PROPERTIES OF RICE STRAW FIBREBOARD BOUND WITH RECYCLED LOW DENSITY POLYETHYLENE (LDPE)

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DECLARATION

I hereby declare that the work in this thesis titled "Properties of Rice Straw Fibreboard Bound with Recycled Low Density Polyethylene (LDPE)" was performed by me in the Department of Building under the supervision of Prof. I.K. Zubairu and Dr S.A. Bustani. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for award of any other degree or diploma at any University.

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CERTIFICATION

This thesis titled "PROPERTIES OF RICE STRAW FIBREBOARD BOUND WITH RECYCLED LOW DENSITY POLYETHYLENE (LDPE)" by LADAN, Ahmad Adamu meets the regulations governing the award of the degree of M.Sc in Construction Technology of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

The environmental impact of deforestation and the non biodegradability of synthetic polymer as a major product of household waste, necessitate the need to look into agricultural residue and low density polyethylene (LDPE) as an alternative source of raw material for the production of fibreboard panels. This study investigated the properties of fibreboard made from Rice Straw (as main matrix) and LDPE (as filler material and binder), with a view to establishing their suitability for use as panels in the Construction Industry. The composite were produced using the dry blend/hot press method. Processed Rice Straw was mixed with shredded LDPE from sachet water at 20%, 30%, 40%, and 50% replacement levels, based on the dry weight of the straw. The mixed material was pressed at an optimum temperature and pressure of 170^{o}C and 1.4N/mm^{2} respectively in Moore's Hydraulic Press machine. Ten test samples of nominal size 200mm x 200mm x 6 mm were produced at each replacement levels. The test samples were evaluated for both physical and mechanical properties according to the relevant standards. The results showed that the density ranged from 800kg/m^{3} to 1000 kg/m^{3}. The mean value for surface absorption was observed to increase from 149mm for samples with 20% replacement level to 200mm for samples with 50% polymer content. As the concentration level of LDPE increases, it was generally observed that both thickness swell and moisture absorption decreases in value from 31% to 4% and 57% to 24% respectively. The bending strength properties showed a non linear behavior with the lowest mean value of 20N/mm^{2} for samples with 20% replacement level and the highest mean value of 43N/mm^{2} for samples with 30% Polyethylene content. The Internal Bond property was observed to vary from 1.07N/mm^{2} to 3.07N/mm^{2} for samples with 20% and 50% replacement levels respectively. Similar trend was observed with regards to the screw holding properties. The screw holding properties vary from 720N to 1220N for samples with 20% and 50% polymer content respectively. However the result on bending stiffness was observed to be unsatisfactory. The maximum mean value recorded for the samples at 30% replacement level was 2279N/mm^{2}, which was 16% lower than the 2700N/mm^{2} specified by BS 622-5: 2003. The study concluded that samples with 30%, 40% and 50% Polyethylene replacement levels met the requirements set out by BS 622-5: 2003. It was therefore recommended that fibreboards made with these materials can be used for interior furniture works, wall paneling and ceiling board.

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ABBREVIATIONS AND SYMBOLS

3D	Three dimensional
^{o}C	Degree Centigrade or Degree Celsius
° F	Degree Fahrenheit
ABUCONS	Ahmadu Bello University Consultancy Services
ASTM	American Society for Testing and Materials
BS	British Standard
BS EN	European Standard with British Standard status
BSI	British Standard Institution
CARRB	California Rice Research Board
C_2H_4	Ethylene monomer
$–CH_2–CH_2–$	Polyethylene
$[–CH_2–CH.CH_3–]_n$	Polypropylene
$[–CH_2–CH.Cl–]_n$	Polyvinyl Chloride
$[–CH_2–CH.F–]_n$	Polyvinyl Fluoride
$[–CF_2–CF_2–]_n$	Polytetra Fluoroethylene (PTFE)
[ETFE]	Ethylene tetrafluoroethylene
cm	centimeter
EU	European Union
FAO	Food and Agricultural Organisation
FAOSTAT	Food and Agricultural Organisation Statistics
g/cm^3	grams per cubic centimetre
HDF	High Density Fibreboard
HDPE	High Density Polyethylene
IRRI	International Rice Research Institute
IUPAC	International Union of Pure and Applied Chemistry
kg/m^3	Kilogram per cubic metre
LDPE	Low Density Polyethylene
LLDPE	Linear low density polyethylene
MDF	Medium Density Fibreboard
MDPE	Medium density polyethylene
mc	Moisture Content
mm	millimetre

NCRI	National Cereal Research Institute
NRC	National Rice Council (Nigeria)
OPC	Ordinary Portland Cement
OSB	Oriented Strand Board
PB	Particle Board
PEX	Cross linked polyethylene
RIFAN	Rice Farmers Association of Nigeria
RPR	Residue to Product Ratio
SPI	Society of the Plastics Industry
UHMWPE	Ultra high molecular weight polyethylene
UNCTAD	United Nation Conference on Trade and Development
VLDPE	Very low density polyethylene
WARDA	West African Rice Development Association
WPIF	World Panel Information Federation

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Studies have shown that factors such as environmental, health and economic implications of residues and/or "wastes" from agricultural and wood processing outfits have necessitated the need for their use for the production of value-added products (Hussaini and Zubairu 1997; Erakhrumen, 2006; Mamza and Kambai 2008). This need has led to series of research efforts spanning decades on composite materials based on plant fibres. An example is the production of different types of composites boards from various types of materials particularly from those considered residues or "waste" (Erakhrumen, *et al* 2008).

Researches on a wide variety of agricultural residues and/or "wastes" including those from animals and lesser known or lesser utilized vegetal materials from different regions of the world including Nigeria for composite boards production have been carried out (Erakhrumen, *et al* 2008; Hussaini and Zubairu, 1997; Jimoh *et al*, 2009; Mamza and Kambai 2008; Nnabuife and Ibekwe, 1985; Mo *et al*., 2003; Pan and Cathcart, 2004; Sampathrajan *et al*., 1992; Wang and Sun, 2002; Winandy *et al*., 2003), among which is fibreboard making (Petruzzi, 2001; Christianson,2009).

BS EN 7916: (1998) defines fibreboard as panel material with a thickness of 1.5mm and greater, manufactured from lignocellulosic fibres with application of heat and/or pressure. The bond is derived from either the felting of the fibres and their inherent adhesive properties or from a synthetic binder added to the fibres. Other

additives may be included. Several different types of products may be obtained, depending on the degree of compression of the fibres. The standard classified fibre building boards as hardboard, medium density fibre board, medium board and softboard, according to density.

The standard further described 'Medium Density Fibreboards'(MDF) or dry process fibreboards as fibreboards having a fibre moisture content of less than 20% at the forming stage, and having a density of at least 600 kg/m^3. The so called "Medium Density Fibreboards" (MDF) are produced with a synthetic adhesive under heat and pressure. Taylor (2002) explained that MDF can be treated in much the same way as solid wood without its inherent defects and problems of instability. In the same work, it was observed that standard board (MDF) is not waterproof and must be protected by sealing of surface if used in potentially damp environment. Applications of MDF include mouldings, such as architraves, window boards, and skirting and furniture.

The environmental impact of fibreboard has greatly improved over the years. Today many boards are made from a variety of materials. These include other woods, scrap, recycled paper, bamboo, carbon fibers and polymers, steel, glass, forest thinning and sawmill off-cuts (WPIF, 2009).

Rice is the seed of the monocot plant *Oryza sativa*, of the grass family (*Poaceae*). As a cereal grain, it is the most important staple food for a large part of the world's human population, especially in tropical Latin America, the West Indies, East, South and Southeast Asia, and Africa. It is the grain with the second highest worldwide production, after maize ("corn") (FAOSTAT, 2009). Since a large portion of maize crops are grown for purposes other than human consumption, rice is probably the most

important grain with regards to human nutrition and calorie intake, providing more than one fifth of the calories consumed worldwide by the human species (Smith, 1998). A traditional food plant in Africa, rice has the potential to improve nutrition, boost food security, foster rural development and support sustainable landcare (National Research Council, 1996).

Straw is the stem of a small grain cereal plant, such as wheat or rice, or the shaft left after the growing of grass for grass seed (Petruzzi, 2001). Rice straw has a relatively low lignin content and high silica content (CARRB, 2009). Studies have shown that the Residue-to-Product-Ratio (RPR) of rice straw to rice ranges from 0.416 to 3.96 depending on the mode of harvest of the rice as was reported by Koopmans and Koppejan (1997). While some straw is left to condition the soil, in many places it is cleared from fields after grain harvest by burning, which has caused serious air pollution problems (Petruzzi, 2001).

Using straw as the fibre for fibreboard provides an alternative to burning straw in fields. Petruzzi (2001) explained that although processing straw into fibreboard and particleboard is similar to processing wood residues, breaking straw into fibers requires less processing and less drying, therefore less energy use. In addition, the properties of strawboard, such as internal bond strength, resistance to rupture, moisture resistance, and screwholding strength (as measured by tests developed by the American National Standards Institute or the American Society for Testing and Materials (ASTM C208-8a)), are equal to or better than wood-based fibreboard and particleboard.

While use of some of the more traditional organic materials in the construction industry continues at a steady rate, other materials such as plastics have enjoyed a

spectacular rise in application and this trend is likely to continue, because they offer the advantage of low density and good resistance to the environment (Taylor, 2002). The incorporation of polymer in the production of the board is due to its binding properties (Brandrup and Immergut, 1975); most especially the Low Density Polyethylene (LDPE) which is used for the production of plastic bags and the so called "pure water" sachet that visibly litters our environment. This may help in the moisture resistant properties of the board (Taylor, 2002)

1.2 STATEMENT OF RESEARCH PROBLEM

Food and Agricultural Organisation Statistics (FAOSTAT 2009) shows that Rice production in Nigeria increased from 2.4 million metric tonnes in 1994 to 3.6 million metric tonnes in 2007 and will continue to rise since it is an important staple food for many households (Amaza and Maurice, 2005). To every Rice produced twice that amount is straw (Koopmans and Koppejan, 1998). Traditionally, straw was used as reinforcement for local bricks and production of local mattress, but with the advent of synthetic materials the application of such material is eroded. Disposing the straw has been a cause for concern, because the option available is burning which has its own attendant health risk (Petruzzi, 2001)

Depleting forests and the availability of wood chips for fibreboard production due to the over-cutting of forests is a factor that has reduced the amount of available timber. Governments are now more concerned than ever about regulating the annual allowable cutting which takes place. Due to the depletion of the timber supply, the quantities of wood in the form of sawdust and planer shavings have also been reduced. These products are the basic feedstock for wood-based fibreboard and particleboard

company (Petruzzi, 2001). As a result of the declining supply, prices of wood products and residue have increased.

Presently, fibreboard and particleboard uses Urea formaldehyde as the main binder. Reports have shown that breathing even a small amount of formaldehyde can result in eye, nose, and throat irritation and respiratory symptoms, which can increase the risk of contracting lung and nasal cancer (Petruzzi, 2001).

The wide use of plastic for packaging item in our society makes it an important environmental issue. Though it can be recycled, polyethylene is not considered biodegradable as it takes several centuries before it is efficiently degraded. Most of the commercial polyethylene ends up in landfills and in the ocean, while those from household end up in streets and drainage due to lack of good waste management system (Dauda and Osita 2003) thereby blocking the drainages and other water channels resulting in severe flooding. Therefore the study will try to establish the suitability of these 'waste' in the production of fibreboards.

1.3 JUSTIFICATION FOR THE STUDY

The development of composite material based on agricultural residue reinforcement with polymer will help to reduce the pressure on timber thereby solving the problem of forest conservation. The use of recycled polymeric` material for the manufacturing of composites will add a further advantage in promoting environmental sustainability by checking the growing problem of waste in developing countries such as Nigeria. Since polymer material will be used as binder, the attendant health risk associated with Urea formaldehyde resin will be eliminated.

1.4 AIM AND OBJECTIVES

1.4.1 Aim

The aim of this study is to evaluate the properties of fibreboard produced with rice straw and recycled Low Density Polyethylene (LDPE) as binder and filler material. This was measured through the objectives listed below.

1.4.2 Objectives

The objectives of this research are to

i. produce samples of dry process fibreboard using rice straw as the raw material and incorporating recycled Low Density Polyethylene from waste packaged water sachets as the main binder and filler material using standard processes;
ii. establish the properties of the fibreboard samples produced according to relevant standards; and
iii. determine from the result possible areas of application of the board being produced.

1.5 SCOPE AND LIMITATION OF THE STUDY

1.5.1 Scope

The research involves the use of rice straw as the main matrix and recycled LDPE from sachet water as the binder and filler material in the production of fibreboard using the dry process method (BS EN 622-1, 2003).

All tests on the physical and mechanical properties of the samples produced were conducted according to the relevant standards (as acknowledged at the relevant sections) and all the results were compared with those provided in BS EN 622-5 (2003).

1.5.2 Limitations

Cyclic test and the dimensional changes due to changes in relative humidity test were not conducted due to equipment constraints. The length of the sample used for surface absorption test was 200mm instead of 300mm; this was due to the size of the hot plate in the hydraulic press machine that was used for the production of the samples.

Also, only Rice Straw and LDPE were considered for use here; other household recyclable polymers like Polyvinyl Chloride (PVC), High Density Polyethylene (HDPE) and Poly Propylene (PP) were not considered.

1.6 METHODOLOGY

Literature search was done to articulate existing knowledge. The research work was essentially experimental.

1.6.1 Materials

The materials employed for this work included the following;

a. Rice straw

Rice straw was obtained from Rice farms within Zaria after the harvesting period and was screened, stored and thereafter used for the experiment.

b. Polymer Material

Waste LDPE which was used as packaged water sachet from ABUCONS packaged water factory within A.B.U. Zaria was gathered, washed and then shredded to small sizes for ease of handling.

1.6.2 Production of Test Samples

The rice straw retrieved was washed, soaked in water for 48 hours, pretreated with hot water at between 80^{o}C-100^{o}C for an hour (Erakhrumen, *et al* 2008) and then dried to average moisture content (*mc*) of 4.5% (Hussaini and Zubairu, 1997).

Samples of board were produced from rice straw with LDPE as the main binder and filler material in 4 different replacement levels of 20, 30, 40 and 50 percents of dry weight of rice straw. This was after trial mixes of between 8 and 15 percent were conducted on the basis of information by Taylor (2002) that commercial boards are produced with 8 – 10 Percent by weight resin binder, proved unsatisfactory.

1.6.2 Test of Samples

The samples produced were subjected to some physical and mechanical test as prescribed by the relevant standards which included: Density (BS EN 12369-1:2001), Screw withdrawal (BS EN 320:1993), Nail resistance test (ASTM D 1037:1999), Swelling in Thickness (BS EN 317:1993), Surface absorption (BS EN 382-1: 1993), Bending Strength and Bending Stiffness (BS EN 310: 1993) and Tensile Strength perpendicular (or internal Bond strength) and parallel to surface of board (BS 319 :1993 and ASTM D 1037;1999) .

CHAPTER 2

LITERATURE REVIEW

2.1 BOARDS

In order to carry out a justified appraisal of the properties and quality of fibreboard produced from rice straw, it is pertinent to review the characteristics of its co products.

Board is a generic term used to describe panel products from wood and other lignocellulosic based material in the form of strips, veneers, chips, strands or fibres. The categories usually recognised within this group of panel materials are:

i. Plywood, including blockboard and laminboard
ii. Particleboard, including particleboard (chipboard), flaxboard and cement bonded particleboard
iii. Oriented Strand Board (OSB)
iv. Fibreboards, including Medium Density Fibreboard (MDF)

These panels are versatile products with a wide variety of end-uses. Their use continues to expand because of:

i. their good strength/weight ratio
ii. their good strength/cost ratio
iii. their ease of working/finishing/fixing
iv. the range of sizes and thicknesses available
v. the range of types and special products available

vi. their good environmental credentials (made from a renewable raw material, recyclable, low life-cycle costs)

Plywood is a term generally used to designate glued wood panels made up of layers, or plies, with the grain of one or more layers at right angle, to the grain of the other (BS EN 313-2: 2000). An odd number of plies are used, since this enables symmetrical distribution of plies about the centre sheet. The core may be veneer, lumber, or various combinations of veneer and lumber; the total thickness may be less than 1.5 mm or more than 76 mm; the different plies may vary as to number, thickness, and wood species. Also, the shape of the members may vary.

Plywood is a versatile product that can maintain a high performance under hazardous conditions, retaining comparatively high strength to weight ratios. It is available in a range of wood species (both hardwood and softwood), some of which can have an attractive surface appearance, and a range of glue types for interior and exterior conditions (WPIF, 2009).

Blockboard and laminboard are produced in a similar fashion to plywood except that the core of the material is made up from strips of solid wood or veneer laid on edge and this core is then faced with two or more veneers on each side (Schwartz, 2002).

