Maize cob 500μm	Maize cob 300μm	Sawdust 500μm	Sawdust 300μm	Coconut shell 500μm	Coconut shell 300μm	Recommended
Board density	kg/m^3	300	340	330	380	320	390	310	350	370	400	300-400
Thickness	mm	10	10	10	10	10	10	10	10	10	10	12max
Deflection	mm	3.1	2.4	2.6	1.9	2.7	1.4	2.9	2.2	2.0	1.2	4max

Max - maximum

Tale 4.10: Deflection results of the mixture boards

The Process Variables			Mixture Proportions									
Temp. (°c)	Pressure (N/mm²)	Time (min)	(1,0,0)	(0,1,0)	(0,0,1)	2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
120	3	5	3.2	1.0	3.6	2.0	3.7	4.0	3.6	4.2	3.37	1.8
160	3	5	1.5	0.9	2.2	1.6	1.9	1.9	2.0	2.1	1.8	1.0
120	4	5	1.5	1.4	1.9	3.2	1.5	1.9	1.7	2.0	2.4	1.2
160	4	5	2.3	1.9	1.8	3.8	4.3	3.7	3.9	2.1	3.9	2.8
120	3	15	2.4	1.5	3.7	2.0	0.6	1.4	3.8	3.9	2.7	1.5
160	3	15	1.4	0.7	1.1	1.3	1.4	1.7	1.4	1.1	1.5	1.2
120	4	15	1.3	0.8	0.9	1.3	1.5	1.0	1.2	1.4	1.5	1.2
160	4	15	3.0	2.5	3.7	4.1	3.3	4.0	3.9	2.5	2.2	1.9

4.2.6 Surface Soundness

Table 4.11 and 4.12 show the surface soundness of the boards produced from five different agricultural wastes and the mixtures of the wastes, respectively.

For boards prepared from pure component wastes the surface soundness values ranged from 200-1180N for boards with lowest and highest densities, respectively. From Table 4.11, it can be concluded that only boards of minimum density of 356 kg/m^3 satisfy the minimum requirement of 1000N as specified in FAO (1963).

Table 4.12 shows the effects of pressure, mixture proportions and interactions of temperature and time, temperature, pressure and time on the surface soundness are significant.

When their averages were compared using least significant difference, it was observed that use of high pressure increases the surface soundness of the boards. The interaction between high temperature and long time decreased the surface soundness. The surface soundness of the boards increased with increase in pressing pressure and time at low temperature. At low temperature and short time, it also decreased. This may be attributable to the fact that the binder get charred at high temperature, but not completely cured at low temperature causing warpage of the boards, hence the reduction in the surface soundness.

Pure coconut shell boards had better surface soundness

than the coconut shell mixed with other components. The combination of miaxe cob or rice husk with other two components, respectively, yielded better surface sound boards than the results obtained from using pure maize cob and rice husk components.

However, pure coconut shell and coconut shell with rice husk boards have the surface soundness property above the reference minimum value of 1000N. Other boards have on average surface soundness close to 1000N. This might be that at high temperature, the cohesive resin bonds, the resin-material bonds and the bonds between the materials the near and at the surface were degraded.

Table 4.11: Surface Soundness of the boards produced from five different agricultural wastes.

Property	Components		Low Density				Particle boards						FAO, 1963
		Particle Size μm	Grounnut Shell 500μm	300μm	Rice husk 500μm	300μm	Maize cob 500μm	300μm	Sawdust 500μm	300μm	Coconut shell 500μm	300μm	Recommended
Board density		kg/m^3	300	340	330	380	320	390	310	350	370	400	300-400
Thickness		mm	10	10	10	10	10	10	10	10	10	10	12max
Surface soundness		N	200	760	620	1060	480	1100	340	900	1040	1180	1000min

Min - minimum, Max - Maximum

Tale 4.12: Surface soundness of the mixture boards (N)

The Process Variables			Mixture Proportions									
Temp. (°c)	Pressure (N/mm²)	Time (min)	(1,0,0)	(0,1,0)	(0,0,1)	2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
120	3	5	770	835	428	822	630	850	894	820	790	720
160	3	5	865	1290	790	920	990	850	815	808	860	986
120	4	5	985	1090	845	900	957	992	800	830	887	1050
160	4	5	780	795	425	880	840	670	924	760	689	833
120	3	15	678	990	880	870	1050	838	760	775	995	855
160	3	15	1100	1250	1195	990	985	1192	1156	992	980	1155
120	4	15	998	1372	1070	1022	885	1245	997	1010	890	1230
160	4	15	600	960	440	776	550	770	740	880	780	1050

4.2.7 Water absorption and Thickness Swelling

Tables 4.13 and 4.14 show the water absorption and thickness swelling of boards produced from five different agricultural wastes (pure components) and their component mixture proportions, respectively.

