ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

School of Chemical and Bio Engineering

Particle Board Production from Maize Cob

A Thesis Submitted to the School of Chemical and Bio Engineering, Addis Ababa Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Master of Science in Chemical Engineering (Process Engineering Stream).

By

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This is to certify that the thesis prepared by **Dagne Abetie,** with entitled: **Particle Board Production from Maize Cob** and submitted in partial fulfillment of the requirements for Degree of Master of Sciences in Process Engineering that complies with the regulations of the University that meets the accepted standards with respect to the originality and quality.

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DECLARATION

I have declared that the thesis project on which is being presented in this entitled “particle board production from maize cob” is original work of my own, has not been presented for any other students, all processes and materials have been duly acknowledged for master of science in process engineering.

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ABSTRACT

Particleboard is a wood-based panel product manufactured under pressure and temperature from the particles of wood or other any lignocellulosic fibrous materials and a binder. This study presented an experimental work which investigates the potentiality maize cob in the production of particle board using modified starch adhesives and wood glue (top bond) as an alternative source of adhesive and also studied effects of control variables in the product. A general factorial design was used for to prepare 27 experiments by varying control parameters. The maize cob particle, modified starch, wood glue (top bond) and the mixed ratio adopted were 69.2% : 15.4, 17.9%, 20.3% and 15.4% respectively, thoroughly mixed manually by using the mixer. The mixture was then poured into a mould with a dimension 100mm × 100mm × 15mm. The particleboard was compacted using a hydraulic press in two compacts. The panels of densities were varied between 6840kg/m^3 and 9083.33kg/m^3. Percentage of water absorption was increased with increasing time of immersion. An average moisture content of all boards was found to be 11.43%. The average internal bonding was 0.132 N/mm^2 relatively low internal bonding compared with urea and phenol formaldehyde resin made PB. The results showed that the maize cob, starch and wood glue (top bond) combination have high potential to be used indoor application for ceiling roof or by laminating Formica or veneers, it can be used for building and furniture applications.

Keywords: Particle Board; Maize Cobs; Modified Starch; Top Bond Glue; Biodegradable.

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LIST OF ABRIEVATIONS

a	Weight of maize cob in its natural state
ANOVA	Analysis of variance
AC	Ash content
c	Weight of oven dry sample
CC	Corn cobs
cm	Centimeter
CO_2	Carbon dioxide
ECAFCO	Ethiopian Chipwood and Furniture
EPS	Expanded polystyrene
FAO	Food and Agriculture Organization
GFD	General Factorial Design
gm	Gram
GPa	Giga Pascal
h	Height
HCF	Hawassa Chipwood Factory
IB	Internal Bonding
Kg/m^3	Kilogram per meter cubic
l	Length
M	Mass
m	Meter
m^3	Meter cubic
mc	Moisture content
MC	Maize cobs
MCL	Measure of the sum total by percent of cellulose and lignin
MCLdry	dry sample measure of the sum total by percent of cellulose and lignin
ML	The measure of the percentage of lignin only
mm	Millimeter
MOE	Modulus of elasticity
MOR	Modulus of rupture
MPa	Mega Pascal

N/mm^2	Newton per millimeter square
NaOH	Sodium hydroxide
P	Pressure
PF	Phenol Formaldehyde
PLC	Private Limited Company
RH	Rice Husk
RL	Resin Load
SR	Starch Ratio
T	Temperature
Th	Thickness
TS	Thickness of Swelling
UN	United Nation
UNIDO	United Nation Industrial Development Organization
UR	Urea Formaldehyde
V	Volume
Va	Air dried volume
w	Width
WA	Water Absorption
Wa	Air dried weight
Wcr	Weight of crucible
Wo	Oven dried weight of the particle board
XPS	Extruded Polystyrene
ρ	Density
%	Percent
µm	Micro metre
^0C	Degree centigrade

CHAPTER ONE

INTRODUCTION

1.1 Back-Ground

Traditionally, composite panel manufacture is based on materials obtained from wood. Along with the growing production of particleboard, the raw material mix has extended and shifted over the years. While at the beginning, industrial wood acquired from the forest was the predominant resource, the ratio of industrial waste wood increased over the past five decades, the amounting in 2005 was 54%. Additionally, during the 1990`s, wood scrap and recycled particleboards were introduced. Today, the material mix consists of 60 to 70 % industrial waste wood, 10 to 20 % industrial wood from the forest and 10 to 20 % wood scrap and recycled particleboard (Kuntz, 2009). In recent years, raw materials derived from agricultural residues have been increasingly investigated for their potential to substitute wood in various applications of particleboard production. This development goes back to several causes. Already in 1997, Markessini et al. mention that the rate of deforestation along with its impact on the environment had triggered manufacturers to search for alternative feedstock, especially in countries with low availability of wood compared to other cellulosic materials.