Particleboard or chipboard is a wood-based panel manufactured under pressure and heat from particles of wood (wood flakes, chips, shavings, saw-dust, wafers, strands and similar) and/or other lignocellulosic material in particle form (flax shives, hemp shives, bagasse fragments and similar) with the addition of an adhesive (BS EN 309: 2005). The resin normally occupying about 8% by weight of the dry board, and the wood chips are graded, with coarser chips at the centre of the board and finer chips

at the surface to give greater surface hardness than is available from ordinary softwoods (Taylor, 2002). The strength and moisture resistance of chipboards depends greatly on the type of adhesive used. Those based on urea formaldehyde lose about 60% of their strength and increase in thickness by about 10% on wetting. Recovery does not occur on drying; hence such chipboards must be kept dry during use.

Particleboard is manufactured in a wide variety of densities, but greater part of present production is of the density between 480 kg/m^3 and 800 kg/m^3 (Zubairu, 1989). Thickness ranges between 2 mm and 30 mm. It is generally used in the manufacture of furniture and built-in fitments and in building industry for flooring, sheathing and roofing (BS EN 7916: 1998).

Cement-bonded particleboards are also available in which a cementitious binder, usually Ordinary Portland Cement, is used or with magnesium-based cements (BS EN 633: 1994). They have a very high durability and are suitable for use in dry, humid or exterior conditions. Their high density gives them good acoustic and fire performance. They are used for flooring, modular buildings and applications where high durability is required (WPIF, 2009). There are also particleboards made from non-wood based materials e.g. flaxboard. They can also be bonded with Ordinary Portland Cement (OPC).

Flaxboard is a wood-based panel manufactured under pressure and heat from particles of wood (wood flakes, chips, shavings, saw-dust, wafers, strands and similar) and/or other lignocellulosic material in particle form (flax shives, hemp shives, bagasse fragments and similar) with the addition of an adhesive (BS EN 309: 2005). It is similar in some ways to particleboard but has different properties and applications. It is not a

chipboard substitute and is generally required where thicker, low-density panels are an advantage. Flaxboard would normally be used where it would not be exposed to moisture and common usages include door cores, fire-check doors, and partitions (Schwartz, 2002). Flaxboard shall have at least 70% flax content and can contain other raw materials.

Oriented Strand Board (OSB) was developed in the mid 1970's to utilise smaller logs that are not suitable for plywood production. Made of strands normally about 75mm long, they are often in three layers, with the strands in the surface layer oriented roughly in line with the length of the panel (Schwartz, 2002). The strands in the centre layer or layers can be randomly oriented, or aligned, generally at right angles to the strands of the external layers. This gives the panel higher mechanical properties in that direction. OSB was developed from the earlier waferboards or flakeboards, which had random particle orientation.

Common applications include flooring, wall sheathing, roof sarking, packaging, and furniture. OSB is also commonly used as site hoarding although it generally has a limited life in this application. Some specialist products, with a surface coating, are now available for site hoarding giving a prolonged service life.

Plywood, particleboards and fibreboards all include both general purpose, or utility, boards and special purpose products. Several types of panel can be engineered to meet specific property requirements.

2.2 FIBREBOARDS

2.2.1 Definition

Fibreboard as defined in BS EN 316: 1999 is a wood-based panel with a nominal thickness of 1.5mm or greater, manufactured from lignocellulosic fibres with application of heat and/or pressure. The bond is derived either from the felting of the fibres and their inherent adhesive properties, or from a synthetic adhesive added to the fibres. Other additives can be included.

2.2.2 Basic Processes in the Manufacture of Fibreboard

Since wood fibreboard is the major board in the market, its method of production shall be discussed here. The trees are debarked after being cut. The bark can be sold for use in landscaping, or burned in on-site furnaces. The debarked logs are sent to the Fibreboard plant where they go through the chipping process. A typical disk chipper contains 4-16 blades. Any resulting chips that are too large may be re-chipped; undersized chips may be used as fuel. The chips are then washed and checked for defects.

The chips are then compacted using a screw feeder, and will be heated for 30-120 seconds to soften the wood; they are then fed into a defibrator which maintains high pressure and temperature. The pulp that exits from the defibrator is fine, fluffy, and light in weight and in colour.

At the defibrator, the two major types of fibreboard manufactured are separated into either wet process or dry process board production method.

In the wet process boards, water is added into the wood fibres to form slurry. This is then formed into a mat on a moving wire mesh. During processing, the water is removed and the final heated pressing promotes bonding of the fibres using the adhesive properties of the natural lignin adhesive present in the wood. Depending upon the degree of pressing involved and hence the final density of the panel, the product is termed softboard, mediumboard or hardboard. Additives are sometimes included to improve properties.

In the case of dry process boards, the wet fibres are dried and an adhesive is added. This is then formed into a mat and pressed in a similar way to particleboard. The resulting product is generally termed medium density fibreboard (MDF) and should not be confused with the wet process mediumboard. After pressing, MDF is cooled in a star dryer, trimmed and sanded. In certain applications, boards are also laminated for extra strength.

2.2.3 Origin and Development of Fibreboard Plants

Fibreboard was accidentally invented in 1924 by William Mason, a Mississippi inventor. Mason attempted to turn wood chips discarded by lumber mills into affordable insulation, but when he forgot to shut down his equipment one evening, his machinery continued working, turning the wood chips into a thin, durable sheet which was then called Masonite (Fahlman, 2010). Hence he invented a method for using a steam press to produce the hardboard from slurry of wood chips in 1925.

Based on the design of hardboard, the first MDF was produced commercially in Deposit, New York State, USA in 1966. Since then the market for MDF has increased dramatically world-wide replacing more and more solid wood lumber and plywood

products most especially in the past decade. In fact, the combined production of PB and MDF in North America during 1999 was approximately 10.7 million cubic meters (over 12 billion square feet of 3/8-inch thick panel), (Petruzzi, 2001). The first MDF was produced in Europe in 1973 and today European production capacity rivals that in the USA, with 13 million cubic metres per annum produced in 2006. (WPIF, 2009)

2.2.4 Types of Fibreboards

Generally fibreboards are classified based on two methods namely

2. Their method of production and
3. Their density.

Based on their method of production we have wet process and dry process fibreboards which were earlier discussed. On the basis of density, both the wet and dry process fibeboards are further subdivided into Hardboards with density > 900 kg/m^3, Mediumboard with density > 400 kg/m^3 to <900 kg/m^3 and Softboards with density > 230 kg/m^3 to <400 kg/m^3.

Mediumboards which should not be confused with Medium Density Fibreboard can be sub-divided into Low density mediumboards with density range of 400 kg/m^3 to <560 kg/m^3 and High density mediumboards with a density range of 560 kg/m^3 to <900 kg/m^3

For marketing purposes, MDF of specific density ranges can be given different denominations. For example, the following, density-related marketing terms for MDF have become established:

i. High Density Fibreboard (HDF): MDF with a density ≥800 kg/m^3
ii. light MDF: MDF with a density ≤650 kg/m^3

iii. ultra-light MDF: with a density ≤ 550 kg/m^3

2.2.5 Applications of Fibreboards

Due to the particular machining and finishing attributes combined with good working properties and its availability in a wide range of sheet thicknesses and sizes, fibreboard finds application in a wide range of construction and furniture applications. It is used increasingly for interior design and building applications such as skirtings and architraves, window boards, wall linings, and decorative facades, as well as the core material for some flooring.

Fibreboard can be cut without breakout or splintering and it can be profiled on the edges and surfaces. The smooth and relatively dense surface provides an excellent base for painting, veneering and laminating. Consequently MDF is used extensively in furniture production, and with the range of value added variants, its use is being extended into shop fitting and display, interior fitments, exterior application (e.g. signage and shop fronts) as well as components within numerous other products.

2.2.6 Advantages and Disadvantages of Fibreboards

Advantages: -

There are a number of reasons why fibreboard may be used instead of plywood or chipboard which might include;

i. It is dense, flat, and stiff, has no knots and is easily machined.
ii. Because it is made up of fine particles it does not have an easily recognisable surface grain.
iii. Fibreboard can be painted to produce a smooth quality surface.

iv. Because fibreboard has no grain it can be cut, drilled, machined and filed without damaging the surface.

v. Door skins and architraves are easily moulded.

vi. Aesthetically pleasing.

vii. Although attractive enough in its raw form fibreboards is usually coated with a Melamine paper, which can provide a full palette of colours and artificial wood veneers.

viii. It has greater moisture tolerance than particleboard

ix. Fibreboards may be dowelled together and traditional woodwork joints may even be cut.

x. True wood veneers, other plastics, paints and aluminium will all adhere to fibreboards.

Disadvantages: -

The disadvantages include

i. Fibreboards can be dangerous to use if the correct safety precautions are not taken.

ii. Wood fibreboard contains Urea formaldehyde as binder, which may be released from the material through cutting and sanding. Urea formaldehyde may cause irritation to the eyes and lungs. Proper ventilation is required when using it and facemasks are needed when sanding or cutting fibreboards with machinery.

iii. The dust produced when machining fibreboards is very dangerous. Masks and goggles should always be worn at all times.

iv. Due to the fact that fibreboards contain a great deal of glue the cutting edges of your tools will blunt very quickly.

v. Fibreboards can be fixed together with screws and nails but the material may split if care is not taken.

vi. Urea formaldehyde is always being slowly released from the surface of fibreboards.

vii. Wax and oil finishes may be used as finishes but they are less effective at sealing in the urea formaldehyde.

2.3 The Rice Plant

Rice is the monocot plant of the grass family *Poaceae* [formerly *Graminae* (Encarta, 2009)], belonging to the genum *Oryza linn* of which two species out of over 14,700 varieties were cultivated – *Oryza sativa linn* and *Oryza glaberrima stend*. The former (*O. sativa linn*) is by far the more important; *O. glaberrima* being confined to small areas in West Africa.

Rice is normally grown as an annual plant, although in tropical areas it can survive as a perennial and can produce a ratoon crop for up to 20 years (IRRI, 2009). The rice plant can grow to 1–6 m tall, occasionally more depending on the variety and soil fertility. The grass has a fibrous root system, with long, slender leaves 50–100 cm long and 2–2.5 cm broad attached to the stem (culm). The small wind-pollinated flowers are produced in a branched panicle arching to pendulous inflorescence 30–50 cm long. The edible seed is a grain (caryopsis) 5–12 mm long and 2–3 mm thick (Plate I). In many varieties, the plant tillers freely and usually bear four or five culms that grow 60-240 cm tall (IRRI, 2009)

Rice cultivation is well-suited to countries and regions with low labor costs and high rainfall, as it is very labor-intensive to cultivate and requires plenty of water for cultivation. Rice can be grown practically anywhere, even on a steep hill or mountain.

Although its parent species are native to South Asia and certain parts of Africa, centuries of trade and exportation have made it commonplace in many cultures worldwide.

The traditional method for cultivating rice is flooding the fields while, or after, setting the young seedlings. This simple method requires sound planning and servicing of the water damming and channeling, but reduces the growth of less robust weed and pest plants that have no submerged growth state, and deters vermin. While with rice growing and cultivation the flooding is not mandatory, all other methods of irrigation require higher effort in weed and pest control during growth periods and a different approach for fertilizing the soil.

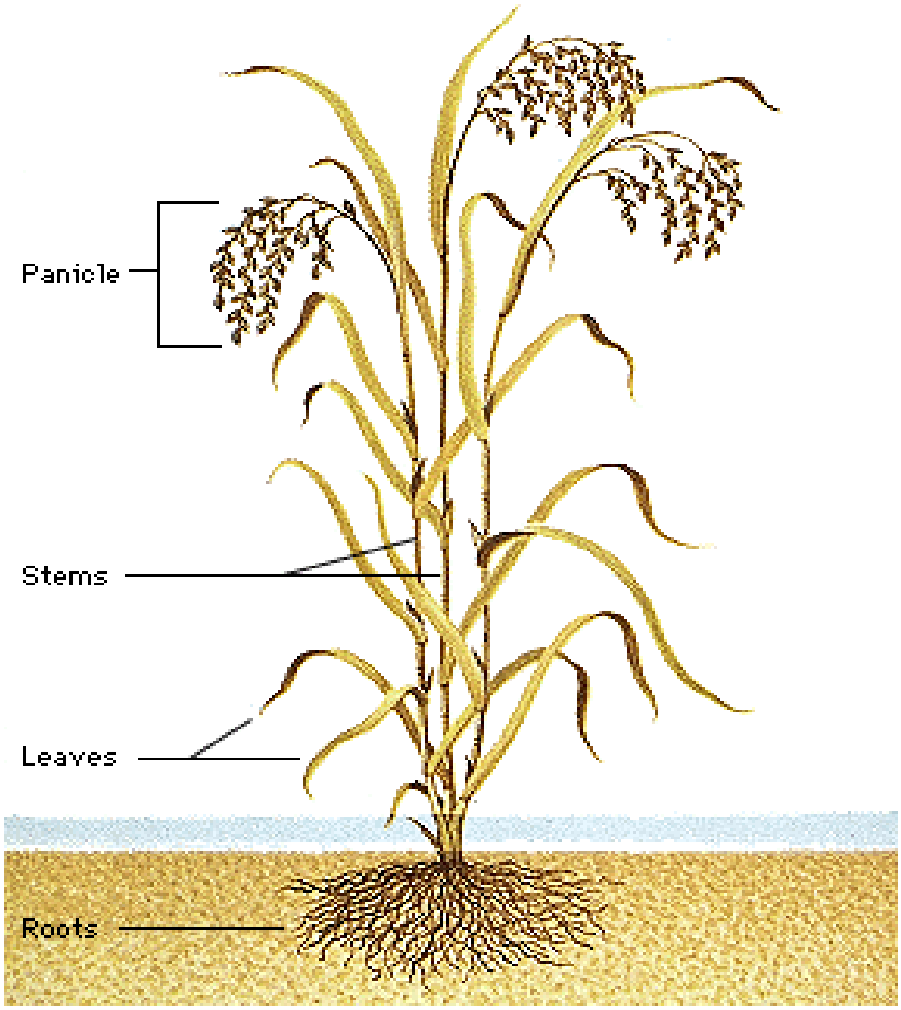


Plate I: The rice plant. Source: UNCTAD, 2009.

2.3.1 World Rice Production

In the beginning rice grew wild, but today most countries cultivate varieties belonging to the Oryza type which has around twenty different species. Only two of them offer an agricultural interest for humans. The first is *Oryza sativa*, common Asian rice found in most producing countries which originated in the Far East at the foot of the Himalayas. *O. sativa japonica* grew on the Chinese side of the mountains and *O. sativa indica* on the Indian side. The majority of the cultivated varieties belong to this

species, which is characterized by its plasticity and taste qualities. The second common specie is *Oryza glaberrima*, an annual species originating in West Africa, covering a large region extending from the central Delta of the Niger River to Senegal.

It is believed that rice cultivation began simultaneously in many countries over 6500 years ago (UNCTAD, 2009). The first crops were observed in China (Hemu Du region) around 5000 B.C. as well as in Thailand around 4500 B.C. They later appeared in Cambodia, Vietnam and Southern India. From there, derived species Japonica and Indica expanded to other Asian countries, such as Korea, Japan, Myanmar, Pakistan, Sri Lanka, Philippines and Indonesia. Japonica is an irrigated rice of temperate zone, with medium or short grains, also called round grain, and is a rainfed lowland rice of warm tropical zones. Indica is an irrigated rice of warm tropical zones, with long, thin and flat grains.

The Asian rice *O. sativa* was adapted to farming in the Middle East and Mediterranean Europe around 800 B.C. The Moros brought it to Spain when they conquered the country, near 700 A.D. After the middle of the 15th century, rice spread throughout Italy and then France, later propagating to all the continents during the great age of European exploration. In 1694 rice arrived in the South Carolina, probably originating from Madagascar. The Spanish took it to South America at the beginning of the 18th century.

Between 1500 and 800 B.C., the African species *O. glaberrima* propagated from its original center, the Delta of Niger River, and extended to Senegal. However, it never developed far from its original region. Its cultivation even declined in favor of

the Asian species, possibly brought to the African continent by the Arabians coming from the East Coast from the 7th to the 11th centuries.

Rice is the world's most consumed cereal after wheat. It provides more than 50 percent of the daily calories ingested by more than half of the world population. It is so important in Asia that it influenced local language and beliefs. In classical Chinese, the same term refers to both "rice" and "agriculture". In many official languages and local dialectics the verb "to eat" means "to eat rice". Indeed, the words "rice" and "food" are sometimes one and the same in eastern semantics.