As shown in Table 4.13, the water absorptions of boards (pure components) decreased from 67.0 to 4.0% with increase in board density. though, the maximum value of 75 per cent water (absorption) content as specified in British Standard of BS 2604 was not attained.

This property was satisfactory in all materials. The analysis of variance of water absorption at 120° and 160°c for 5 minutes and 15 minutes under $3N/mm^2$ and $4N/mm^2$, respectively is shown in Table 4.14. The effects of pressure, temp and time, pressure and time as well as temp, pressure and time combined together on the boards were highly significant. When their arithmetic means were compared with the least significant difference it was observed that use of high pressure is better than low pressure. The water absorption decreased at high temperature and short pressing time.

Based on this information, it can be concluded that at high temperature and short time, the boards absorbed less water than at high temperature and time or low temperature and time. It was observed that neither process variables nor mixture compositions had effect on the thickness swelling of

the boards.

The thickness swelling results, it was observed that the thickness swelling decreased from 11.5 to 2.0 percent with increase in density. Boards with lower density absorbed more water as against those boards with high density. The water absorption and thickness swelling were less than the specified values of 75 percent and 12 percent maxima, respectively, because of the addition of paraffin wax that improved the water repellent property of the boards which invariably reduced the water absorption and swelling in thickness of the boards.

Table 4.13: **Water absorption and Thickness swelling results of five different agricultural wastes.**

Property	Units	Particle boards: Low Density										FAO, 1963
		Particle Size μm	Grounnut Shell 500μm	Grounnut Shell 300μm	Rice husk 500μm	Rice husk 300μm	Maize cob 500μm	Maize cob 300μm	Sawdust 500μm	Sawdust 300μm	Coconut shell 500μm	Coconut shell 300μm	Recommended
Board density	kg/m^3		300	340	330	380	320	390	310	350	370	400	300-400
Thickness	mm		10	10	10	10	10	10	10	10	10	10	12max
Water absorption	%		60	35	48	13.0	27	8.5	67	66	26	40	75min
Thickness swelling	%		10.4	6.0	9.5	4.0	11.0	3.0	11.5	10.0	11.0	2.0	12max

Min - minimum, Max - Maximum

Tale 4.14: Water Absorption results of the mixture boards (%)

The Process Variables			Mixture Proportions									
Temp. (°c)	Pressure (N/mm²)	Time (min)	(1,0,0)	(0,1,0)	(0,0,1)	2/3,1/3,0)	(2/3,0,1/3)	(1/3,2/3,0)	(1/3,0,2/3)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,1/3,2/3)
120	3	5	38.03	17.49	34.73	22.82	37.64	34.40	29.74	29.24	32.68	27.39
160	3	5	19.54	19.19	19.01	17.96	18.93	27.52	34.39	22.78	24.11	20.14
120	4	5	21.15	26.73	15.11	17.89	30.20	23.84	27.79	29.00	19.44	14.91
160	4	5	28.01	14.33	32.78	32.62	35.95	15.11	23.24	29.35	35.28	16.15
120	3	15	30.18	16.09	25.31	24.57	35.22	23.69	26.73	33.77	41.18	34.39
160	3	15	20.37	10.70	14.37	12.79	19.53	4.811	11.87	5.05	7.62	10.05
120	4	15	20.39	12.33	10.83	16.81	11.62	12.93	22.90	21.69	7.02	13.15
160	4	15	34.56	33.69	32.61	34.75	33.97	34.52	35.43	33.97	21.11	35.59

COMPARATIVE STUDY OF PARTICLE BOARDS

PRODUCED FROM USING VARIOUS AGRICULTURAL WASTES

A THESIS

Presented to

The Posgraduate School
Ahmadu Bello University, Zaria

by

4.2.8 Moisture Content

Table 4.15 shows result of the moisture content of the boards produced from five different agricultural wastes.