According to Deppe and Ernst (2000), agricultural residues have been successfully implemented as raw report agricultural waste provisional materials for particleboard production ever since it's beginning. Applications with agricultural residues other than those do exist, but they are of minor importance. Along with the processing of agricultural waste products there are some obstacles compared to wood hindering the extension of their use as long as there is no strong need to replace wood. As stated above, this need has evolved in recent years (Dunky and Niemz, 2002). Additionally, Markessini et al. (1997), shows that the low bulk density of agricultural residues imposing constraints on their use for particleboard production as it implies high volume for storage and transport limiting the economic radius of material collection. Development is supported in sustainable parameters, cities are becoming smart and green. Finding alternative sustainable building materials and low technological building methodologies are solutions to give a contribution in this context. Sustainable and affordable construction, complemented with the comfort standards required now a days, may be an objective to achieve in the building industry. CO_2 emissions to the atmosphere, energy and water consumptions, and affordability are some parameters to take into consideration in the perspective of green product manufacturing processes. In addition, there are other aspects that contribute to green building solutions or practices, such as re-using, opting for green building materials (which must be renewable, local, and abundant), retrofitting, and choosing low technology methods and techniques. Therefore, in the building industry, a range of several different products or building solutions based on the application of raw organic materials have already been experimented. Among these organic based building materials, wood and wood engineered products, bamboo, and cork and cork engineered products are perhaps the most commonly applied ones. However, different agricultural products have also been reported as possible raw organic building materials according to, Younquist et al., (19930), such as bagasse, cereal, straw, corn stalk, corncob, cotton stalks, kenaf, rice husks, rice, corn or maize cobs, straw, sunflower hulls and stalks, banana stalks, coconut coir, bamboo, durian peel, and palm leaf oil, among others. These raw organic building materials are recommended for the manufacturing of different thermal insulation products. Among the above identified agricultural products, corncob has an advantage of being an agricultural waste (Pinto et al., 2012). In fact, the maize production amount has shown an increasing tendency during the last years. Applications for this agriculture waste may result in an alternative and sustainable product that may be relevant, taking into account the overall amount of corncob produced worldwide per year (Pinto et al., 2012).

Corn stalks, like many agricultural fiber sources, consist of a pithy core with an outer layer of long fibers. Currently in the United States, corn stalks are chopped and used for forage, left on the field, or baled for animal bedding. The cobs are occasionally used for fuel. Research shows that corn stalks and cobs can be made into reasonably good particleboard and fiberboard (Chow, 1974). Particle board has been defined as generic term for a panel manufactured from linger cellulosic materials, usually wood, primarily in the form of discrete pieces or particles, as distinguished from fibers, combined with a synthetic resin or other suitable binder and bonded together under heat and pressure in a hot press by a process in which the entire inter particle bond is created by the added binder, and to which other materials have been added during manufacture to improve certain properties (Rocket, 1997). Historically, the products from the light wood technology were very expensive and exclusive. They were used in the aeronautic field or in the automotive field. Over the time, the light wood products could be produced cheap, but with a better quality through increased efficiency in production processes, research and development. This trend is very strong in the furniture industry (Gadea, 2010). Particleboard is cheaper, denser and more uniform than conventional wood and plywood and is substituted for them when appearance and strength are less important than cost. However, particleboard can be made more attractive by painting or the use of wood veneers that are glued onto surfaces that will be visible. There are over a hundred particle board plants in operation today worldwide and particle board is one of the strongest reconstituted panel products and is considered as an ideal substitute to wood and plywood. (George et al., 1997).

According to Shahidur et al., (2017) the primarily purpose of maize cob used for generating energy for rural areas and the remaining is simply discarding. Post predicting in Ethiopia 2017/18 corn production was 6.5 million metric tons, the country's overall corn production is expected to be increased since maize is a major food crop in our country Ethiopia. The majority of the country's corn is grown in the western half of Ethiopia. Based on crop survey assessment and the reported humanitarian food needs that existed in the country at that time. In the future, corn production is expected to continue growing, especially with the introduction of improved seed varieties, fertilizer, and irrigation. Every year, from total production 6.5 metric tons half of metric tons 3.25metric tons maize cobs can we get.