2.3.2 Rice Production in Nigeria

Nigeria, with a conservative population of over 128 million people, has variety of factors that favour rice production. National Cereal Research Institute (NCRI) the nation's premier rice and other cereal research institute has revealed that, Nigeria has approximately 5million hectares of land suited for rice production. The climatic condition that cut across the mangrove, forest and savanna regions terminate at Sahel region. NCRI and WARDA (West African Rice Development Association), have reported that apart from the latest NERICA ('New Rice for Africa'; which is a cross breed between African and Asian rice), over 50 varieties of rice have been developed with a variety or more suited for each of the six geo-ecological regions in Nigeria. The climatic condition is a natural facility for rice programme in Nigeria. Major Rice producing zones in Nigeria include: Kano, Niger, Benue, Yobe, Kaduna, Anambra, Ebonyi, Kwara, Edo, Taraba and Kebbi states etc. In order of production level, Zamfara, Jigawa, Borno, Adamawa, Ondo, Ogun, Cross River states follow very closely especially with specialization on processing facilities.

In spite of recent positive developments in rice production, the crop is still predominantly produced by small-holders and based on this early records showed that on the average, rice producing-households produce 4.6 tons of Paddy rice per year from an annual crop area of 3.3 hectares, corresponding with an overall average yield of 1.8 tons of paddy per hectare as reported by Rice Farmers Association of Nigeria (RIFAN, 2006).

2.3.2 Uses of Rice

Generally, the milled grain of rice is mainly used in the food and beverages industries in the production of;

i. Cooked rice
ii. Cakes (moshi)
iii. Extruded rice noodles
iv. Rice based baby food
v. Bread
vi. Crackers
vii. Rice snacks (okoshi)
viii. Tablets/pills
ix. Food stabilizers
x. Seasoning (miso)
xi. Rice drinks
xii. Vinegar
xiii. Rice wines (sake)

3.4 The Rice Straw

The rice straw, which is the main residue in rice production consist mainly of **culm** (Another name for the stem of the rice plant). The culm consists of several **nodes** spaced apart by **Internodes** 1 cm apart near the base, and further apart towards the top of the rice plant. The internodal length can reach 10-30 cm at the formation of the panicle from the last internode (Figure 2.1).

At the base of the culm is a bladeless bract called the **prophyllum**. At the base we also find **adventitious roots** that aid the plant in support.

The first leaves are generated at the first node. Their **sheaths** envelop the main culm or what is called the **primary tiller**. It is common to see **secondary tillers** that also have leaves with leaf sheaths (Figure 2.1). Secondary tillers arise from the first node of the primary tiller and generally have a fewer number of leaves.

At the leaf junction at the furthermost node, **ligules** and a pair of **auricles** occur. The panicle also forms at the uppermost node and gives rise to the spikelets or fruits of the rice plant (Figure 2.1).

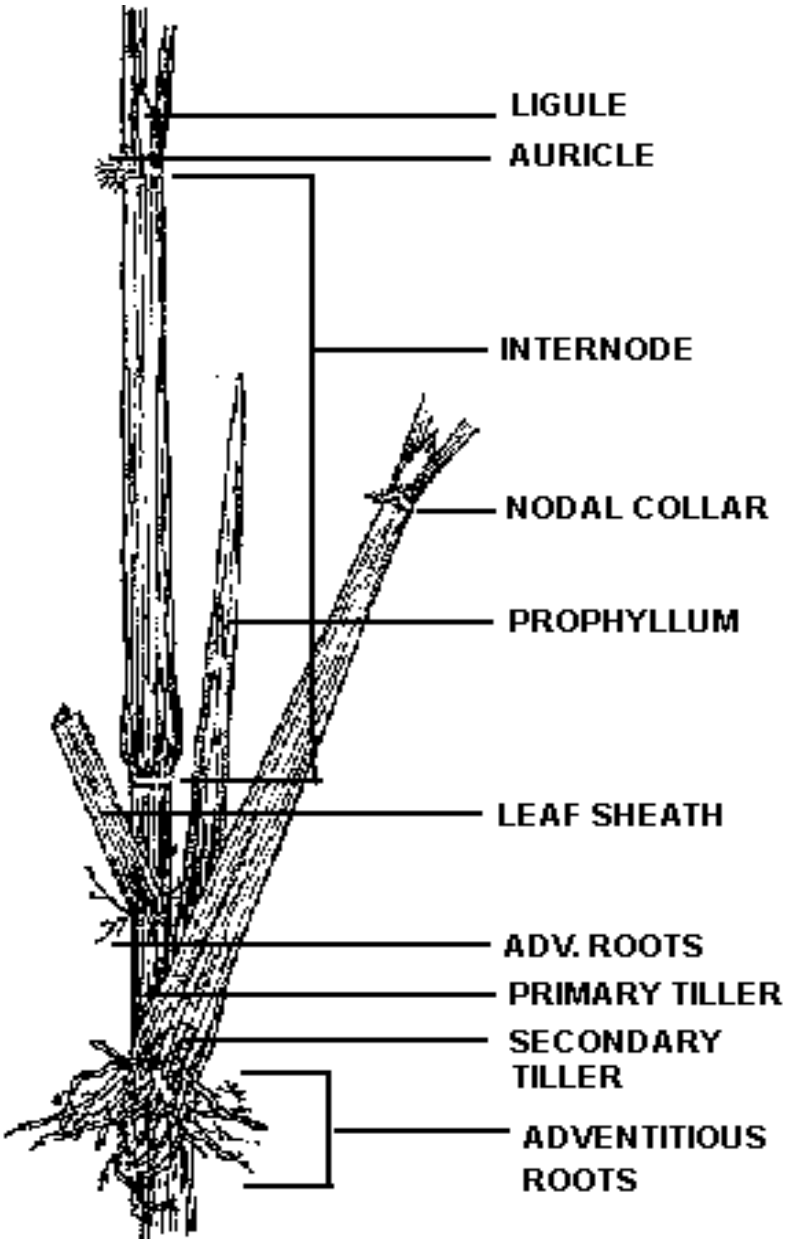


Figure 2.1: The rice straw

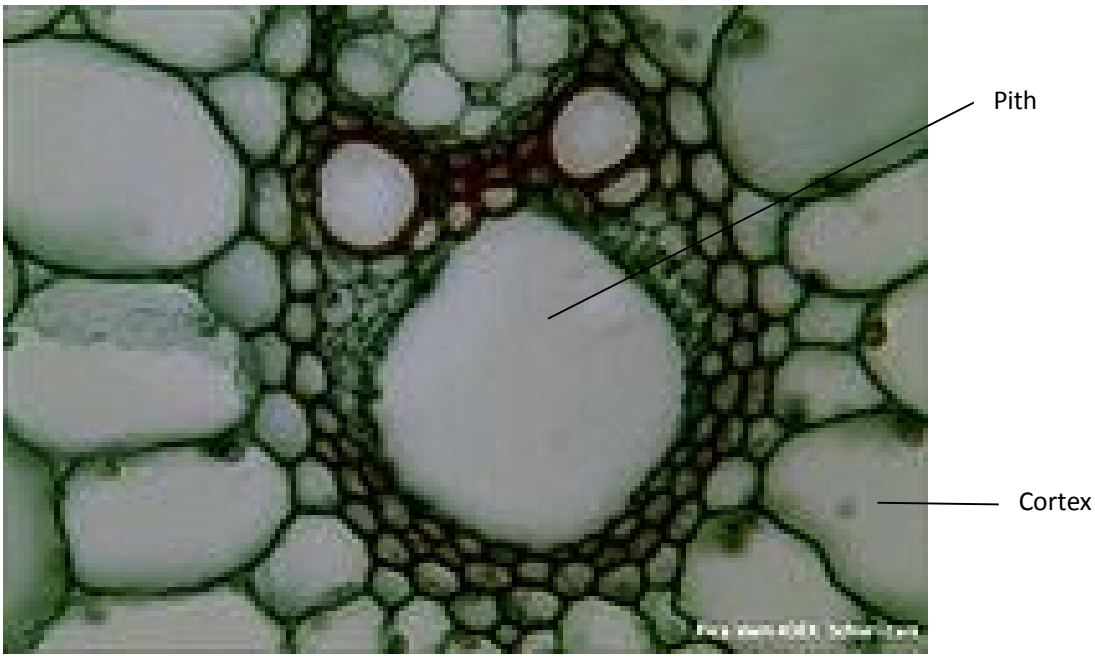


Plate II; The rice stem magnified 400x. Source IRRI 2009

3.4.1 Uses of Rice Straw

The Rice Research Board of the United States funded several research projects from 1979 until 1983 to find economic uses for rice straw. The principal objective of these projects was to reduce or eliminate rice straw burning as the means for disposal which is the practice in many countries then. Uses for straw that were studied and found viable include:

Biofuels: The use of straw as a carbon-neutral energy source is increasing rapidly, especially for biobutanol.

Biomass: The use of straw in large-scale biomass power plants is becoming main stream in the EU, with several facilities already online. The straw is either used directly in the form of bales, or densified into pellets which allows for the feedstock to be transported over longer distances.

Bedding humans or livestock: the straw-filled mattress, also known as palliasse, is still used in many parts of the world. It is commonly used as bedding for ruminants and horses and even humans in some area.

Animal feed: Straw may be fed as part of the roughage component of the diet to cattle that are on a near maintenance level of energy requirement. It has a low digestible energy and nutrient content. The heat generated when microorganisms in a herbivore's gut digest straw can be useful in maintaining body temperature in cold climates.

Hats: There are several styles of straw hats that are made of woven straw.

Thatching: Thatched roofs are becoming increasingly popular, most especially in Hotels and Eatries.

Packaging: Straw is resistant to being crushed and therefore makes a good packing material.

Paper: Straw can be pulped to make paper.

Construction material: bricks / cob - In many parts of the world, straw is used to bind clay and concrete. This mixture of clay and straw, known as cob, can be used as a building material. There are many recipes for making cob. When baled, straw has excellent insulation characteristics. It can be used, alone or in a post-and-beam construction, to build straw bale houses. Enviroboard can be made from straw.

Rope: Rope made from straw was used by thatchers, in the packaging industry and even in iron foundries.

Basketry: Bee skeps and linen baskets are made from coiled and bound together continuous lengths of straw. The technique is known as lip work.

Horticulture: In Japan, certain trees are wrapped with straw to protect them from the effects of a hard winter as well as to use them as a trap for parasite insects.

It is also used in ponds to reduce algae by changing the nutrient ratios in the water.

The soil under strawberries is covered with straw to protect the ripe berries from dirt, and straw is also used to cover the plants during winter to prevent the cold from killing them.

2.4.2 Properties of Rice Straw as Material for Board Making

The rice straw can be easily crushed into chips or particles, which are very similar to wood particles or fibers. The rice straw is mainly consisting of carbohydrate components such as hemicelluloses, cellulose, and lignin (Lee, *et al* 2004). These are the basic requirements in a material to be used for the production of fibreboard (lignocellulosic) as stated by the standard (BS EN 622-1: 2003).

The carbohydrates content is variable, as well as other components, such as ash and silica. The hydrophilic character of the rice straw is one of the reasons for relatively high moisture content, approximately 60-90% on a wet base, or 10-12% on a dry base (Buzarovska *et a,l* 2008). The ash content of up to 22% and low protein content result in a material decomposing not as readily as other straws (Pan *et al*, 1999). The rice straw resistance to bacterial decomposition makes this material suitable as filler in building composite materials. On the other hand, high content of silica (up to 20%) represents an additional potential benefit regarding the flame-retardant when used in building industry.

2.5 PLASTICS

2.5.1 Definition and Characteristics

Plastics are a major group of materials that are primarily non crystalline hydrocarbon substances composed of large molecular chains whose major element is carbon. The three terms — *plastics*, *polymers*, and *resins* — are sometimes used interchangeably to identify these materials. However, the term *plastic* has now come to be the commonly used designation (Schwartz 2002). A plastic material, as defined by the Society of the Plastics Industry (SPI, 2009), is "any one of a large group of materials consisting wholly or in part of combinations of carbon with oxygen, hydrogen, nitrogen, and other organic and inorganic elements which, while solid in the finished state, at some stage in its manufacture is made liquid, and thus capable of being formed into various shapes, most usually through the application, either singly or together, of heat and pressure."

Some major characteristics of plastics that distinguish them from other materials, particularly metals include:

i. They are essentially non-crystalline in structure.
ii. They are nonconductors of electricity and are relatively low in heat conductance.
iii. They are, with some important exceptions, resistant to chemical and corrosive environments.
iv. They have relatively low softening temperatures.
v. They are readily formed into complex shapes.
vi. They exhibit visco-elastic behavior — that is, after an applied load is removed, plastics tend to continue to exhibit strain or deformation with time.

Polymers can be built of one, two, or even three different monomers, and are termed homopolymers, copolymers, and terpolymers, respectively (Schwartz 2002). Their geometrical form can be linear or branched. Linear or unbranched polymers are composed of monomers linked end-to-end to form a molecular chain that is like a simple string of beads or a piece of spaghetti (Plate III).

Branched polymers have side chains of molecules attached to the main linear polymer. These branches can be composed either of the basic linear monomer or of a different one. If the side molecules are arranged randomly, the polymer is atactic; if they branch out on one side of the linear chain in the same plane, the polymer is isotactic; and if they alternate from one side to the other, the polymer is syndiotactic.

Plastics are produced in a variety of different forms. Most common are plastic moldings, which range in size from 2 cm to several meters.



Plate III: Space-filling model of a polyethylene chain

2.5.2 Development of Plastics

Before the invention of plastic, the only substances that could be molded were clays (pottery) and glass. Hardened clay and glass were used for storage, but they were heavy and brittle. Some natural substances, like tree gums and rubber, were sticky and moldable. Rubber wasn't very useful for storage because it eventually lost its ability to bounce back into shape and became sticky when heated.

In 1839, Charles Goodyear accidentally discovered a process in which sulfur reacted with crude rubber when heated and then cooled. The rubber became resilient upon cooling -- it could stretch, but it snapped back to its original shape. It also retained its resilience when heated. We now know that the sulfur forms chemical bonds between adjacent rubber polymer strands. The bonds cross-link the polymer strands, allowing them to "snap back" when stretched. Charles Goodyear had discovered the process now known as vulcanization, which made rubber more durable.

In 1846, Charles Schonbein, a Swiss chemist, accidentally discovered another polymer when he spilled a nitric acid-sulfuric acid mixture on some cotton. A chemical reaction occurred in which the hydroxyl groups of the cellulose fibers in the cotton were converted to nitrate groups catalyzed by the sulfur. The resultant polymer, nitrocellulose, could burst into a smokeless flame and was used by the military in place of gunpowder. In 1870, chemist John Hyatt reacted nitrocellulose with camphor to make celluloid, a plastic polymer that was used in photographic film, billiard balls, dental plates and Ping-Pong balls.

In 1909, a chemist named Leo Baekeland synthesized Bakelite, the first truly synthetic polymer, from a mixture of phenol and formaldehyde. The condensation reaction between these monomers allows the formaldehyde to bind the phenol rings into rigid three-dimensional polymers. So, Bakelite can be molded when hot and solidified into a hard plastic that can be used for handles, phones, auto parts, furniture and even jewelry. Bakelite is hard, resistant to heat and electricity, and can't be easily melted or scorched once cooled. The invention of Bakelite led to a whole class of plastics with similar properties, known as phenolic resins.

In the 1930s, a Dupont chemist named Wallace Carruthers invented a plastic polymer made from the condensation of adipic acid and a certain type of diaminohexane monomers that could be drawn out into strong fibers, like silk. This plastic became known as nylon. Nylon is lightweight, strong and durable and became the basis of many types of clothing, coverings (tents), luggage, bags and ropes.

The use of these early polymers became widespread following World War II and continues today. They lead to the creation of many other plastics, like Dacron, Styrofoam, polystyrene, polyethylene and vinyl.

2.5.3 Types of Plastics

There are two basic types of plastics based on intermolecular bonding. Thermoplastics, because of little or no cross-bonding between molecules, soften when heated and harden when cooled, no matter how often the process is repeated. Thermosets or thermosetting plastics, on the other hand, have strong, intermolecular bonding. Therefore, once the plastic is set into permanent shape under heat and pressure, reheating will not soften it.

Within these major classes, plastics are commonly classified on the basis of base monomers. There are over two dozen such monomer families or groups. Plastics are also sometimes classified roughly into three stiffness categories: rigid, flexible, and elastic.

2.5.3.1 Thermoplastics

When polymers retain a chain structure, there being no primary bonds between the chain, the material is described as thermoplastic (Taylor, 2002). Thermoplastic molecules, which are linear or slightly branched, do not chemically bond with each other when heated. Instead, thermoplastic chains are held together by weak *Van der Waal* forces (weak attractions between the molecules) that cause the long molecular chains to clump together like piles of entangled spaghetti (Schwartz, 2002). Thermoplastics can be heated and cooled, and consequently softened and hardened, repeatedly, like candle wax. For this reason, thermoplastics can be remolded and reused almost indefinitely. Thus, a foamed-polystyrene cup can be heated and reshaped into a new form—for instance, a dish.