The result shows that the boards moisture content values were within the range of 6-14% specified in BS 2604 for wood particle board in the same density range. The moisture contents were satisfactory as their values ranged from 6-9%.

Table 4.15: **The result of the moisture content of the boards produced from five different agricultural wastes.**

Property		Low Density				Particle boards						BS 2604
	Particle Size μm	Grounnut Shell 500μm	300μm	Rice husk 500μm	300μm	Maize cob 500μm	300μm	Sawdust 500μm	300μm	Coconut shell 500μm	300μm	Recommended
Board density	kg/m³	300	340	330	380	320	390	310	350	370	400	300-400
Thickness	mm	10	10	10	10	10	10	10	10	10	10	12max
Moisture content	%	9.0	8.0	8.2	6.7	8.6	6.4	8.8	7.9	7.3	6.8	6-14

Min - minimum, Max - Maximum

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

This investigation was conducted to produce low density particle boards from different agricultural wastes by flat-pressed method using gum arabic as a binder. From the results the following conclusions can be deduced:

1. For the production of low density particle boards by flat-pressed method, the favourable processing conditons are temperature 160°c to 120°c, pressing time ranged from 5 minutes to 15 minutes, and pressure at $4Nmm^{-2}$. The boards so manufactured possessed properties that compared favourably with literature reports.
2. It is possible to substitute gum arabic for synthetic resin as a binder for some agricultural wastes to formulate particle boards.
3. A board from mixture of maize cob, rice husk and coconut shell has lower strength properties than pure coconut shell boards. In combination the components strength properties are higher than in pure maize cob and rice husk boards.
4. The strength properties increased linearly with board densities. This is a very useful information when considering process design for selecting the type of agricultural wastes for particle boards development.
5. The maximum bending strength of $35N/mm^2$ obtained shows

that the boards were strong enough compared with the minimum standard of 13.8N/mm^2 (BS 2604 Part 2, 1970). Since bending strength is a measure of the ultimate load carrying capacity of a beam, these boards would suitable in areas where load bearing is of importance such as flooring roof-decking and shelves.

6. Other properties of the board were also satisfactory. This means that they can be used in other areas such as furniture, ceilings, interior finish in houses and other buildings, where acoustic treatments are desired and in partitions if they are attached to wood or other framing.

7. The fact that the deflection property of the boards were good indicates that the boards can be used in ceilings for insulation purposes and false ceilings, to conceal trunking for air conditioning, where their low thermal conductivity might be an advantage.

8. It can be concluded from the water absorption and thickness swelling tests that the boards showed comparable resistance to water penetration as well as satisfactory dimensional stability.

RECOMMENDATIONS

Based on the results of this investigation, the following recommendations can be made for future work on gum arabic bonded particle board.

1. Investigations have so far been carried out on processing and establishment of the optimum process conditions for the production of gum arabic-bonded particle board to determine their suitability for making various particle board end - products such as furnitures, roof decking, shelves and ceilings. However, more research work is needed in these areas of formulation and processing of the gum arabic-bonded particle boards by the addition of pesticide to prevent the attack of rodents on the board in order to ensure its durability.
2. Since the production of agricultural waste particle boards with gum arabic resin is particularly sensitive to the mass ratio of agricultural waste particles to resin content, there is the need to further investigate the production at stepwise starting from 45-50% of the resin.
3. Although the water resistance and thickness swelling of the boards compared favourably with the literature reports (BS 2604, Part 2, 1970), there is a need to further investigate the formulation and processing of the boards at an increased range of the paraffin wax content from 0.3-10% to avert the gum arabic bonded particle

boards high water absorption.

4. The local production of gum-arabic bonded particle boards using agricultural wastes should be further investigated before they can be used in fabricating counter-tops, cabinets, shelves, wall panelling and as structural materials, since the physcial properties of the agricultural wastes are numerous, such as bulk density, apparent porosity, particle size distribution and water absorption. It is recommended that some low-density agricultural wastes, such as saw dust, rice husk and maize cob particle mixture boards be further investigated thoroughly. This is supported by the fact that the findings from the present investigation showed maize cob and rice husk mixture compositions mixed with high density component (coconut shell) to posses relatively better mechanical properties compare to pure maize cob and rice husk boards. Tests should be conducted on the acoustic property of the boards which must prove adequate before they can be used for wall panelling, roof decking and ceilings.