In Ethiopia, not yet companies that are manufactured particleboard from maize or corn cob but the excess cob is present in most part of Ethiopia. In our country Ethiopia, only three companies are making particleboard using *Eucalyptus* particles. These are ECAFCO S. CO, Awassa Chipwood Factory PLC and Maichew Particleboard Factory PLC. All listed companies are not fully meeting the demand of the country. Due to this, importing particleboard from abroad to satisfy their demand, but not used agricultural waste (maize cob) as an alternative a raw material for manufacturing particleboard. Currently, a sufficient amount of maize cobs are available in our country.

1.2 Statement of the Problem

Most Ethiopian particle board manufacturers use wood chips this may cause forest deforestation that leads to environmental depletion. Based on literature search, there is no currently commercial utilization of maize cobs in lignocellulosic composite production. In addition to this, almost all manufacturer use expensive adhesives i.e. phenol and urea formaldehyde. This synthetic adhesives formaldehyde emission are very high that causes carcinogen to human health.

In our country Ethiopia industrialization and urbanization have ever been increasing. In developing countries, the construction industry is growing at a rapidly while using wood and wooden products. This has caused great havoc to our environment. Agricultural residues are materials generated in large quantities in the world and can accumulate to such extent as to cause environmental problems. When forestlands are depleted, the agrochemical circles are negatively affected especially the carbon cycle, since nature depends on plants to reduce the amount of carbon dioxide in the atmosphere and when they are not in the environment as a result of man's activities and this demand for wood, carbon dioxide in the atmosphere tends to increase, thereby resulting in the rising temperature of the biosphere.

Maize is a major food crop in many regions of the world including our country Ethiopia. Due to global demand, maize production is expected to grow from year to year. According to the end uses of wood wastes and their possible reuse products, particleboard has found typical applications as flooring, wall and ceiling panels, office dividers, bulletin boards, furniture, cabinets, counter tops, and desk tops and it seems that the manufacture of particleboard from biomass wastes is the most common way to reuse such waste materials. Although most agricultural panels are environmentally friendly, in some cases the panels present poor mechanical and water resistance, which limits their commercialization. For this reason, agricultural waste may be an alternative solution.

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1.3 Objectives of the Study

1.3.1 General Objective

The general objective of this study was to investigate the suitability of maize cob particles with modified starch adhesives as raw material for particle board production.

1.3.2 Specific Objectives

1. To characterize the raw materials (maize cob) and the physico-mechanical properties of particleboards.
2. To know the optimum operating variables and effects of control parameters on the product by varying modified starch ratio, pressing temperature and pressing pressure.

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1.4 Scope of the Study

The scope of this research work covers; a collection maize cob from Addis Ababa, characterization of their contents, preparation of particleboard, physico-mechanical property testing, determining the operating parameters. In this study the suitability of raw material solid maize cob and modified starch adhesive according to the standard was studied for the preparation of particleboard.

1.5 Significance of the Study

The significance of this thesis is mainly focus on transforming maize cob into the valuable products a so called maize cob particleboard. The use of maize cob is used to create and increase awareness of the beneficial of effects of the use of solid organic wastes for particle board as environmental friendly, renewable and biodegradable, to make the use of Ethiopian renewable wastes or natural resources for its sustainable development and to determine the optimum process conditions for producing particle board from maize cob and modified starch adhesive.

CHAPTER TWO

LITERATURE REVIEW

2.1 Particle Board Production from Organic Waste

When it comes to particleboard production, there is less research on corn residues than on rice residues. Without doubt, corn residues are abundantly available with a yearly amount of 70 million tons of corn cob (CC) and 190 million tons of corn stalk and their applicability for particleboard. Nevertheless, there are several reasons which may explain this phenomenon. Firstly, corn residues are already used for various applications. The entire plant can be shredded and used as animal feed. Granulated residues of CC hold excellent water absorption properties and can be utilized as poultry bedding, mulches and soil conditioners, component of compost for growing mushrooms and filling material in industrial applications. Their chemical properties allow the production of furfural, the use as intermediate in the production of chemicals, the generation of glucose and xylose and the use for energy and heat production. There is already a market with some competition for CC and their collection impairs timely harvest and leads to additional expenses that must be covered by the product. Special attention must be paid to the removal of stones and other materials that disturb the grinding process and endanger the machines (Watson and Ramstad, 1987).