Plastic materials that fall under this category include; Polyethylene [$–CH_2–CH_2–$], Polypropylene [$–CH_2–CH.CH_3–]_n$, Polyvinyl Chloride [$–CH_2–CH.Cl–]_n$, Polyvinyl Fluoride [$–CH_2–CH.F–]_n$, Polytetra Fluoroethylene (PTFE) [$–CF_2–CF_2–]_n$, Ethylene tetrafluoroethylene [ETFE] and Polystyrene.

2.5.3.2 Thermosetting plastics

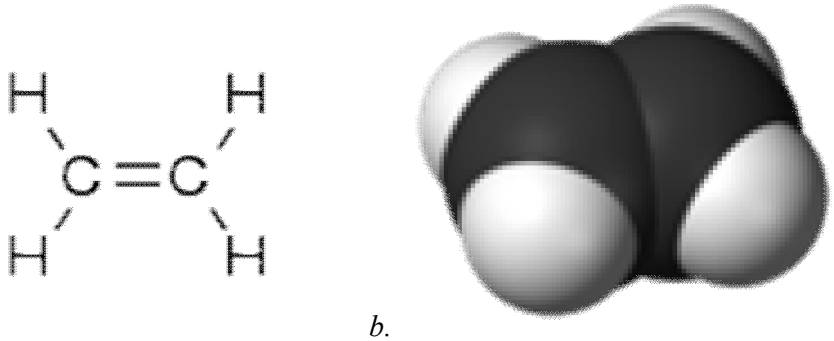
Thermosetting plastics consist of chain molecules that chemically bond, or cross-link, with each other when heated. When thermosetting plastics cross-link, the molecules create a permanent, three-dimensional network that can be considered one giant molecule. Thermosetting plastics cannot be re-melted in the same way that cured concrete cannot be reset. Consequently, thermosetting plastics are often used to make heat-resistant products because these plastics can be heated to temperatures of 260° C (500° F) without melting. For example, the epoxy polymer used in making a fibre-reinforced laminate for a golf club undergoes a cross-linking reaction when it is molded at a high temperature. Subsequent application of heat does not soften the material to the point where it can be reworked and indeed may serve only to break it down.

2.6 POLYETHYLENE

Polyethylene (PE) is a polymer consisting of long chains of the monomer ethylene (IUPAC name ethene). The recommended scientific name polyethene is systematically derived from the scientific name of the monomer (Kahovec *et al*, 2002). It is a water-repellent, white, tough, leathery, thermoplastic resin very similar in appearance to paraffin wax. Properties vary from a viscous liquid at low molecular weights to a hard waxlike substance at high molecular weights.

The basic building blocks for polyethylenes are hydrogen and carbon atoms. These atoms are combined to form the ethylene monomer, C_2H_4, i.e., two carbon atoms and four hydrogen atoms (Figures 2.2*a and b*). In the polymerization process, the double bond connecting the carbon atoms is broken. Under the right conditions, these

bonds reform with other ethylene molecules to form long molecular chains (Figure 2.3).



a. *b.*

Figure 2.2: Ethylene monomer showing the double bond (a) and a 3D model (b).

In general, the advantages gained with polyethylene are light weight, outstanding chemical resistance, good toughness, excellent dielectric properties, and relatively low cost compared to other plastics. The basic properties of polyethylene can be modified with a broad range of fillers, reinforcements, and chemical modifiers, such as thermal stabilizers, colorants, flame retardants, and blowing agents.

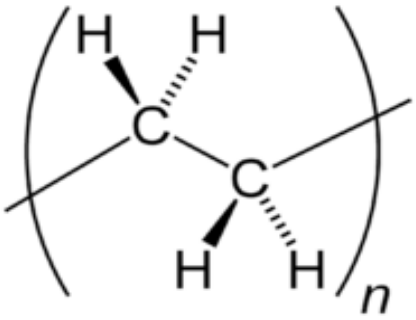


Figure 2.3: The repeating unit of polyethylene, showing its stereochemistry.

Further, polyethylenes are considered to be very easy to process by such means as injection molding, sheet extrusion, film extrusion, extrusion coating, wire and cable

extrusion coating, blow molding, rotational molding, fiber extrusion, pipe and tubing extrusion, and powder coating (Schwartz, 2002). Major application areas for polyethylenes are packaging, industrial containers, automotive, materials handling, consumer products, medical products, wire and cable insulation, furniture, housewares, toys, and novelties (Taylor, 2002).

2.6.1 Properties of Polyethylene

TABLE 2.1; Properties of Polyethylene

ASTM Test	Property	Low Density	Medium Density	High Density	Ultrahigh Molecular Weight
			Physical		
D792	Specific gravity	0.910–0.925	0.926–0.940	0.941–0.965	0.928–0.941
D792	Specific volume ($in.^3$/lb)	30.4–29.9	29.9–29.4	29.4–28.7	29.4
D570	Water absorption, 24 h, 1/8-in. thk (%)	0.01	0.01	0.01	0.01
			Mechanical		
D638	Tensile strength (psi)	600–2,300	1,200–3,500	3,100–5,500	4,000–6,000
D638	Elongation (%)	90–800	50–600	20–1,000	200–500
D638	Tensile modulus (10^5 psi)	0.14–0.38	0.25–0.55	0.6–1.8	0.20–1.10
D790	Flexural modulus (10^5 psi)	0.08–0.60	0.60–1.15	1.0–2.0	1.0–1.7
D256	Impact strength, Izod (ft-lb/in. of notch)	No break	0.5–16	0.5–20	No break
D785	Hardness, Rockwell R	10	15	65	67
			Thermal		
C177	Thermal conductivity (10^{-4} cal-cm/s-cm^2-°C)	8.0	8.0–10.0	11.0–12.4	11.0
D696	Coefficient of thermal expansion (10^{-5}in./in.–°F)	5.6–12.2	7.8–8.9	6.1–7.2	7.8
D648	Deflection temperature (°F)				
	At 264 psi	90–105	105–120	110–130	118
	At 66 psi	100–121	120–165	140–190	170
			Electrical		
D149	Dielectric strength (V/mil)				
	Short time, 1/8-in. thk	460–700	460–650	450–500	900[a]
D150	Dielectric constant				
	At 1 kHz	0.0002	0.0002	0.0003	0.0002
D257	Volume resistivity (□-cm)				
	At 73°F, 50% RH	10^{15}	10^{15}	10^{15}	10^{18}
D495	Arc resistance(s)	135–160	2,000–235	—	
			Optical		
	Refractive index	1.51	1.52	1.54	—
	Transmittance (%)	4–50	4–50	10–50	—

[a] kV/cm.

Source: Schwartz, 2002

2.6.2 Classification and Uses of Polyethylene

Polyethylene is classified into several different categories based mostly on its density and branching. The mechanical properties of PE depend significantly on variables such as the extent and type of branching, the crystal structure and the molecular weight.

2.6.2.1 Ultra High Molecular Weight Polyethylene (UHMWPE)

UHMWPE is polyethylene with a molecular weight numbering in the millions, usually between 3.1 and 5.67 million (Schwartz, 2002). The high molecular weight makes it a very tough material, but results in less efficient packing of the chains into the crystal structure as evidenced by densities of less than high density polyethylene (for example, 0.930–0.935 g/cm^3). UHMWPE can be made through any catalyst technology, although Ziegler catalysts are most common. Because of its outstanding toughness and its cut, wear and excellent chemical resistance, UHMWPE is used in a diverse range of applications. These include can and bottle handling machine parts, moving parts on weaving machines, bearings, gears, artificial joints, edge protection on ice rinks and butchers' chopping boards. It competes with Aramid in bulletproof vests, under the tradenames Spectra and Dyneema, and is commonly used for the construction of articular portions of implants used for hip and knee replacements (Schwartz, 2002).

2.6.2.2 High Density Polyethylene (HDPE)

HDPE is defined by a density of greater or equal to 0.941 g/cm^3 (Schwartz, 2002). HDPE has a low degree of branching and thus stronger intermolecular forces and tensile strength. HDPE can be produced by chromium/silica catalysts, Ziegler-Natta catalysts or metallocene catalysts. The lack of branching is ensured by an

appropriate choice of catalyst (for example, chromium catalysts or Ziegler-Natta catalysts) and reaction conditions. HDPE is used in products and packaging such as milk jugs, detergent bottles, margarine tubs, garbage containers and water pipes.

2.6.2.3 Cross Linked Polyethylene (PEX)

PEX is a medium- to high-density polyethylene containing cross-link bonds introduced into the polymer structure, changing the thermoplast into an elastomer. The high-temperature properties of the polymer are improved, its flow is reduced and its chemical resistance is enhanced (Schwartz, 2002). PEX is used in some potable-water plumbing systems because tubes made of the material can be expanded to fit over a metal nipple and it will slowly return to its original shape, forming a permanent, water-tight, connection.

2.6.2.4 Medium Density Polyethylene (MDPE)

MDPE is defined by a density range of 0.926–0.940 g/cm^3 (Schwartz, 2002). MDPE can be produced by chromium/silica catalysts, Ziegler-Natta catalysts or metallocene catalysts. MDPE has good shock and drop resistance properties. It also is less notch sensitive than HDPE, stress cracking resistance is better than HDPE. MDPE is typically used in gas pipes and fittings, sacks, shrink film, packaging film, carrier bags and screw closures.

2.6.2.5 Linear Low Density Polyethylene (LLDPE)

LLDPE is defined by a density range of 0.915–0.925 g/cm^3 (Schwartz, 2002). LLDPE is a substantially linear polymer with significant numbers of short branches, commonly made by copolymerization of ethylene with short-chain alpha-olefins (for example, 1-butene, 1-hexene and 1-octene). LLDPE has higher tensile strength than LDPE, it exhibits higher impact and puncture resistance than LDPE. Lower thickness (gauge) films can be blown, compared with LDPE, with better environmental stress cracking resistance but is not as easy to process. LLDPE is used in packaging, particularly film for bags and sheets. Lower thickness may be used compared to LDPE. Cable coverings, toys, lids, buckets, containers and pipe. While other applications are available, LLDPE is used predominantly in film applications due to its toughness, flexibility and relative transparency (Schwartz, 2002). Major uses at present are grocery bags, industrial trash bags, liners, and heavy-duty shipping bags for such products as plastic resin pellets (Schwartz, 2002).

2.6.2.6 Low Density Polyethylene (LDPE)

LDPE is defined by a density range of 0.910–0.940 g/cm^3 (Schwartz, 2002). LDPE has a high degree of short and long chain branching, which means that the chains do not pack into the crystal structure as well. It has, therefore, less strong intermolecular forces as the instantaneous-dipole induced-dipole attraction is less. This results in a lower tensile strength and increased ductility. LDPE is created by free radical polymerization. The high degree of branching with long chains gives molten LDPE unique and desirable flow properties.

About half of LDPE production goes into packaging applications such as industrial bags, shrink bundling, soft goods, and produce and garment bags. Other applications include blow-molded containers and toys, hot-melt adhesives, injection-molded housewares, paperboard coatings, and wire insulation.

2.6.2.7 Very Low Density Polyethylene (VLDPE)

VLDPE is defined by a density range of 0.880–0.915 g/cm^3 (Schwartz, 2002). VLDPE is a substantially linear polymer with high levels of short-chain branches, commonly made by copolymerization of ethylene with short-chain alpha-olefins (for example, 1-butene, 1-hexene and 1-octene). VLDPE is most commonly produced using metallocene catalysts due to the greater co-monomer incorporation exhibited by these catalysts. VLDPEs are used for hose and tubing, ice and frozen food bags, food packaging and stretch wrap as well as impact modifiers when blended with other polymers (Schwartz, 2002).

CHAPTER 3

MATERIALS AND METHODS

3.1 MATERIALS AND PROCESSES

The materials used for this research were procured from the same source. The rice straw used for the production of the fibreboard were collected from farms around Samaru Village, while the waste packaged water sachet (LDPE) used were produced by ABUCONS table water factory A.B.U. Zaria and gathered from within the school premises.

The experimental works were carried out in the concrete laboratory of the Department of Building; physical and polymer laboratory of the Department of Chemistry and the strength of material test laboratory of the Department of Mechanical Engineering of A.B.U. Zaria.

The following steps were followed in the production of the fibreboard;

i. Chipping of rice straw
ii. Washing of rice straw
iii. Soaking of rice straw
iv. Cooking of rice straw
v. Felting of rice straw
vi. Drying of rice straw
vii. Washing of polymer material
viii. Shredding and sieving of polymer material
ix. Blending
x. Mat formation

xi. Pressing

xii. Trimming and Conditioning

3.1.1 Chipping, Washing, and Soaking

The process of the manufacture of the board starts with the cutting of the rice straw into chips. This was done manually with the aid of cutlass to reduce the size of the chips to 1cm to 4cm length (Plate IV), so as to ease the handling of material (Apeh, 1999).

The chipped straw is then soaked in clean water for about 20 minutes to remove suspended materials, impurities and debris that settles at the bottom of the container. Then it was later washed. After which the straw was soaked for 48 hours in clean water to soften the material so as to enhance ease and reduce time of cooking.



Plate IV**:** Chipping of rice straw

3.1.2 Cooking, Felting and Drying

After the 48 hours soaking exercise, the soaked material is then drained of the water. The materials were then cooked for 1 – 2 hours. The cooking was done in a 'half cut' drum containing some quantity of water using firewood (Plate V). Fresh water was poured into the drum and allowed to reach boiling point (between 80^{o}C - 100^{o}C) before the material was introduced into it. The essence of the cooking process is to further soften the material, and to enhance complete mechanical disintegration of the material (Zubairu, 1989).



Plate V: Cooking of rice straw

After the cooking exercise, the next process is the felting of the material. This is the process of turning the straw material into fibre bundles. Commercially it is done

mechanically with the aid of defibrator disc or hammer milling, but for the purpose of this work, pestle and mortar were employed. The content of the cooking container was first drained of excess hot water with the aid of sieve. The straw material was then pounded immediately until it disintegrates into fibre strands (Plate VI).

The soaking and cooking exercise have increased the moisture content of the material to over 100 percent. The fibre need to be taken to a residual moisture content of less than 20 percent as recommended by the standard (BS EN 622-1: 2003) for the production of dry process fibreboard. Therefore the fibres were spread on a sack and allowed to dry in open air (Plate VII).



Plate VI: Defibration or felting of rice straw



Plate VII: Drying of rice straw fibres

3.1.3 Washing, Shredding and Sieving of Polymer Material

As was stated before, for the purpose of this research work, Low Density Polyethylene (LDPE) from sachet water package will be used as the binder because of their usage as hot melt adhesives (Schwartz, 2002). The polymer material was first washed with little detergent to remove debris from it. Then it was open air dried for about 4 hours.

The polymer upon drying, were shredded to finer particle. A Dae Heung Gae mechanical plastic crusher was used for the crushing of the material (Plate VIII). The essence of the shredding is to have a good mix between the composite materials during the mat formation process.

After the shredding the material was observed to have particles with sizes that will not be conducive for the mixes, therefore it was sieved. Those materials passing 4mm sieve size were used for the research work (Plate IX).



Plate VIII: Plastic crushing machine.



Plate IX: Shredded Plastic Material from LDPE.

3.1.4 Blending of Material

Blending of the shredded polyethylene and the rice straw was done manually and in dry condition, since the dry process method of board production was to be employed. Since a pre targeted density is aimed at (base on the stipulated density range by the standards), the blended materials were weighed with the density in mind. The formula for calculating density was used to determine the mass of material required to achieve the targeted density. Thus;

$$\rho = \frac{m}{v}$$

Where; **ρ** = density in kg/m^3

m = mass in kg

v = volume in m^3

The density here is the targeted density which is placed at 800kg/m^3 (density of MDF is ≥600kg/m^3 [BS EN 7916: 1998]), the volume is that of the mould that was

used for the pressing. The mass that was arrived at is the mass required to give the targeted density and 10 percent of the mass was added to take care of losses during mat formation and pressing.

A digital scale was used to weigh the material (Plate X). A replacement level of 20, 30, 40 and 50 percents of the polymer material to the total weight of the composite was used; this was reached at through trial mixes. The weighed composite were placed in an open bowl and were agitated thoroughly using manual method. This was necessary so as to achieve a uniform blend of the materials. The whole process was carried out manually.



Plate X: weighing of materials with digital scale before blending

3.1.5 Mat Formation

The forming mould was produced in the Mechanical Engineering workshop. It consists of a hollow steel box (200 mm x 200 mm x 6 mm in/in) and two steel plates (220mm x 220 mm). To produce the mat, one of the steel plates was positioned on a horizontal surface. A sheet of aluminium foil was then placed on the steel plate after being rubbed with engine oil (to act as non-stick surface), then the steel box was placed on it. The blended materials were placed inside in an even pattern. The composite was compacted lightly, then another oiled aluminium foil was placed on top of the arrangement and the second steel plate was placed on top of the foil ready for pressing.