5. The design and fabrication of a local particle board plant is highly recommended since all the raw materials required can be obtained locally. Furthermore, there is the need to increase the tonnage and platen sizes of the hydraulic press (machine) which will invariably augment the production of the boards commercially.

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APPENDIX A

Adhesive - A substance capable of holding materials together by surface attachment. It is used to cover the bonding of sheet material and is synonymous with glue.

Binding - A bonding agent used to bond together the particle in a particle board.

Chipboard - A relatively low strength, low density board made from waste paper or other low quality fibre.

Curing - The physical-chemical change brought about in thermosetting synthetic resins under the influence of heat and a catalyst.

Veneer - A thin layer or sheet of wood of uniform thickness, rotary cut or sawn for use in plywood, laminated construction, furniture, veneer container and etc.

APPENDIX A1

(i) Groundnut Shell:

(i) Particle size	(ii(d) Wt.retained (g)	(iii)(n) % of wt retained	(iv) nd
1.18mm	203	15.76	63.04
1.00mm	160	12.42	37.26
500μm	181	14.05	28.1
300μm	583	45.26	45.26
Pan	161	12.51	0
	1288	100	173.06

Fineness modulus (F.M.): the fitness modulus indicates the uniformity of grind in the resultant product and is defined as the sum of the weight fractions retained above each sieve divided by 100.

$$F.M. = \frac{173.66}{100} = 1.74$$

Average particle diameter D = 0.0041(2) F.m

for groundnut shell, D. = 0.0041(2) 1.74

= 0.014mm

(ii) Sawdust:

(i) Particle size	(ii(d) Wt.retained (g)	(iii)(n) % of wt retained	x(iii)
1.18mm	93.40	16.99	67.96
1.00	85.77	15.60	46.80
500μm	185.06	33.66	67.32
300μm	114.11	20.75	20.75
Pan	71.47	13.00	0.00
	549	100	202.83

$$F.M. = \frac{202.83}{100} = 2.03$$

$$D = 0.0041(2)^{2.03} = 0.017\text{mm}$$

iii) Maize Cob:

Particle size	(i) Wt.retained (g)	(ii) % of wt retained	(iii)
1.18mm	311	38.54	154.16
1.00mm	121	15.00	45.00
500μm	214	26.52	53.04
300μm	70	8.67	8.67
Pan	91	11.27	0.00
	807	100	260.87

$$F.M. = \frac{260.87}{100} = 2.61$$

$D = 0.0041(2)^{2.61} = 0.025mm$

(iv) Rice husk:

Particle size	(i) Wt.retained (g)	(ii) % of wt retained	(iii)
1.18mm	641	40.34	161.36
1.00mm	421	26.49	79.48
500μm	260	16.36	32.72
300μm	196	12.33	12.33
Pan	71	4.47	0.00
	1589	100	285.89

$$F.M. = \frac{285.89}{100} = 2.86$$

$D = 0.0041(2)2.86 = 0.03mm$

(v) Coconut Shell:

Particle size	(i) Wt.retained (g)	(ii) % of wt retained	(iii)
1.18mm	18	3.06	12.24
1.00mm	73	12.41	37.23
500μm	219	37.24	74.48
300μm	121	20.58	20.58
Pan	157	26.71	0.00
	588	100	144.53

$$F.M. = \frac{144.53}{100} = 1.45$$

D = 0.0041(2)1.45 = 0.011mm

APPENDIX A2

CALCULATIONS

Let a = weight of the empty specific gravity bottle = 39.25g

b = weight of bottle plus each of the samples

c = weight of each sample = b - a

$$\text{Density} = \frac{\text{mass}}{\text{Vol.}}, \quad \text{volume} = 100\text{cm}^3$$