According to Watson and Ramstad (1987), CC are comprised of four elements which are the pith (1.9 %), the woody ring (60 %), the coarse chaff (33.7 %) and the light chaff (4.1 %). Concerning the chemical composition of CC, data provided by different authors vary greatly. Compared to RH it is striking that the proportion of the basic components cellulose, hemi-cellulose and lignin is higher and thus nearer to the one of wood and that the ash content is significantly lower. Amounting 69 % to dry solids, the water absorption capacity of CC is very high which may be a good prospect for adhesive application with water-based adhesives (Watson and Ramstad, 1987).

Table 2.1 Composition of softwood (Zubairu, 1989)

Softwood constituents	Average in %
Cellulose	42 – 49 %
Hemi-cellulose	24 – 30 %
Lignin	25 – 30 %
Ash	0.2 – 0.8 % (10 % are sulphate, phosphate and silicate)
Fat	0.3 – 0.4 %

From composition of soft wood, cellulose and lignin is the most important property to prepare the particle boards.

Table 2.2 Physical composition of maize cob (Zubairu, 1989)

Portion of maize cob	Average %
Cortical layer	24.97
Wood blast	73.36
Pith	1.67
Total	100.00

From the above table 2.2 the cortical layer is the outer layers of the cob on which corn grains are arranged, it consists of fine and coarse chaff. It is yellowish in colour and is good for making fibres. Wood blast is the main part of the cob. It is a hard tough woody layer surrounding a center of pith. It is good for board making, its proportion increases from top to the bottom and Pith is the central portion of the cob, it composed of soft tissues. It easily becomes powdered during grinding process.

Table 2.3 Chemical composition of maize cob particles (Zubairu, 1989)

Constituents	Average %
Ash	3.2
Pentosan	20.6
Lignin	31.2
Cellulose	45.0

From table 2.3, it is therefore, assumed tentatively that maize cob might be a suitable raw material for particle board manufacturer. The cobs are then used to produce particle board samples. The pentosan content of 20.6 % shows that the maize cob could be used in manufacturer for furfurals and other products (Mantell, 1975).

Most literature on particleboard of corn residues deals with corn stalk instead of corn cob. In this context, one exceptional example of pre-treatment is worth mentioning, where researchers applied a flame treatment to eliminate the wax layer from the surface of corn stalk and report good adhesion properties resulting from this treatment (Watson and Ramstad, 1987). According to Sampathrajan et al., (1992) produced panels between 190 and 540 kg/m^3 density of corn stalk, corn cob, rice straw, coconut pit and groundnut shell with urea formaldehyde adhesive and without pre-treatment of the materials. In their sample, CC panels hold the highest mechanical properties in all tests including bending tests, nail and screw withdrawal tests and others. Producing particleboard from different mixtures of CC, bagasse and wood shavings bonded with tannin resorcinol respectively tannin, urea formaldehyde adhesive and making dry and wet bending tests therewith, found most of their panels outperforming commercial grade wood based panels. The content of CC in the mixtures ranged from 25 to 50% by weight and none of the materials was treated to increase adhesion properties prior to bonding. While for most of their trials the RL was 10 %, they increased it up to 25%, which showed no effect on the dry bending strength, whereas the wet bending strength and the water absorption were substantially improved (Ntare et al., 2008).

Maize cobs which are now the area of interest in this research are part of the maize plant. The maize grain is arranged around the outside of blast cob. The cobs of the common varieties of maize generally are 17 - 20 cm long and 2 - 4 cm in diameter at the bottom. The cob tappers to about 2 cm near the opposite end (Mantell, 1975).

(I) The Cortical Layer: This is the outer layers of the cob on which corn grains are arranged, it consists of fine and coarse chaff. It is yellowish in colour and is good for making fibres.

(II) The Wood Blast: This is the main part of the cob. It is a hard tough woody layer surrounding a center of pith. It is good for board making, its proportion increases from top to the bottom.

(III) The Pith: This is the central portion of the cob, it composed of soft tissues. It easily becomes powdered during grinding process.