3.1.6 Pressing

The press used for this research is a hydraulic pressing machine manufactured by Moore Company, England and belonging to the Department of Chemistry A.B.U. Zaria (Plate XI). The machine is fitted with a temperature and pressure indicating devices and a timer. The machine has the following specification;

Temperature limit – 0 – 200^{o} C

Maximum Pressure – 4.905 N/mm^{2}

Voltage - 220 – 240v @ 50Hz

Plate size - 200 mm x 200 mm

The pressing process is of two stages; pre-pressing and final pressing.

In the pre-pressing, the machine heating plates were set to a temperature gauge of 170^{o} C before the mat was introduced and pressed to a pressure of 1.0 N/mm^{2} which is lower than the pressure required for the final pressing. The pressed mat was allowed to stay at this temperature and pressure for two minute after which the pressure was

released. This pre-pressing was necessary in order to release trapped gasses and the remaining moisture that has turned into steam to escape.

In the final pressing, the pressure is raised to the required gauge of 1.4 N/mm^2 and the temperature at 170^o C. The heat is necessary so as to melt the polymer material and allow it to flow into the fibres and bind them together. The pressed mat was left in the press at the same temperature and pressure for another 8 minutes before it was removed and allowed to cool off in the mould, after which it is removed from the mould, trimmed (Plate XII) and ready for conditioning.

3.1.8 Conditioning

The boards produced were conditioned to constant mass in an atmosphere with a mean relative humidity of (65 ± 5) % and a temperature of (20 ± 2) ℃. Constant mass was considered reached when the results of two successive weighing operations, carried out at an interval of 24 h, do not differ by more than 0.1 % of the mass of the samples produced (BS EN 382-1). This was achieved after a week of conditioning. The essence of this exercise is to equalize the moisture content of the board and thus minimize warping that might otherwise occur (Zubair, 1989).



Plate XI: MOORE's hydraulic pressing machine (Chemistry Department, A.B.U. Zaria)



a



b

Plate XII: Samples of board produced *(a)* before and *(b)* after trimming.

3.1.9 Process Flowchart

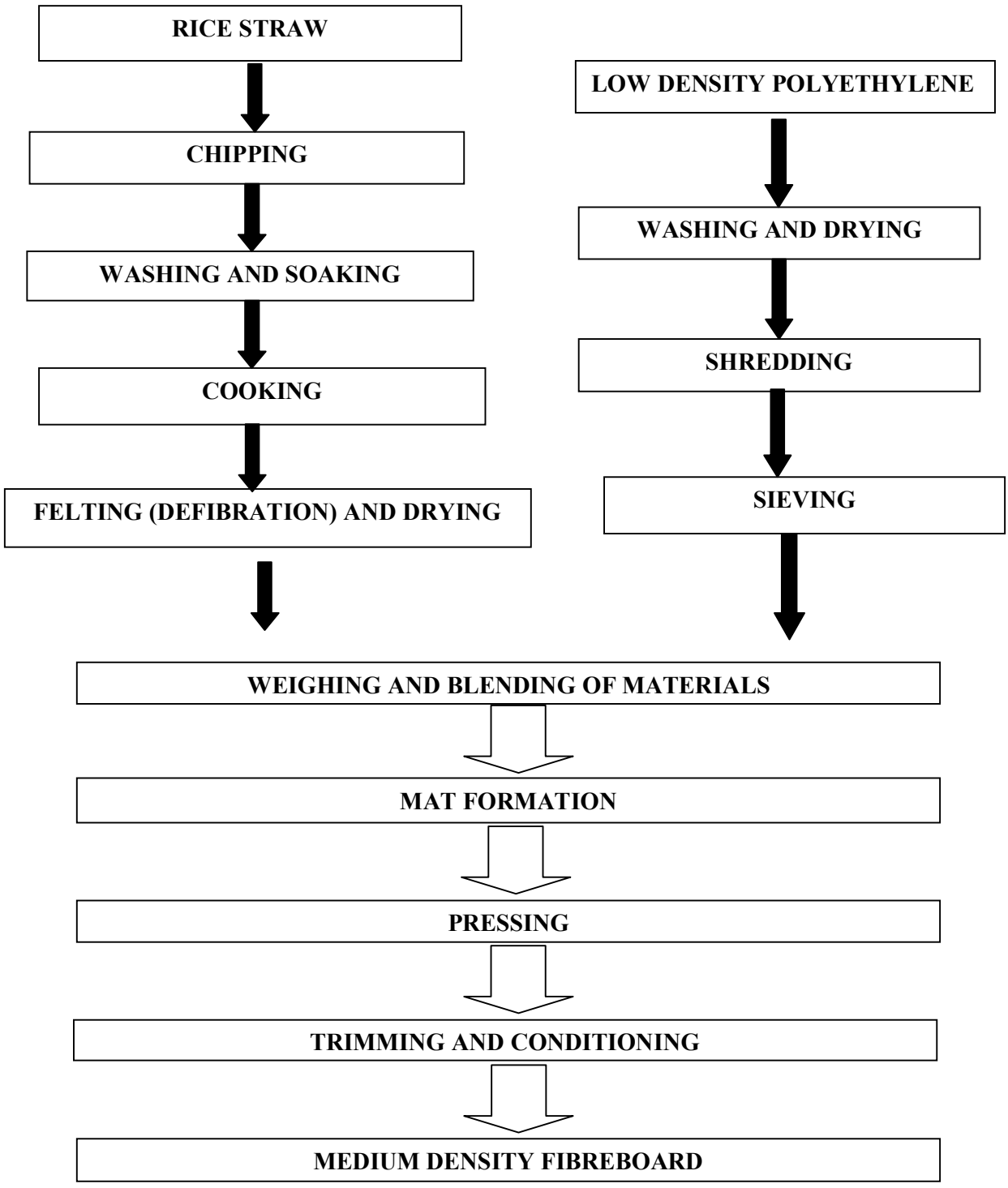


Figure 3.1: Flow chart of the laboratory production of rice straw Fibreboard.

3.2 TEST OF SPECIMEN

For the boards produced to be certified for use as an engineering material, it has to be subjected to certain test, so as to give a concise evaluation of its physical and mechanical properties. Such tests that were conducted are generally destructive in nature.

The tests and its procedure are briefly described below. The fibreboard samples produced are sawn into test specimens as described in BS EN 324: 1993 and BS EN 325: 1993 for each test that was conducted. The tests conducted are in accordance with the relevant standards which were enumerated in the relevant sections.

3.2.1 Determination of Density

The test was conducted as described in BS EN 323: 1993 which covers the determination of density of wood based panels. The dimensions of the samples were taken at four different positions and the average of the measurements was considered to be the dimension of the specimen. The measurement was carried out with a caliper. Each test specimen was weighed to an accuracy of ±0.01gm with the aid of digital weighing machine. The volume of the specimen was calculated to the nearest 100cm^3 as stipulated by the standards.

The average density of each specimen was calculated to the nearest 10 kg/m^3, thus;

$$\rho = \frac{m}{v}$$

Where; **ρ** = density in kg/m^3

m = mass in kg of the test sample

v = volume in m^3 of the test sample

The test results are presented in Appendix 1 since all the samples fall within the predetermined density.

3.2.2 Bending Strength (Modulus of Rupture) and Bending Stiffness (MOE in Bending) Test

These tests were carried out according to the provisions in BS EN 310: 1993. Three specimens of 170mm x 50mm x 6mm from each sample group were tested on rollers of 100mm x 12mm diameter. The rollers were spaced at a distance 20 times the thickness of specimen and an increasing load was applied through a third roller at the centre of the span using the Enerpac Universal material testing machine (Figure 3.2 and Plate XIII). The results were obtained using the following formula given by the standards (BS EN 310:1993 and ASTM D1037: 1999) for bending strength as;

$$R = \frac{3PL}{2bt^2}$$

Where, R = Bending strength in N/mm^2

P = Load at rupture in Newton (N)

L = Length of span (distance between support), in millimetres (mm).

b = width of the test specimen in millimetres (mm).

t = thickness (depth) of specimen in millimetres (mm).

The modulus of elasticity is calculated from the deflection noted when the applied load has reached approximately one third of the failing load as read from a dial

gauge attached to the apparatus (Plate XIII). The following formula is used to calculate the Modulus of Elasticity in Bending;

$$\mathbf{E} = \frac{P_1 L^3}{4bd^3 y_1}$$

Where, E = Modulus of Elasticity or Bending Stiffness in N/mm^2

P_1 = Load at proportional limit in Newton (N)

L = Length of span (distance between support), in millimetres (mm).

b = width of the test specimen in millimetres (mm).

d = thickness (depth) of specimen in millimetres (mm).

y_1 = center deflection at proportional limit load in millimetres (mm)

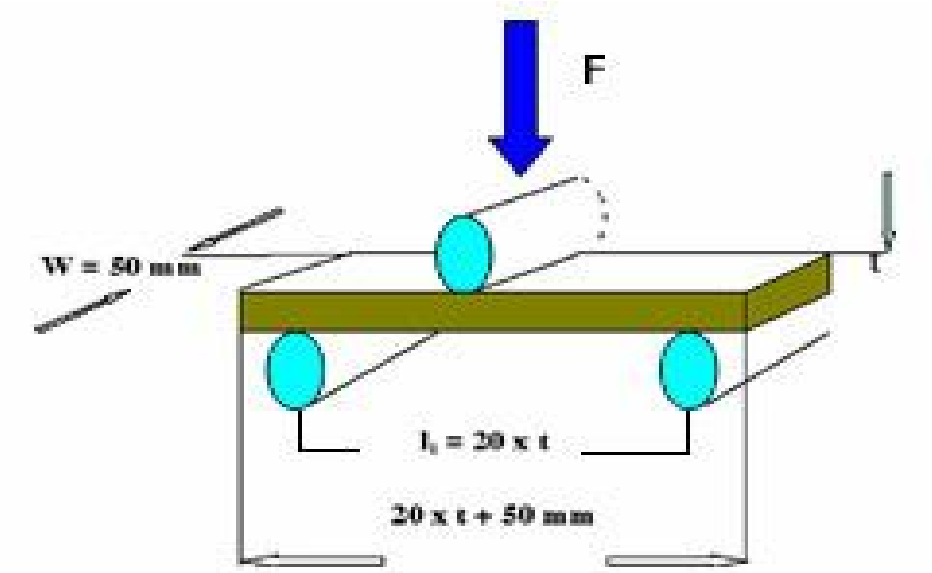


Figure 3.2: Bending Strength test apparatus setup.



Plate XIII: Bending Strength and Stiffness test assembly

3.2.3 Tensile Strength Parallel to Surface Test

The test was conducted according to BS EN 319:1993. Three dumbbell shaped specimen from each sample group were tested for tensile strength with the effective dimension as shown in Figure 3.3 with the reduced section at 38mm x t (mm), and the length at 200mm (Figure 3.3). Each specimen was clamped to the Enerpac Universal Material Testing Machine which has self aligning self tightening serrated gripping surfaces of nominal width of 50mm (see Plate XIV). Load was applied mechanically from the machine.

The tensile strength was calculated using the following formula;

$$T = \frac{P}{A}$$

Where, T = Tensile strength in N/mm^2

P = Maximum Load in Newton (N)

A = Cross sectional area in millimetre Square (mm^2)

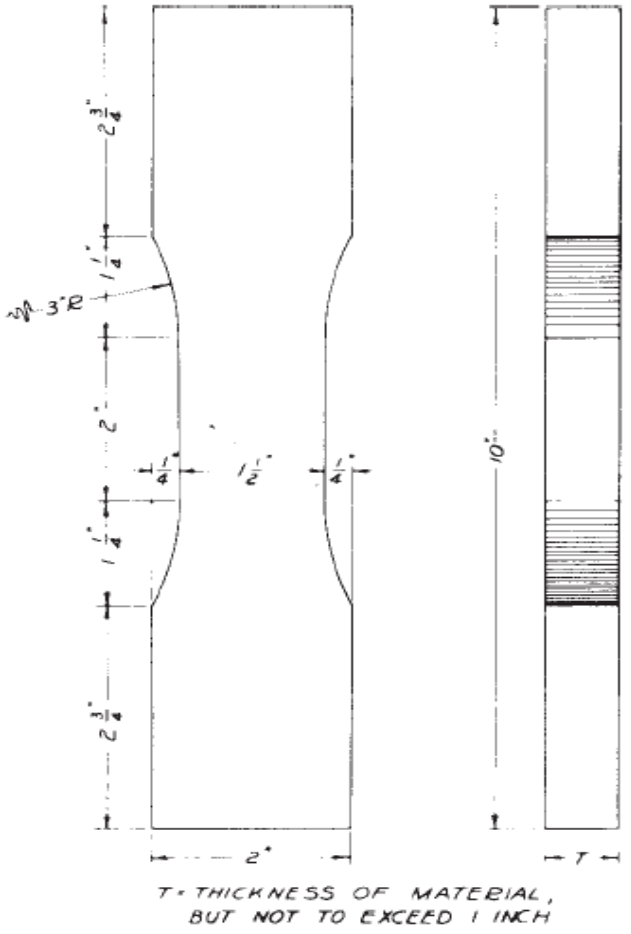


Figure 3.3: Effective dimensions of samples for Tensile Strength test



Plate XIV: Tensile strength parallel to surface test apparatus assembly

3.2.4 Tensile Strength Perpendicular to Surface (Internal Bond) Test

The property was measured by bonding two wood holding blocks on either side of a 50mm x 50mm specimen cut from the board samples with adhesive (BS EN 319: 1993). The prepared test piece is pulled apart in a tensile testing machine (Plate XV). The tensile strength is the force, in N/mm^2, required to split the test piece, failure normally occurring approximately along the centre line of the test piece. The tensile strength perpendicular to surface was calculated using the same formula with tensile strength parallel to the surface as presented above.

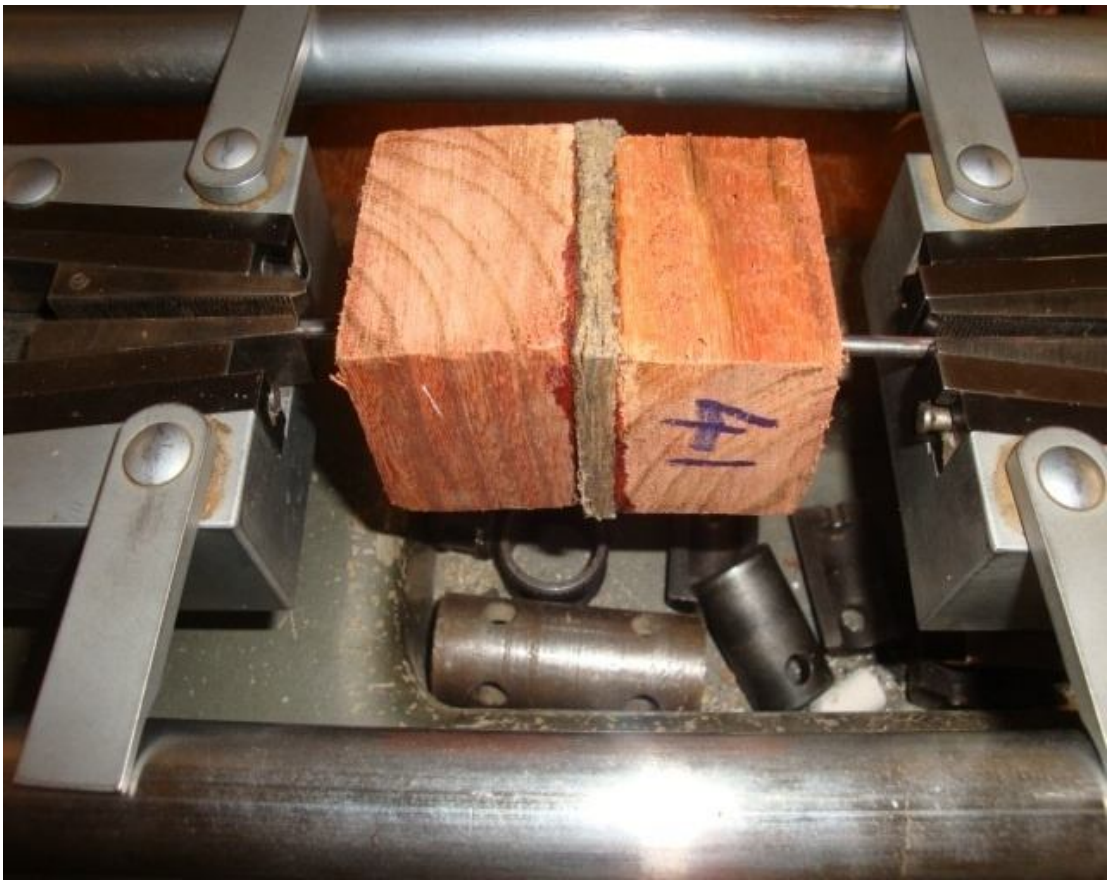


Plate XV: Internal Bond Strength test apparatus assembly

3.2.5 Lateral Nail Resistance Test

The test was conducted as described in ASTM D 1037: 1999. Three specimens from each sample group were tested. The effective dimensions of each specimen were 152mm x 76mm x t (mm). A 2.80mm diameter concrete nail was driven at right angle to the face of the board, such that about an equal length of the nail projects from each face of the board. The nail was centered on the width of the board and located 18mm from the edge. The end of the specimen opposite the end with the nail was clamped to the grips of the tensile testing and a stirrup was used to engage the nail on top (see Plate XVI).