Samples: (1) coconut shell

300μm: c: = 50.00g

$$\text{density, d} = \frac{50\text{g}}{100\text{cm}^3}$$

$$= 0.5\text{g/cm}^3$$

Density of water at 4°c = 1g/cm^3

$$\therefore \text{ specific gravity, G} = \frac{0.5\text{g/cm}^3}{1\text{g/cm}^3}$$

$$= 0.5$$

500μm: C = 51.99g

$$\text{Density, d} = \frac{51.99\text{g}}{100\text{cm}^{3n}} = 0.52\text{g/cm}^3$$

$$\therefore \text{ G} = \frac{0.52\text{g/cm}^3}{1\text{gcm}^3} = 0.52, \text{ Mean G} = 0.51$$

(ii) Maize cob

300μm: c: = 27.70g.

$$\text{density, d} = \frac{27.70\text{g}}{100\text{cm}^3}$$

$$= 285\text{g/cm}^3$$

$$\therefore \text{specific gravity, G} = \frac{0.28\text{g/cm}^3}{1\text{g/cm}^3}$$

$$= 0.28$$

500μm: C = 24.04g

$$\text{Density, d} = \frac{24.04\text{g}}{100\text{cm}^{3n}} = 0.24\text{g/cm}^3$$

$$\therefore \text{G} = \frac{0.24\text{gm/cm}^3}{1\text{g/cm}^3} = 0.24, \text{ Mean G} = 0.26$$

iii) Groundnut Shell

300μm: c: = 37.00g.

$$\text{density, d} = \frac{37.00\text{g}}{100\text{cm}^3}$$

$$= 0.37\text{g/cm}^3$$

$$\therefore \text{specific gravity, G} = \frac{0.37\text{g/cm}^3}{1\text{g/cm}^3}$$

$$= 0.37$$

500μm: C = 36.98g

$$\text{Density, d} = \frac{36.98\text{g}}{100\text{cm}^{3n}} = 0.37\text{g/cm}^3$$

$$\therefore \text{G} = \frac{0.37\text{gm/cm}^3}{1\text{g/cm}^3} = 0.37, \text{ Mean G} = 0.37$$

(iv) Rice

300μm: c: = 51.79g.

$$\text{density, d} = \frac{51.79\text{g}}{100\text{cm}^3}$$

$$= 0.52\text{g/cm}^3$$

$$\therefore \text{ specific gravity, G} = \frac{0.52\text{g/cm}^3}{1\text{g/cm}^3}$$

$$= 0.52$$

500μm: C = 37.62g

$$\text{Density, d} = \frac{37.62\text{g}}{100\text{cm}^{3n}} = 0.38\text{g/cm}^3$$

$$\therefore \text{ G} = \frac{0.38\text{gm/cm}^3}{1\text{g/cm}^3} = 0.38, \text{ Mean G} = 0.45$$

Bulk density (B) and apparent porosity (P_A)

The determination involved the measurement of the dry weight, D; suspended weight, S; and saturated weight, w; in air of each agric wastes. Each of the samples was immersed in a container of water for 24 hours. The particles were entirely covered with water in room temperature except those who were suspended on top of the water. The saturated ones sunk to the bottom of the container. These were later filtered and the weights were taken. The samples were then surface dried by spreading them on a metallic sheet in open air for 24 hours and re-weighed.

CALCULATIONS

Bulk density, $B = \frac{D}{W-S}$

Apparent porosity, $P_A = \frac{W - D}{W - S}$

Rice: 500μm, D = 37.62g, W = 78.76g, S = 20.42g

$$B = \frac{37.62g}{78.76-2042g} = \frac{37.62g}{58.34g}$$

volume of water absorbed, $v = \frac{m}{d}$

$$V = \frac{58.34g\ cm^3}{0.38g} = 153.53cm^3$$

$d = 0.38g/cm^3$

$$\therefore B = \frac{37.62g}{153.53cm^3} = 0.25g/cm^3$$

$$P_A = \frac{41.14g}{58.34g} = 0.71$$

300μm = D = 51.79g, W = 66.75g, S = 5.77g.

$$B = \frac{51.79g}{60.98g} \qquad v = \frac{60.98g/cm^3}{0.52g} = 117.27cm^3$$

$d = 0.52g/cm^3$

$$\therefore B = \frac{51.79g}{117.27cm^3} = 0.49g/cm^3$$

$P_A = 0.25$

Coconut Shell

300μm = D = 52g, W = 87.91g, S = 34.65g.