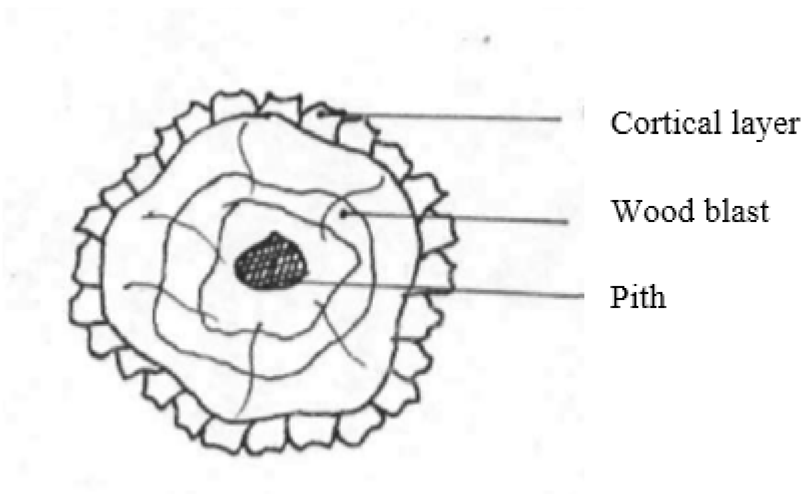
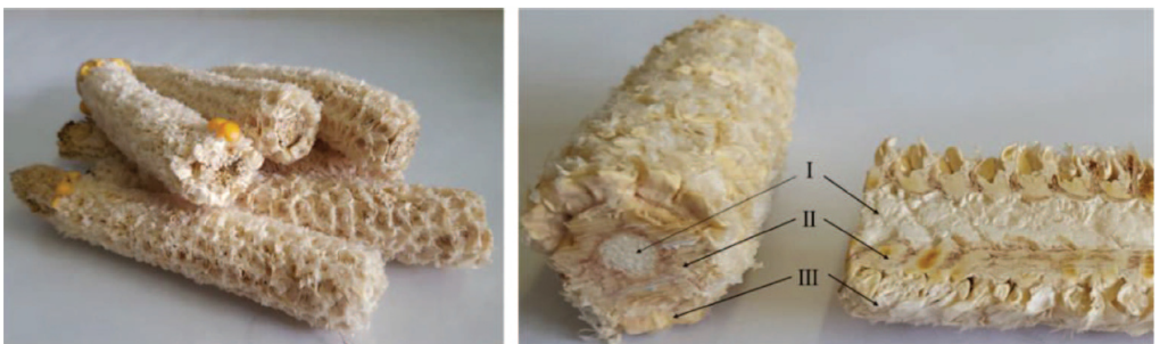


Figure 2.1 Cross section of maize cob (Mantell, 1975).

2.2 Properties of Maize or Corn Cob

The properties of particleboards greatly depend on the kind of bonding agents used in their production. Currently, about 90% of the world production of particleboards is manufactured with the use of urea formaldehyde (UF) resins (Mohamed, 1993). Moreover, the hardening agents also affect the strength of properties of particleboard. Particleboard that is not densely compacted will have rough edges and the interior may contain cavities.

Particleboard might typically be used for your kitchen counter, (where it would covered), and thus protected from moisture, by laminate material, such as Formica. Particleboard can be manufactured in different sizes, thicknesses, densities and grades for a variety of end uses. It has relatively homogeneous properties making it an excellent core material for furniture manufacturing. Over the years, the industry has concentrated its effort on improving board surface smoothness for improved finishing and laminating purposes. Maize cob is a raw organic material, and therefore a relevant material heterogeneity is expected. Material discontinuity and anisotropy are also two material characteristics of maize cob.



a b

Figure 2.2 Corncob macrostructure a) general view and b) longitudinal section (Jorge et al., 2016).