Plate XVI: Nail Resistance test apparatus assembly

3.2.6 Nail Head Pull-Through Test

The test was carried according to provisions in ASTM D1037: 1999. The test was conducted on three specimens from each sample. The effective dimensions of each specimen were 152mm x 76mm x t (mm). A 2.80mm diameter common wire nail was driven at right angle to the face of the board, with the nail head flushed to the surface of the board. The specimen is placed inside a specimen holding fixture such that the tail end of the nail is upward and attached to the upper platen of the Enerpac Universal Material tesying machine. The specimen holding fixture involves four 57mm x 57mm American standard angles of 152mm length that are bolted together in such a way that the top angles are separated 25mm from each other, which provides support to specimen during test. The base of the device was attached to the lower platen of the testing machine. The device and the assembly for the test are as shown in Figure 3.4 and Plate XVII.

3.2.7 Screw withdrawal test

Three specimens from each sample with 76mm width, 100mm length and thickness of 18mm were tested; the thickness was achieved gluing three samples of 6mm thickness. Though Many different types and sizes of screws can be used in Fibreboards, but for the purpose of determining screw holding strengths test according to BS EN 320: 1993 and ASTM D 1037: 1999, 38 mm length, 4.2 mm diameter, parallel shank, steel screws with two start threads with pitch l.4mm were inserted at right angle to the face of the board and at relevant positions, to a depth of 15 mm into predrilled pilot holes in the face and two edges of the test piece. The specimen holding fixture was used to hold the specimen and the resistance to axial withdrawal of these

screws is measured using the Enerpac tensile testing machine (Figure 3.4 and Plate XVII).

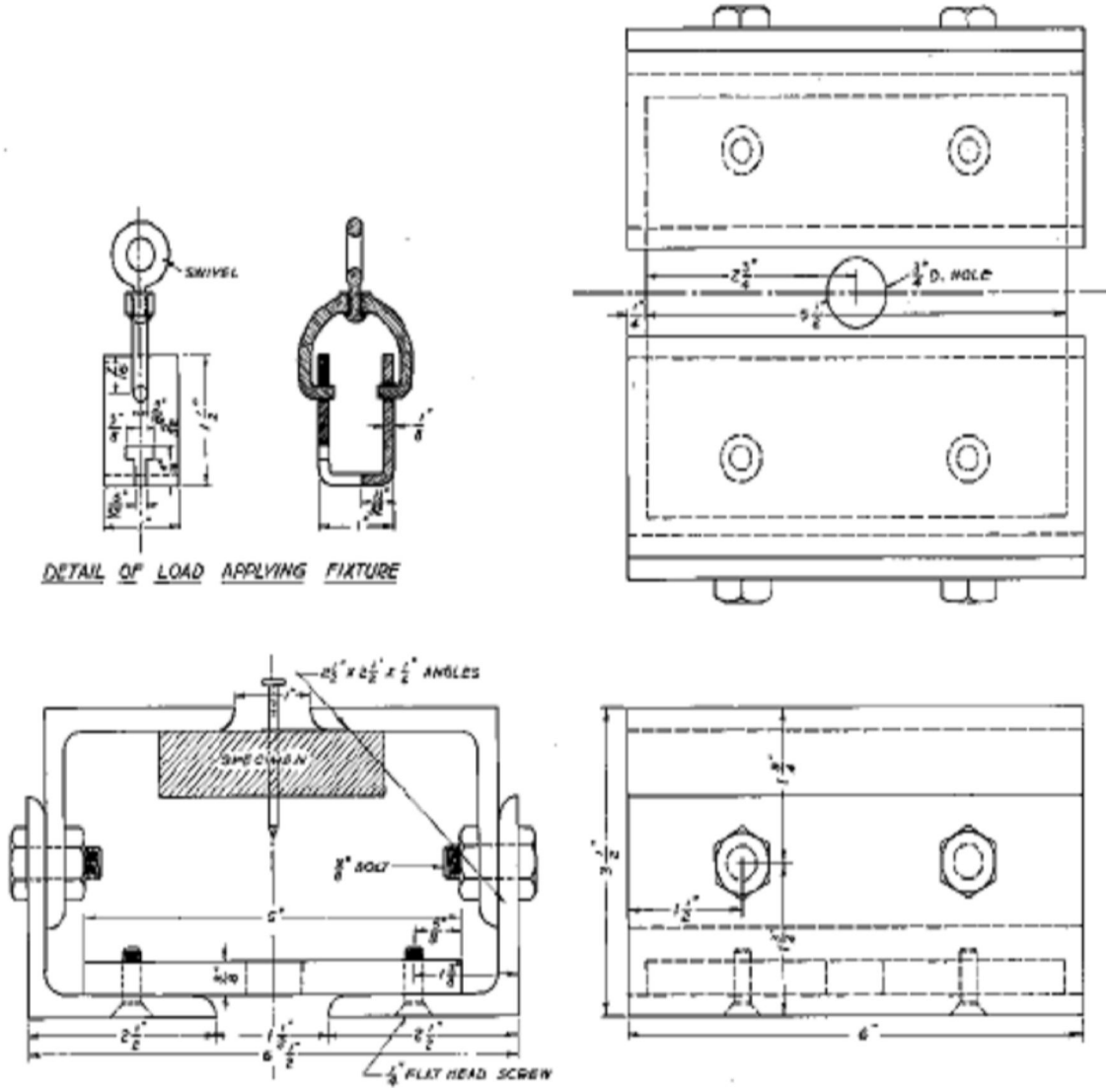


Figure 3.4: Details of Specimen Holding Fixture for Screw and Nail resistance test



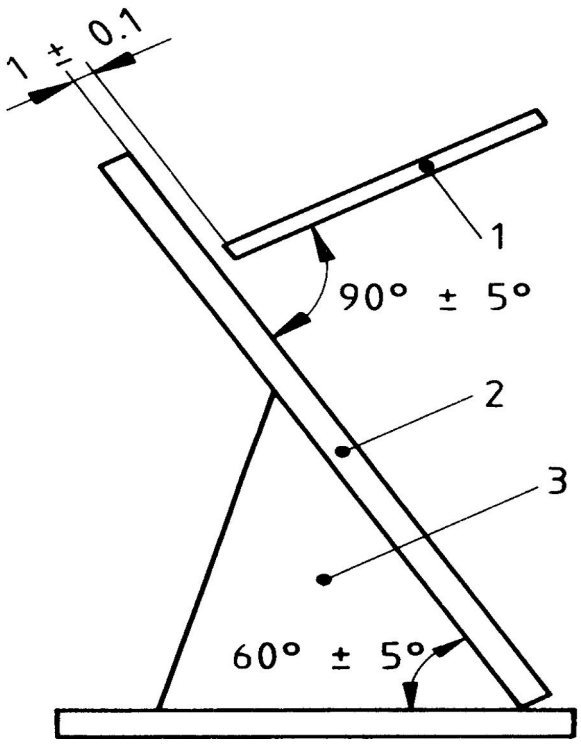
Plate XVII: Screw withdrawal and Nail Head Pull-through test apparatus assembly

3.2.8 Surface Absorption Test

The surface absorption of dry process fibreboards is determined by letting a drop of toluene run down the surface of a test piece and measuring the length of the stain. The test was carried out in a fume cupboard at the department of Chemistry and according to the provision in BS EN 382-1: 1993.

Three test specimens from each sample measuring 200mm x 100mm x t (mm) were used for the test. The test piece was positioned on a metal support inclined at an angle of (60 ± 5)°. A graduated pipette with nominal capacity of 5ml was clamped at an angle of (90 ± 5)° to and at a distance of (1 ± 0,1) mm from the face of the test piece

(see Figure 3.5 and Plate XVIII). 1ml of toluene, having a temperature of (20 ± 2) °C was discharged from the pipette onto the face of the test piece within (4 ± 2) s. the toluene was allowed to run freely down the inclined surface of the test piece. The maximum length of the stain caused by the toluene, along a line parallel to the edges of the test piece was measured.



1 Pipette
2 Test piece
3 Support

Figure 3.5: Surface Absorption test apparatus setup



Plate XVIII: Surface Absorption test apparatus assembly

3.2.9 Swelling in Thickness and Water Absorption Test

Three test specimen of dimension 50mm x 50mm x t (mm) were used for this test (Fig. 3.6). The test pieces were measured to determine their weight with the aid of digital balance with an accuracy of ±0.001g and their thickness with the aid of a Vernier Caliper. The specimen were then immersed in clean and calm water and allowed to soak for a period of 24 hours (see Plate XIX). After which the specimen were removed and the excess water was wiped away with a clean damp cloth.

The test pieces were measured for the second time to determine their weight and thickness using the same apparatus. The water absorption of the specimen was determined using the following formula;

$$A = \frac{M_2 - M_1}{M_1} \, x \, 100$$

Where, A = Water absorption (Percent)

M_1 = Mass of test specimen before immersion in water in gram (g)

M_2 = Mass of test specimen after immersion in water in gram (g).

The swelling in thickness was also determined using the following formula;

$$G = \frac{T_2 - T_1}{T_1} \, x \, 100$$

Where, G = Swelling in thickness (Percent)

T_1 = Thickness of test specimen before immersion in water (mm)

T_2 = Thickness of test specimen after immersion in water (mm)

The test was conducted according to the provision in BS EN 317: 1993

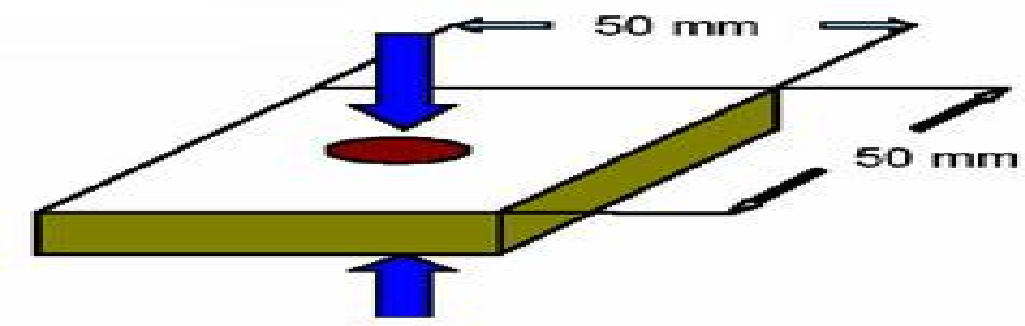


Figure 3.6: Swelling in Thickness and Moisture Absorption sample details



Plate XIX: Samples for Swelling in Thickness and Water Absorption test, water soaked for 24 hours

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 PREAMBLE

The results presented in this chapter are based on the tests carried out on experimental board samples produced from Rice Straw and utilizing Low Density Polyethylene from sachet water container as binder and filler material. The results obtained are compared with the standard values set for such boards as contained mostly in British Standards; BS EN 622, part 5, 1997 [for dry process or Medium Density Fibreboards (MDF)], and other standards which are acknowledged accordingly.

4.2 BENDING STRENGTH AND BENDING STIFFNESS

Figure 4.1 illustrates the result of the bending strength test conducted on the samples. It can be deduced that there is no consistent relationship between the ratio of the Polymer material present in the sample and the bending strength of the board sample.

The strength values obtained ranges from 20 N/mm^2 for boards with 20% polymer material, to 42 N/mm^2 for boards with 30% polymer material which is the highest value obtained. Boards with 40% and 50% polymer as binder have 34 N/mm^2 and 27 N/mm^2. Of all the values obtained only those with 20% polymer as binder are below the minimum values set by the Standard for boards of similar thickness (i.e. between 4mm – 6mm) which ranges from 23 N/mm^2 to 34 N/mm^2 depending on the area of application of the board (BS EN 622-5: 2003; Table 2-5). This was anticipated because researches carried out utilizing polyethylene and other matrix in the production of composite material starts with polyethylene at 30% replacement levels. For example,

Brent (1992) combines Western Juniper with 35% polyethylene; 25% LDPE from garbage bags and 10% fiberised HDPE as matrix.

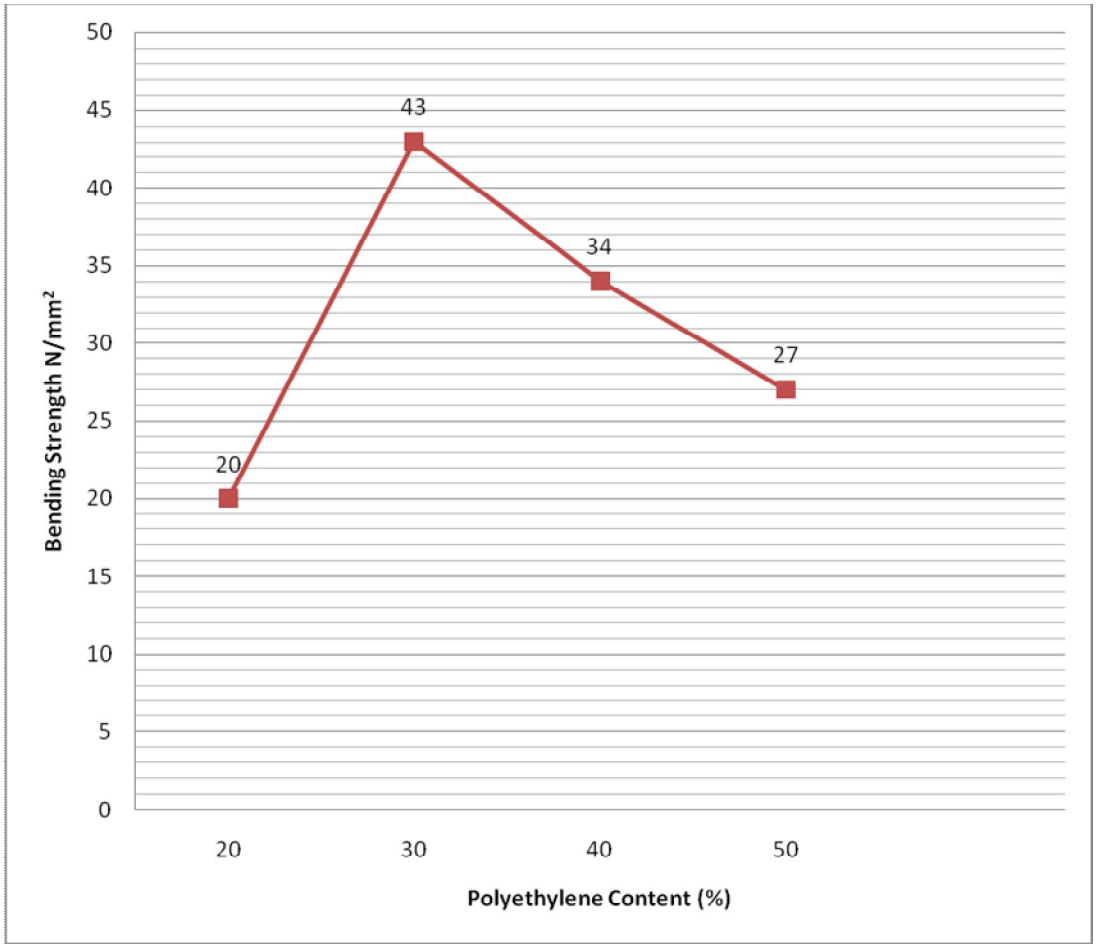


Figure 4.1: Effects of polyethylene content on bending strength of board

For the bending stiffness or modulus of elasticity in bending the trend is the same with the Bending Strength test result (Appendix IV and Figure 4.2), the only difference is that the results obtained are rather very low and did not meet the minimum requirement set out by BS EN 622-5: 2003 which is set at 2700N/mm^2, this may be because only LDPE (a flexible thermoplastic material) was used as the binder without the addition of other additives and the commercial ones uses Epoxy resin called

polyurethane (a strong Thermosets) as binder. This doesn't mean that this board samples cannot be applied in such areas where Bending Stiffness is a Prerequisite; all it means is that the material should be properly reinforced where necessary before application.