$$B = \frac{52g}{53.26g}, \qquad v = \frac{53.26g/cm^3}{0.52g} = 102.42cm^3$$

$d = 0.52g/cm^3$

$$\therefore \quad B = \frac{52.0g}{102.42cm^3} = 0.49g/cm^3$$

$P_A = 0.67$

300μm = D = 50g, W = 98.54g, S = 3.67g.

$$B = \frac{50g}{94.87g}, \qquad v = \frac{74.87g/cm^3}{0.50g} = 189.74cm^3$$

$d = 0.50g/cm^3$

$$\therefore \quad B = \frac{0.5g}{189.42cm^3} = 0.86g/cm^3$$

$P_A = 0.51$

Groundnut Shell: 500μm, D = 36.98g, W = 72.50g, S = 32.97g

$$B = \frac{36.97g}{39.53g}, \qquad v = \frac{39.53g/cm^3}{0.37g} = 106.89cm^3$$

$d = 0.37g/cm^3$

$$\therefore \quad B = \frac{36.98g}{106.89cm^3} = 0.35g/cm^3$$

$P_A = 0.89$

300μm = D = 37g, W = 73.81g, S = 32.97g

$$B = \frac{37g}{40.83g}, \qquad v = \frac{40.83g/cm^3}{0.37g} = 110.36cm^3$$

$d = 0.37g/cm^3$

$$\therefore \quad B = \frac{37g}{110.36cm^3} = 0.34g/cm^3$$

$P_A = 0.09$

Maize cob: 500μm, D = 24.04g, W = 56.84g, S = 3044g

$$B = \frac{24.04g}{26.40g}, \qquad v = \frac{26.40g/cm^3}{0.24g} = 109.82cm^3$$

$d = 0.24g/cm^3$

$$\therefore \quad B = \frac{24.04g}{109.82cm^3} = 0.22g/cm^3$$

$P_A = 0.24$

300μm = D = 27.70g, W = 85.46g, S = 24.81g

$$B = \frac{27.70g}{60.65g}, \qquad v = \frac{60.65g/cm^3}{0.28g} = 216.94cm^3$$

$d = 0.28g/cm^3$

$$\therefore \quad B = \frac{27.7g}{216.94cm^3} = 0.13g/cm^3$$

$P_A = 0.95$

Sawdust: 500μm, D = 18.35g, W = 103.21 S = 7.67g,

$$B = \frac{8.35g}{95.54g}, \qquad v = \frac{95.54g/cm^3}{0.18g} = 520.66cm^3$$

$d = 0.18g/cm^3$

$$\therefore \quad B = \frac{18.35g}{520.66cm^3} = 0.04g/cm^3$$

$P_A = 0.89$

300μm = D = 18.18g, W = 76.51g, S = 13.76g

$$B = \frac{18.18g}{62.75g}, \qquad v = \frac{62.75g/cm^3}{0.18g} = 345.15cm^3$$

$d = 0.18g/cm^3$

$$\therefore \quad B = \frac{18.18}{345.15cm^3} = 0.05g/cm^3$$

$P_A = 0.93$

Bulk density is the density of a powder or of a porous or granular substance, calculated for unit volume of the substance including the porous or spaces between the grains, it is generally less than the true density of the material.

(iii) Moisture content of the samples:

This is determined from the results obtained above after drying the samples in the oven. For example: Rice 500μm

let W_1 = Dry wt. of the sample before oven

W_2 = oven dry wt. of the sample

$$\text{Moisture content, M.C.} = \frac{W1 - W2}{W2} \times 100$$

W_1 = 37.62g, W_2 = 35.56g

$$\text{M.C} = \frac{37.62 - 35.56g}{35.56g} \times 100$$

$$= 5.8\%$$

The same is done to the other samples and the average results of these properties are given in table below.