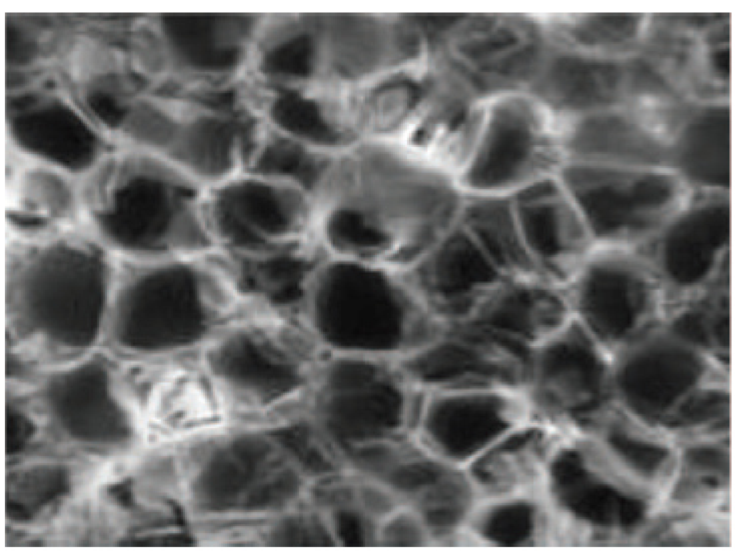


Figure 2.3 Structure layer I of corncob (Jorge et al., 2016).

In terms of macrostructure, maize cob tends to show three distinct layers (layers I-III, from inside to outside; Figure 2.2), which are clearly perceived by their colour, texture, shape, and density. Layer I is quite soft, layer II is similar to solid softwood, and layer III is very irregular. The microstructure of layer I of a maize cob, which is a closed cellular structure (alveolar) is similar to a typical thermal insulation material such as extruded polystyrene (XPS) or expanded polystyrene (EPS) (Jorge et al., 2016).

2.3 Role of Maize Cob in Board Production

The suitability of the raw material be used in particle board production is of paramount importance, in fact, it is one of the aim of this thesis. A knowledge of physical and chemical characteristics is therefore, needful, this will assist in knowing the constituents of the raw material and the extent to which it can be used for the intended purpose. For these reason, the physical and chemical composition of the maize cob particles were studied, although the values riven in the above table 2.1 and 2.2. The differences in their quantitative constituents would not be significant since they are components of the same agricultural product. The absorption capacity of the maize cob is relatively high. This is because of many pores in it, the principal chemical constituents of the maize cobs are cellulose, pentosans and lignin. These are mainly from the wood blast and cortical layer of the cob. Cellulose and lignin are usually good for board manufacturer (Leigh, 1980). The absence of acid and extractive content shows that the board properties may not be affected. These contents according to Foster (1967), affected the board quality (Mantell, 1975).

2.4 Board

According to Zubairu, (1989), to enable the assessment of prosperities and quality of particle board produced from maize cobs, it is necessary to review the characteristics of its allied products. Boards are termed as wood based panel products. This term broadly covers three materials: plywood (including block board and lamin board) fibre building board and particle board.

Ply-wood is made from thin sheets of wood called veneer. The sheets are glued together under pressure so that the grain of the central veneers run at the right angles to that of the outer sheets. Two, three, five, seven or more veneers may be used to and there is a wide variety of poly wood available, differing in thicknesses, in strength, in durability and in appearance. Poly wood is used is used in areas where strength and lightness is primary importance. Associated with plywood are block board and lamin board. They are manufactured by the same mills but construction differs. Block board and lamin board differs from plywood in that their centers or cores are composed of strips of soft wood up to 25mm thick which are glued together. These materials compete greatly with particle board (Zubairu, 1989).

Commercially, plywood is obtained in thicknesses ranging from 3mm - 25mm but this range can be extended for special end uses (Leigh, 1980). Fiber building boards on the other hand are made from wood fibers (i.e., wood pulp). Most fiber boards are made without any additional bonding materials since wood fibers are self-adhesives. There are two main types of fiber board and soft board (insulation board). Insulation boards is soft and porous and has relatively little strength. It is predominately used for its excellent insulating and acoustic properties and it is an ideal in expensive building board. It is obtained in a variety of thicknesses from 9mm up to 25mm. hardboard is the most versatile of all the fibre boards, it is classified according to density as standard, medium and tempered. Thickness ranges from 2mm to a maximum of 12mm, hard board in heavier than plywood but, where lightness is not a pre-requisite, its cheapness and the ease which it takes surface finishes give it many advantages, it is used in furniture making and in building construction (Zubairu, 1989).

2.4.1 Particle Board

Particle board is defined as panel material manufactured under pressure essentially from particles of wood and other lingo-cellulosic fibrous materials, with or without the addition of an adhesive, hydraulic binders being exc1uded. It is usually flat pressed or extruded. It is manufactured in wide range of densities but greater part of present production is of density between 480 kg/m^3 and 800 kg/m^3, and is principally used in the manufacture of furniture and in building industry. Thickness ranges from 2mm up to 30mm, at present, it is made principally from wood chips but work is underway in many research centers for the use of cheaper raw materials (Brinkmann, 1979).