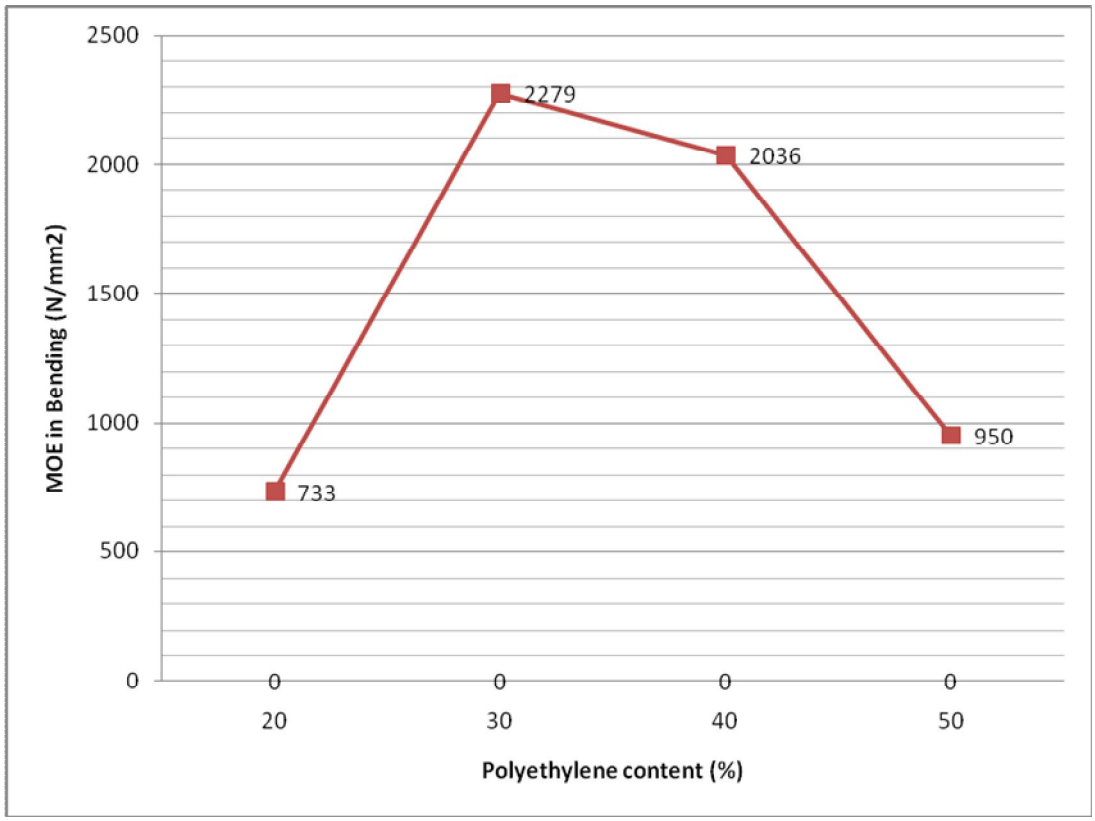


Figure 4.2; Modulus of elasticity in bending of board sample as affected by polymer content

4.8 TENSILE STRENGTH

Results from the test on tensile strength perpendicular to the surface of the board or the Internal Bond Strength properties of the board tends to show a good relationship between the polymer content present in the sample and the internal bond strength of the board.

The internal bond strength values for the samples tested shows that there is a linear increase value from 1.07 N/mm^2 for boards with 20% polymer to 3.07 N/mm^2 for boards with 50% polymer content (Fig. 4.3). The minimum values specified for Medium Density Fibreboard with the same thickness as the samples produced is between 0.63 N/mm^2 for general purpose board, to 0.70 N/mm^2 for boards to be used in extreme conditions as indicated in the standard (BS EN 622-5: 2003; Table 2-5). This means that the values of the test samples produced are above the minimum requirement set out by the standard, even for extreme conditions.

This test which, perhaps more than any other, characterizes Medium Density Fibreboard for interior application is widely used for quality control purposes. A high Internal Bond Strength is an important requirement of MDF to be used for most furniture and fitment applications, but particularly for those applications involving edge fixing and the jointing of panels with mechanical fittings (e.g. door panels).

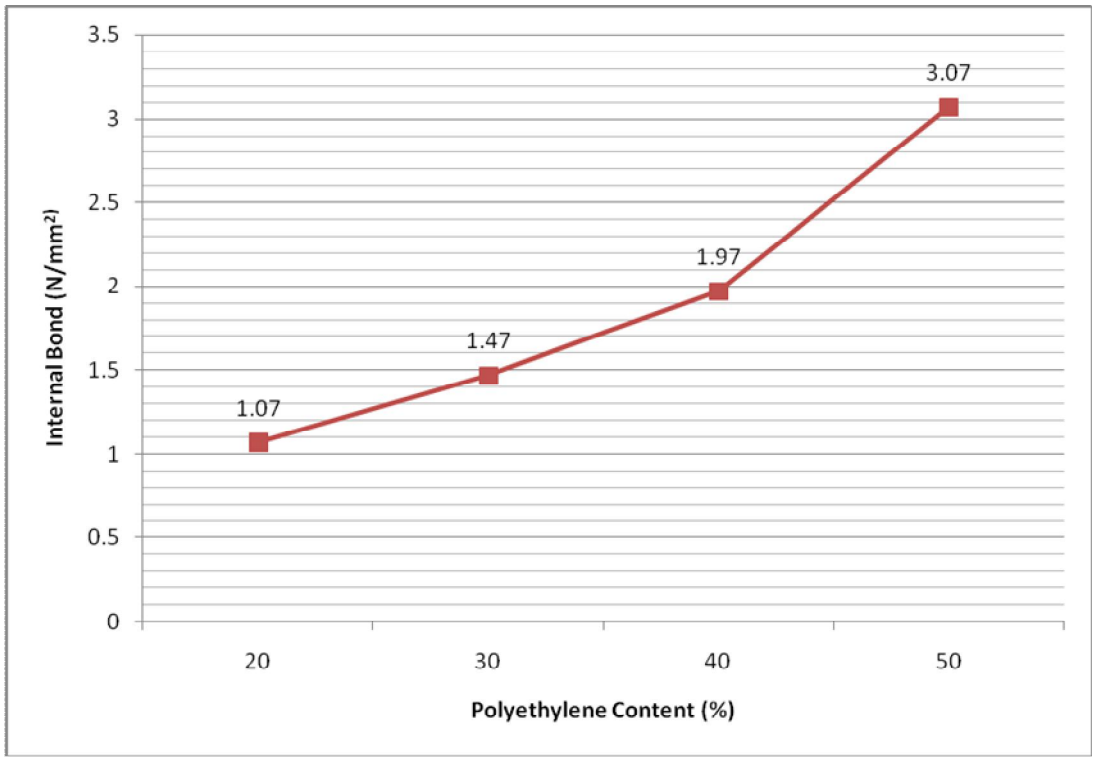


Figure 4.3: Internal bond strength as affected by polyethylene content

The tensile strength parallel to the surface of the board from the test results of the samples shows that there is increase in the tensile strength with increase in the amount of polyethylene used (Fig. 4.4). This properties of the board has no definite standard to compare with, this may be because the material is not expected to be subjected to tensile strength parallel to its surface during application.

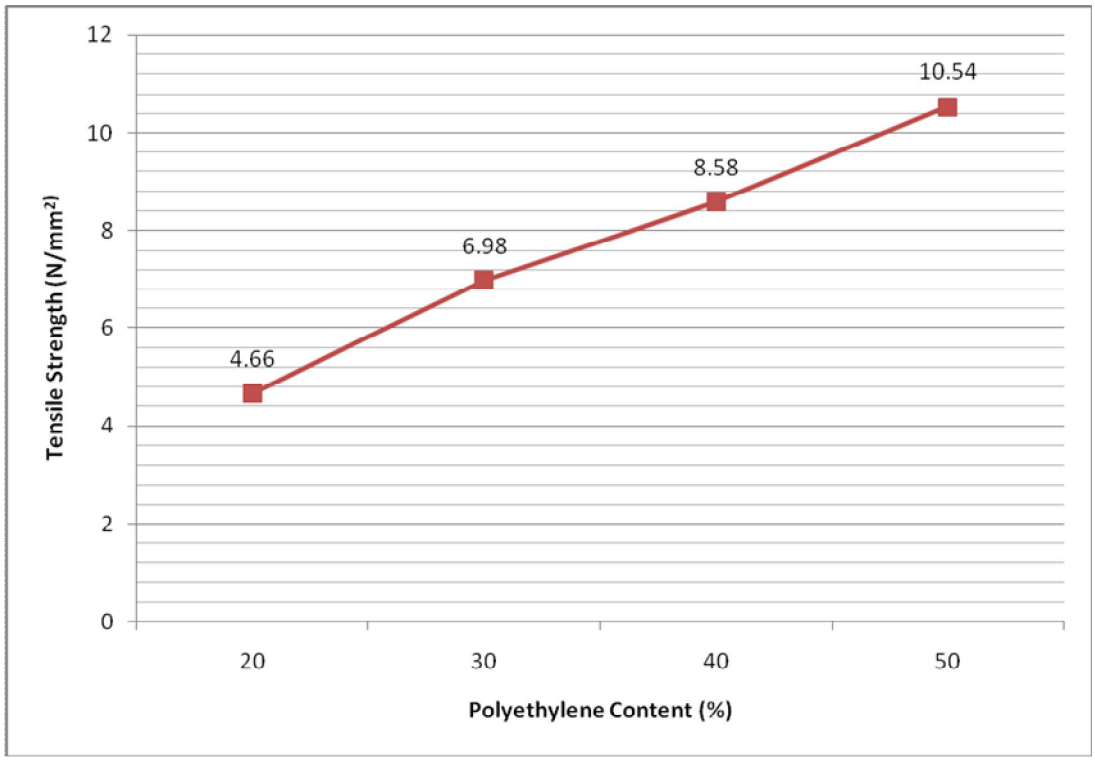


Figure 4.4: Effect of polyethylene content on tensile strength parallel to surface of board

4.4 SCREW WITHDRAWAL

Figure 4.5 shows the result of the test on the screw holding properties of the board samples produced. It can be deduced that there is a consistent relationship between the screw holding properties and the amount of polymer that is present in the board sample.

The screw holding properties of the board increases from 720 N/mm^2 for boards with 20% polymer to 1220 N/mm^2 for boards with 50% polymer as binder. The standard stipulates that a screw holding capacity requirement of 1000N in the face of the board is of particular importance to furniture and fitment manufacturers. This makes the values obtained to be above the minimum requirement set out by the standard, with the exception of those with 20% polymer content which are below the requirement.

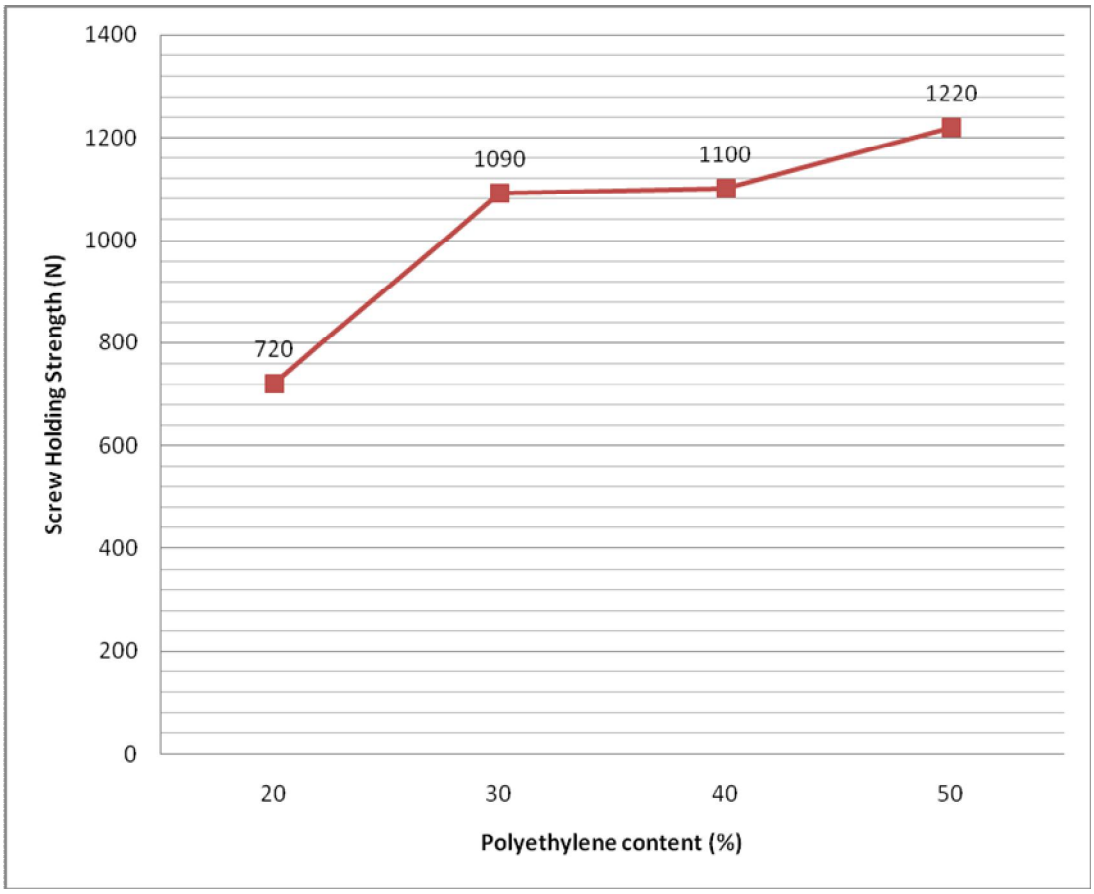


Figure 4.5: Effect of polyethylene content on screw holding properties of board sample

4.5 NAIL RESISTANCE

Figure 4.6 shows the relationship of the lateral nail resistance test result conducted on the board samples produced. The results shows some similarities to that of screw holding properties, that it increases with an increase in the amount of polymer present in the board samples tested.

The relationship is similar with the nail head pull through test conducted. But since at present there is no standard with which to compare the relationships with for the both test conducted, the relationships will be as illustrated in Figure 4.6.

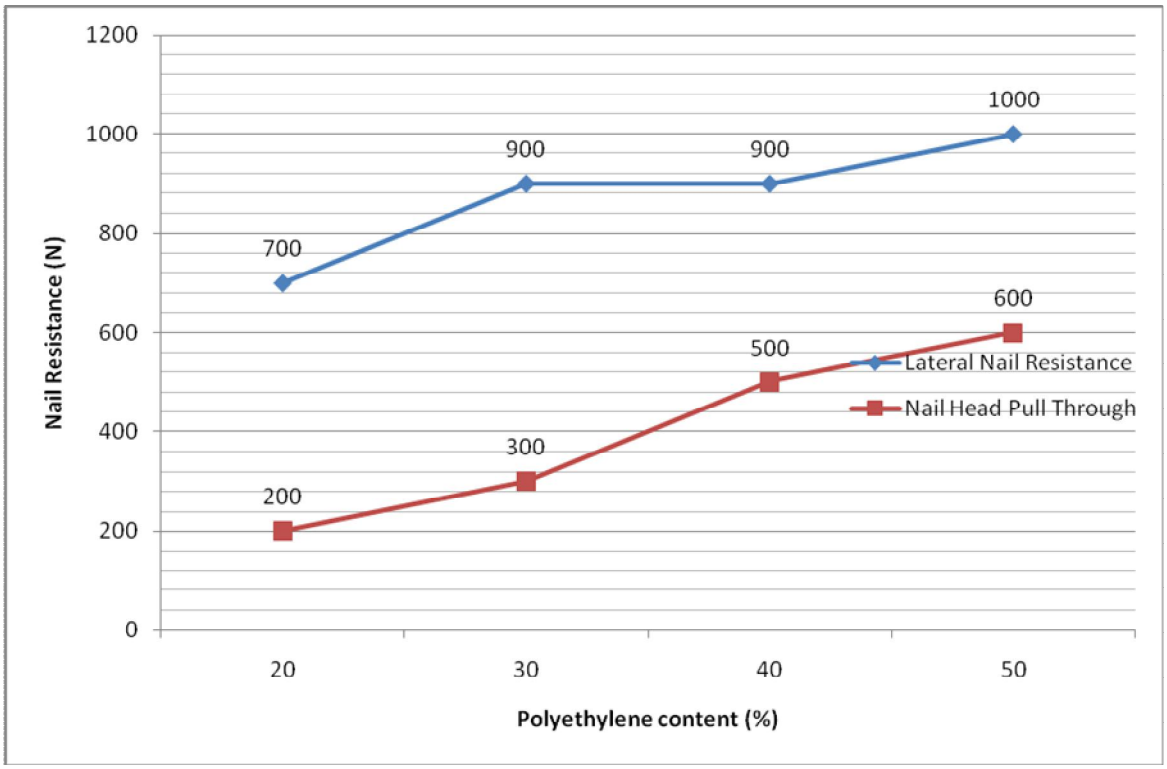


Figure 4.6; Effect of polymer content on nail resistance properties of the board

4.6 SURFACE ABSORPTION

Table 4.1 displays the results of the average surface absorption properties of the sample panels that were tested. As it can be seen in the table, panels with lower polymer content are more absorbent than those with higher polymer content, Sample with 20% polymer content having an average absorption of 149 mm while samples with 50% polymer content have an average absorption of >200 mm (this was because the samples were limited to 200mm of length and the solvent flows to the table top of the fume cupboard which the samples were placed). The result also shows a consistent relationship between the rate of absorption and the polymer content of the samples tested.