Table 3.3: Average Physical Properties of the Materials

Samples	SP. gravity	Bulk density	Porosity	M. C
Rice: 500μm	0.58	0.25g/cm^3	0.71	5.8%
300μm	0.52	0.44g/cm^3	0.25	5.8%
Coconut 500μm	0.52	0.51g/cm^3	70.67	4.5%
300μm	0.56	0.56g/cm^3	0.51	4.5%
G/Nut: 500μm	0.37	0.35g/cm^3	0.89	6.0%
300μm	0.37	0.34g/cm^3	0.90	6.0%
Maize cob 500μm	0.26	0.22g/cm^3	1.24	4.8%
300μm	0.28	0.13g/cm^3	0.95	4.8%
Sawdust 500μm	0.18	0.04g/cm^3	0.89	5.0%
300μm	0.18	0.05g/cm^3	0.93	5.0%

TABLES FOR ANALYSIS OF MIXTURE COMPONENTS

4.16: Analysis of variance for Tensile Strength

Source of Variation	DF	SS	MS	F
Replication (r-1)	9	2.54994	0.28333	8.41
Pressure (P-1)	1	0.05460	0.05460	1.62
Temperation (C-1)	1	0.00231	0.00231	0.06
Time (T - 1)	1	0.4656	0.04656	1.38
Interaction PXC (P-1)(C-1)	1	0.01326	0.01326	0.39
Interaction P.T (P-1)(T-1)	1	0.00091	0.00091	0.02
Interaction C.T (C-1)(T-1)	1	0.98346	0.98346	29.20
InteractionP.C.T(C-1)(T-1)(P-1)	1	0.20503	0.20503	6.08
Residual (error)	63	2.12127	0.03367	
Total	76	3.42741	0.04896	
Grand Total	79	5.97735		

4.17: Analysis of variance for compressive stength

Source of Variation	DF	SS	MS	F
Replication (r-1)	9	70.562	7.840	0.990
Pressure (P-1)	1	57.084	57.004	14.86
Temperation (C-1)	11.560	11.560	11.560	3.01
Time (T - 1)	1	7.620	7.620	1.98
Interaction PXC (P-1)(C-1)	1	0.004	0.004	0.00
Interaction P.T (P-1)(T-1)	1	20.777	20.777	5.41
Interaction C.T (C-1)(T-1)	1	142.330	142.330	37.11
InteractionP.C.T(C-1)(T-1)(P-1)	1	67.326	67.326	17.55
Residual (error)	63	241.624	3.8357	
Total	70	548.262	7.832	
Grand Total	79	618.815		

4.18 Analysis of variance for Bending stength

Source of Variation	DF	SS	MS	F
Replication (r-1)	9	7235.2	803.9	3.25
Pressure (P-1)	1	7811.7	7811.7	31.67
Temperation (C-1)	1	0.0	0.0	0.0
Time (T - 1)	1	187.6	187.6	0.76
Interaction PXC (P-1)(C-1)	1	530.5	530.5	2.15
Interaction P.T (P-1)(T-1)	1	0.1	0.1	0.00
Interaction C.T (C-1)(T-1)	1	4910.8	4910.0	19.90
InteractionP.C.T(C-1)(T-1)(P-1)	1	2887.7	2887.1	11.70
Residual (error)	63	15539.8	246.7	
Total	70	31867.7	455.3	
Grand Total	79	39102.9		

4.19: Analysis of variance for Screw withdrawal resistance

Source of Variation	DF	SS	MS	F
Replication (r-1)	9	419818	46646	5.26
Pressure (P-1)	1	201202	201202	22.72
Temperation (C-1)	1	76138	76138	8.59
Time (T - 1)	1	13624	13624	1.53
Interaction PXC (P-1)(C-1)	1	794	794	0.09
Interaction P.T (P-1)(T-1)	1	55968	55968	6.32
Interaction C.T (C-1)(T-1)	1	496755	496755	56.10
InteractionP.C.T(C-1)(T-1)(P-1)	1	77377	77377	8.73
Residual (error)	63	557794	88.54	
Total	70	1479652	21138	
Grand Total	79	1899470		

4.20 Analysis of variance for nail resistance

Source of Variation	DF	SS	MS	F
Replication (r-1)	9	894295	99366	6.30
Pressure (P-1)	1	151380	151380	9.61
Temperation (C-1)	1	13520	13520	0.85
Time (T - 1)	1	980	980	0.06
Interaction PXC (P-1)(C-1)	1	24500	24500	1.55
Interaction P.T (P-1)(T-1)	1	2880	2880	0.18
Interaction C.T (C-1)(T-1)	1	584820	584820	37.12
InteractionP.C.T(C-1)(T-1)(P-1)	1	109520	109520	6.95
Residual (error)	63	992425	15753	
Total	70	1880025	26858	
Grand Total	79	2774320		