2.4.2 Origin and Development of Particles Board Plants

Report by the Food and Agriculture Organization FAO, (1958) of the Unite Nation (UN) indicates that some experimental works on particle board production was carried out in both North America and Europe before 1940. But the first commercial plant started in Germany in 1941 and by 1949 the extrusion process was developed.

During the period from 1940 - 1946 the posibi1lty of using some agricultural residues had been exported and the first plant based on flax shives was put into operation in Belgium in 1947. So particle board really belongs to the post-war years and its development and utilization have been both rapid and widespread throughout the world. It 1 also known as chip board and flake board. World production of particle board between 1966 and 1977 rose from 11 million cubic meters to 37 million cubic meters (Leigh, 1980).

2.4.3 Types of Particle Board

According to Ariba, (1970) describes particle board types based on the technique of manufacturer platen, pressed or extruded.

2.4.4 Classification of Particle Board

According to, Zubairu, (1989) particles boards are broadly classified by international usage, into three basic class or types, based on density. Generally, particle board are used in two main areas building and furniture industries, In building industry, particle board is used as a flooring material either on joist or on a solid and floors, roof decking and as a dry wall partitioning and ceiling linings. In concrete form-work linings, the board is normally sealed against water absorption. In furniture industry, the board is faced with decorative wood veneers or plastic facings to provide panels of strength, stiffness and, above all dimensional stability. It is used as core stock for desk tops, drawer's fronts, bed rails and shelves.

Table 2.4 Particle board classification based on density (Zubairu, 1989)

Type of board	Low density	Medium density	High density
Density (Kg/m^3)	300 - 400	400 - 800	800 -1200
	Less than 480	480 - 640	640 - 800
	Less than 480	480 - 800	Greater than 800

Table 2.4 indicates particle board classification based on density: low particle board density between 300-400kg/m^3, medium (400-800kg/m^3) and high density (particle board density above 800kg/m^3).

2.5 Production of Particleboards Using Traditional Method

Producing particleboard panels requires combining wood particles, such as wood chips, maize cobs & rice husks with suitable binders while applying pressure in the presence or absence of heat. Maize cobs is quite fibrous by nature requires little energy input to prepare the cobs for board manufacture. Low density boards possess better thermal insulation properties compared to medium-density boards. These boards are resistant to attack by termites, wood-boring insect's wood decaying organisms (Bhatnagar, 1994).

2.6 Production of Particleboards Using Classical Method

Classical approach for manufacturing rice husk ceiling boards of many types of ceiling and roofing materials exist in the market, such as hard boards, paper boards, asbestos cement flat sheets and cellotex boards. The use of maize cobs enables the production of much cheaper ceiling boards. It is produced by combing maize and sawdust. Slurry is produced by heating maize cobs with caustic soda. This slurry is then washed with water and beaten into pulp, to which sawdust (filler) and glue is added. The slurry is formed into sheets in the press and sun dried (Ajiwe et al., 1998).

2.7 Basic Processes in the Manufacturing of Particle Board

The former is more common and usually involves batch or continuous pressing. The extrusion processes are continuous throughout for both types of process, the raw material fed to cutters or shaving machines which produce the particles (splinters or shavings). The particles are screened, cooked and then dried to controlled moisture content (3 - 6 %) before being sprayed with 4 -15 percent resin solution (Flemmich, 1959). Wax may be added to meet water soak requirements. In flat platen press methods the particles are next spread out on trays to a pre-determined thickness. The trays are then placed in hot pressed and subjected to a carefully controlled pressing schedule of 1.4 - 2.4 N/mm^2 at 100°C to 140°C in about 15 minutes. In continuous press method, the particles are spread continuously on to a moving belt which passes through a pre heater and then through the electrically heated press. In the extrusion method, the particles are forced through a horizontal or vertical heated extrusion die from which a continuous length of board emerges. This is carefully led onto horizontal table where it is cut to standard lengths. Extruded are always veneered before sale. After both types of process the boards are trimmed to exact size, conditioned for about a day and crated for shipment (Zubairu, 1989).