The essence of determining the surface absorption is to establish the success of direct painting of any wood based sheet material. Boards with high surface absorption as indicated by short length of wetting will require higher paint coating weights to achieve a satisfactory paint finish and vice-versa.

Panels tested exceeded the requirement for surface absorption as stipulated by Euro MDF Board (EMB) Industrial Standard of 1993 that peg the minimum value at 150mm (EMB, 1993), with the exception of samples with 20% polymer content which are lower. EMB Standard was used here for comparison of panel properties since there are no established values for such panels in the BS or ASTM at the present.

Table 4.1; Surface Absorption test results

Board sample No.	Polyethylene content	Surface Absorption (mm)	Average Surface Absorption (mm)
1	20	145	
2	20	155	149
3	20	146	
4	30	160	
5	30	162	168
6	30	183	
7	40	175	
8	40	195	190
9	40	200	
10	50	200	
11	50	200	200
12	50	200	

4.7 SWELLING IN THICKNESS AND WATER ABSORPTION

Figures 4.7 and 4.8 contains the average values for swelling in thickness and water absorption properties of the fibreboard samples, obtained from the 24 hours water-soak test of the panels produced. The result shows a decrease in the swelling in thickness and water absorption of the board sample with an increase in the percentage of polymer material. The 24 hours swelling in thickness drops from 31% for boards with 20% polyethylene, down to as low as 4% for boards with 50% polyethylene material. While for moisture absorption the value drops from 57% for boards with 20% polyethylene to 24% for boards with 50% polymer material.

Of all the samples tested for swelling in thickness only those with 20% polyethylene did not meet the minimum requirement for boards in this category as contained in the standard (BS 622-5: 2003) for both humid and dry condition which the standard pegged it at 18% and 30% for humid and dry conditions respectively.

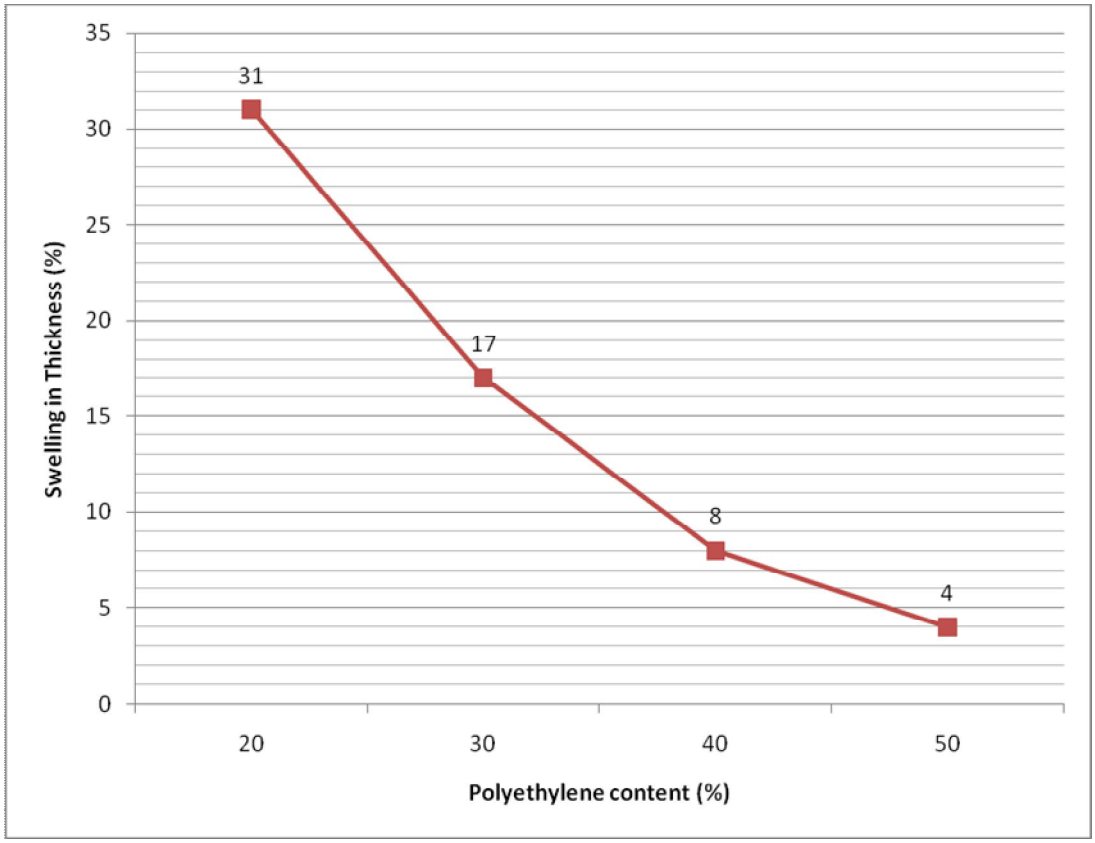


Figure 4.7: Effect of polyethylene content on swelling in thickness properties of board

For the moisture absorption properties, though there is no provision for this property in the standard for fibreboard, the Standard makes provision for Particle Board which is also a wood based panel material like this one, and puts the value at 75% moisture absorption. Therefore if this Standard (BS 2604-2: 1970) is to be used for comparison, it can be said that all the samples tested meets the minimum requirement of this Standard.

From the results obtained from this test, it can deduced that polymer bonded fibreboard samples with higher percentage of the polymer material has very good water repellent and moisture resistance qualities, which will make it good for application in

areas with high humid conditions. The water repellent property of the polymer was transferred to the board in general.

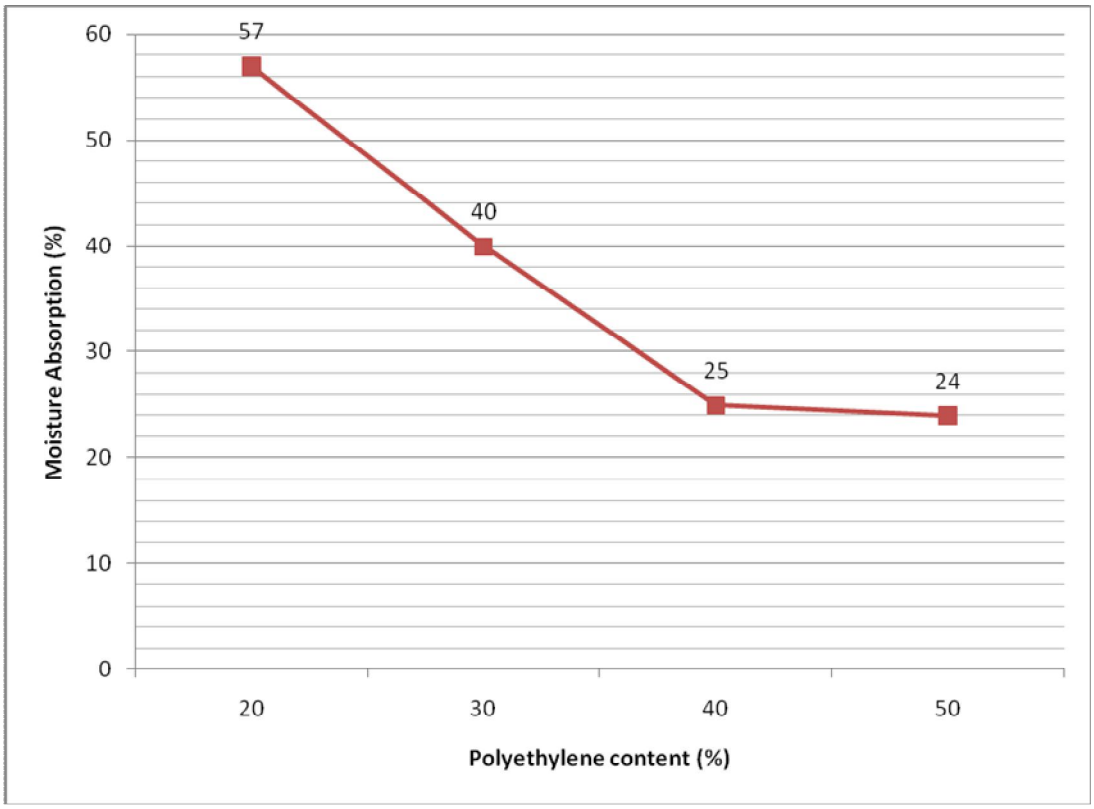


Figure 4.8: Effect of polyethylene content on moisture absorption properties of board

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY OF FINDINGS

From the results obtained after subjecting board samples with Polyethylene binder at 20%, 30%, 40% and 50% replacement levels to series of test. The major findings showed that;

i. With an increase in the Polymer content from 20% to 50%, the dimensional stability properties of thickness swell and water absorption decreases from 31% to 4% and from 57% to 24% respectively.

ii. For surface absorption, the value increases from 149mm for samples with 20% polymer content, to 200 mm for samples with 50% polymer content. Samples with 20% are below the minimum required value of 150 mm.

iii. For strength properties, all samples met the minimum requirement for Internal Bond properties which varied from 1.07 N/mm^2 to 3.07 N/mm^2. The maximum mean Bending strength was recorded by sample with 30% polymer which was 87% higher than the minimum required value of 23 N/mm^2. The minimum mean value recorded by samples with 20% Polymer was 15% lower. Samples with 40% and 50% were 48% and 17% higher than the required value. All samples tested for MOE in bending were below the 2700 N/mm^2 set by the Standard.

iv. For the screw holding properties; samples with 20% Polymer content with a mean value of 720 N were lower than the minimum required value of 1000 N. Samples with 30%, 40% and 50% polymer content met the requirement.

The maximum mean value of 1220 N was recorded by samples with 50% Polymer content.

5.2 CONCLUSIONS

A study was conducted on the physical and mechanical properties of Dry Process Fibreboard produced utilizing Rice Straw and Low Density Polyethylene as the main matrix and binder respectively. Board samples with Polyethylene binder at 20%, 30%, 40% and 50% replacement levels were produced using Hydraulic Press Machine. Based on the limited test result recorded, Rice Straw fibreboard samples produced with 30%, 40% and 50% polymer replacement levels met the requirements set out mostly by BS 622-5: 2003 for Dry Process Fibreboards which was used for comparison.

Therefore fibreboards made with these materials can be used as panels in internal construction works such as partitioning, door panels and even ceiling board. Also its good moisture and surface resistance properties will give it higher advantage for application in high humid environment such as basement and bathroom areas.

5.3 RECOMMENDATIONS

Based on the findings and outcomes of this Research, the following recommendations are outlined;

i. The material is recommended for use in interior design and non-structural furniture works pending further studies to find ways of improving the modulus of elasticity in bending of the composite.

ii. Further research should be carried out to determine the durability properties of panels through cyclic and humidity test.

iii. If the material is to be subjected to more elaborate use, other properties related to panel materials like; anti termite, acoustic, thermal insulation,

hardness, impact strength, compressive strength and flame resistance should be considered before its full application.

iv. Also other thermoplastic materials which are also part of Household waste that can be recycled such as, PVC, HDPE, and the like, should also be considered for further studies, so as to find ways of optimizing the end product.

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APPENDIX 1

SAMPLE CALCULATIONS

v. Density

$$= \frac{M}{V} \quad (kg/m^3)$$

M = 12.52g

V = 50 x 50 x 6 x 10^{-9}

$$= \frac{12.52 \times 10^{-3}}{50 \times 50 \times 6 \times 10^{-9}}$$

$$= 835 \text{ kg/m}^3$$

vi. Bending Strength

$$R = \frac{3PL}{2bt^2}$$

R = Bending strength in N/mm^2

P = 200N

L = 120mm

b = 50mm

t = 6mm

$$= \frac{3 \times 200 \times 120}{2 \times 50 \times 6^2}$$

$$= 20 N/mm^2$$

vii. Bending Stiffness

$$E = \frac{P_1 L^3}{4bd^3 y_1}$$

E = Modulus of Elasticity or Stiffness in N/mm^2

P_1 =70 N

L = 120mm

b = 50mm

d = 6mm

y_1 = 4mm

= 700N/mm^2

viii. Tensile Strength parallel to surface

$$= \frac{P}{A} \quad (kg/m^3)$$

P = 600N

A = 34 x 6

$$= \frac{600}{34 \times 6}$$

$$= 2.94 \text{ N/mm}^2$$

ix. Tensile Strength Perpendicular to surface

$$= \frac{P}{A} \quad (kg/m^3)$$

P = 320N

A = 50 x 6

$$= \frac{320}{50 \times 6}$$

$$= 1.07 \text{ N/mm}^2$$

x. Moisture Absorption

$$A = \frac{M_2 - M_1}{M_1} \times 100$$

A = Water absorption (Percent)

M_1 = 13.36g

M_2 = 21.52g

$$= \frac{21.52 \ \ 13.36}{13.36} \times 100 \quad = \quad 56.62\%$$

7. Swelling in Thickness

$$G = \frac{T_2 - T_1}{T_1} \times 100$$

G = Water absorption (Percent)

T_1 = 6.0mm

T_2 = 7.9mm

$$= \frac{7.9 - 6.0}{6.0} \times 100 \quad = \quad 31.67\%$$

APPENDIX II

Density Test Result

Polyethylene Content %	PROPERTY			
	Sample Number	Swelling in Thickness (mm) Moisture Absorption (g) Measured Parameter		
		Mass (g)	Volume (mm^3)	Density kg/m^3
20	1	12.52	15000	835
	2	14.36	"	957
	3	13.74	"	916
	4	15.94	"	1060
30	1	12.80	"	853
	2	13.98	"	932
	3	13.18	"	879
	4	13.10	"	873
40	1	13.46	"	897
	2	13.94	"	929
	3	12.08	"	805
	4	12.98	"	865
50	1	12.08	"	805
	2	13.50	"	900
	3	12.02	"	801
	4	12.84	"	856

APPENDIX III

Bending Strength test results

Board sample No.	Percentage Polymer	Rupture Load (P) in N	Bending Strength (N/mm^2)	Mean Bending Strength (N/mm^2)
1	20	200	20	
2	20	200	20	
3	20	190	19	20
4	30	430	43	
5	30	430	43	
6	30	440	44	43
7	40	350	35	
8	40	340	34	
9	40	330	33	34
10	50	260	26	
11	50	280	28	
12	50	270	27	27

APPENDIX IV

Bending Stiffness test results

Board sample No.	Percentage Polymer	Load at proportional limit (P_1) in N	Centre deflection at proportional limit load (y_1) in mm	Bending Stiffness (N/mm^2)	Mean Bending Stiffness (N/mm^2)
1	20	70	4	700	
2	20	70	4.3	651	
3	20	70	3.3	848	733
4	30	140	2.75	2036	
5	30	180	2.75	2618	
6	30	180	3.3	2182	2279
7	40	160	2.75	2327	
8	40	150	2.75	2182	
9	40	160	4	1600	2036
10	50	90	4.35	828	
11	50	100	4.35	920	
12	50	120	4.35	1103	950

APPENDIX V

Experimental Readings for Variation of Polymer Content

Polyethylene Content %	PROPERTY				
	Sample Number	Swelling in Thickness (mm)		Moisture Absorption (g)	
		Measured Parameter			
		T_1	T_2	M_1	M_2
20	1	6.0	7.9	12.52	22.52
	2	6.0	8.0	14.36	20.38
	3	6.2	8.0	13.74	21.52
	4	6.5	8.5	15.94	23.74
30	1	5.9	6.7	12.80	17.74
	2	6.0	7.2	13.98	20.18
	3	5.9	6.8	13.18	17.56
	4	5.9	7.0	13.10	18.74
40	1	6.0	6.5	13.46	16.34
	2	6.0	6.8	13.94	16.86
	3	5.8	6.1	12.08	15.96
	4	5.7	6.0	12.98	16.06
50	1	6.2	6.5	12.08	15.00
	2	6.0	6.2	13.50	16.70
	3	6.0	6.4	12.02	14.88
	4	6.0	6.1	12.84	15.90