4169.5

4.21. Analysis of variance for surface Soundness resistance

Source of Variation	DF	SS	MS	F
Replication (r-1)	9	521758	57971	4.19
Pressure (P-1)	1	229837	229837	16.63
Temperation (C-1)	1	12301	12301	0.89
Time (T - 1)	1	18605	18605	1.34
Interaction PXC (P-1)(C-1)	1	6882	6882	0.49
Interaction P.T (P-1)(T-1)	1	32724	32724	2.36
Interaction C.T (C-1)(T-1)	1	974611	974611	70.53
InteractionP.C.T(C-1)(T-1)(P-1)	1	56180	56180	6.06
Residual (error)	63	870518	13818	
Total	70	2201658	31452	
Grand Total	79	2723396		

4.12: Analysis of variance for deflection

Source of Variation	DF	SS	MS	F
Replication (r-1)	9	13.0860	1.4533	3.07
Pressure (P-1)	1	4.0500	4.0500	8.55
Temperation (C-1)	1	0.39200	0.3920	0.82
Time (T - 1)	1	1.2005	1.2005	2.54
Interaction PXC (P-1)(C-1)	1	1.0125	1.0125	2.14
Interaction P.T (P-1)(T-1)	1	0.4500	0.4500	0.95
Interaction C.T (C-1)(T-1)	1	39.2000	39.2000	82.93
InteractionP.C.T(C-1)(T-1)(P-1)	1	0.3645	0.3645	0.77
Residual (error)	63	29.7780	0.4727	
Total	70	76.4475	1.0921	
Grand Total	79	89.5275		

4.23. Analysis of variance of Water absorption

Source of Variation	DF	SS	MS	F
Replication (r-1)	9	536.29	59.59	1.76
Pressure (P-1)	1	197.00	197.00	5.84
Temperation (C-1)	1	20.18	20.18	0.59
Time (T - 1)	1	10.97	1097	0.32
Interaction PXC (P-1)(C-1)	1	35.75	35.75	1.06
Interaction P.T (P-1)(T-1)	1	160.52	160.52	4.76
Interaction C.T (C-1)(T-1)	1	2749.04	2749.04	81.60
InteractionP.C.T(C-1)(T-1)(P-1)	1	721.56	721.56	21.42
Residual (error)	63	2122.18	33.69	
Total	70	6017.20	85.96	
Grand Total	79	6553.50		

Table 4.24 Values of various Average properties of the mixture boards

Property	Units	Mixture Composition									
		(1,0,0)	(0,1,0)	(0,0,1)	$(\frac{6}{3},\frac{1}{3},0)$	$(\frac{6}{3},0,\frac{1}{3})$	$(\frac{1}{3},\frac{6}{3},0)$	$(\frac{1}{3},0,\frac{6}{3})$	$(\frac{1}{3},\frac{1}{3},\frac{1}{3})$	$(0,\frac{6}{3},\frac{1}{3})$	$(0,\frac{1}{3},\frac{6}{3})$
Compressive strength	Nmm^{-2}	2.47	8.69	5.26	3.37	2.73	2.74	2.58	2.51	2.33	2.40
Bending strength	Nmm^{-2}	22.63	31.88	27.89	42.29	23.26	21.40	37.10	25.02	20.55	34.19
Nail Resistance	N	763	979	594	963	856	906	792	798	649	771
Screw withdrawal	N	461	662	424	476	463	507	520	488	468	597
Surface soundness	N	844	1100.22	747	907	912	934	850	853	857	1004
Deflection	mm	2.07	1.29	2.49	2.01	2.04	2.00	2.06	2.03	2.31	1.49
Water absorption	%	26.49	17.88	24.24	21.53	24.11	26.15	21.87	26.51	23.56	21.47
Tensile strength	Nmm^{-2}	0.46	1.17	0.36	0.75	0.48	0.50	0.47	0.47	0.37	0.61