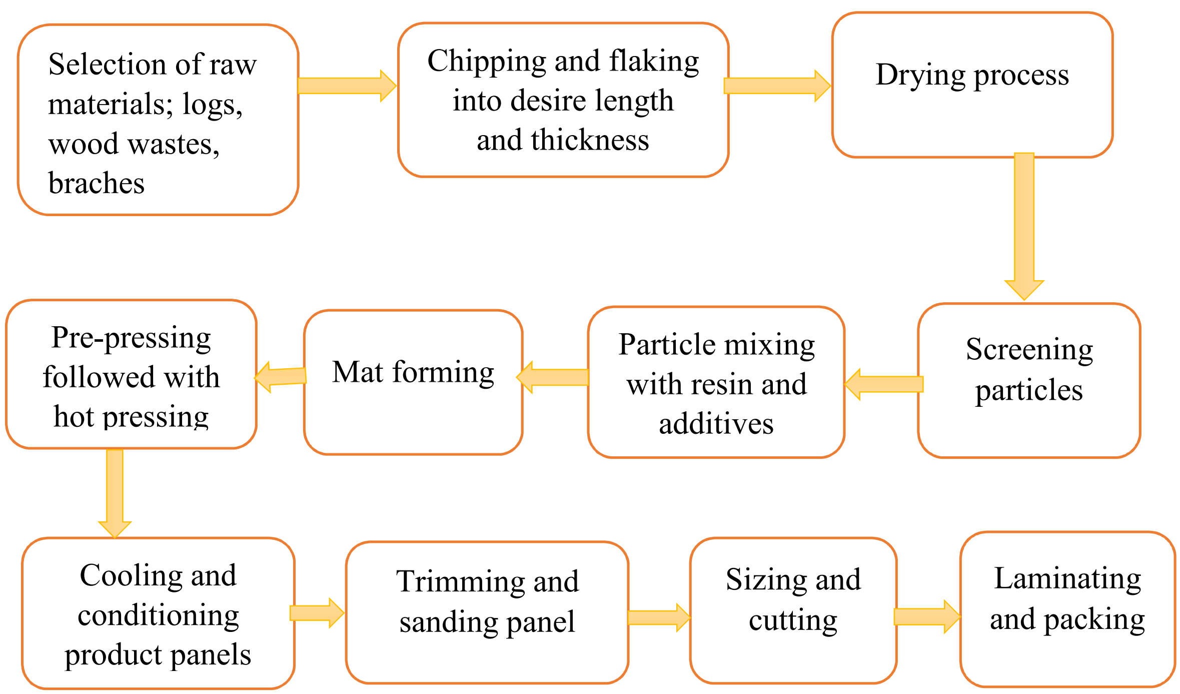


Figure 2.4 Technological process flow diagram of PB production (Maloney, 1993)

2.8 The Role of Adhesives

Adhesive is a compound that adheres or bonds particles together. Adhesives are produced from either natural or synthetic sources. Some adhesives produce extremely strong bonds are becoming increasingly important in the modern construction industry. Adhesives are essential extensively used in wood-based composite products. Adhesive type cure schedule vary according to the composite application. Adhesives used in the manufacture of particleboard should be flexible soft to respond to the dynamic effects of swelling shrinkage, yet impart the required strength. They are classified as natural, starch modified starch adhesives. The natural adhesives are also called biodegradable binder they are predominantly water soluble. However, their major limitation is their inability to be used for outdoor purposes.

Resin is a natural or synthetic compound which is highly viscous in its natural state and hardens with treatment. Typically, resin is soluble in alcohol but not in water. Resin is used as varnishes and adhesives. Adhesives are essential and extensively used in wood-based composite products. Adhesive type and cure schedule vary according to the composite application. Adhesives used in the manufacture of particleboard should be flexible and soft to respond to the dynamic effects of swelling and shrinkage, yet impart the required strength. The adhesive must also withstand the rigours of particleboard manufacturing with sufficient flow to increase particle coverage. Excessive flow, however, will displace adhesive droplets from the glue line into the interstices, thus producing particleboards with inferior properties (Ndasi, 1968).

2.8.1 Synthetic Adhesives

Commonly used synthetic adhesives in the manufacture of particleboards are phenol-formaldehyde and urea formaldehyde.

2.8.1.1 Phenol Formaldehyde (PF)

PF resin creates strong and water resistant bonds, but requires the longest press times and highest temperatures. Cured PF are inherently dark and are undesirable for decorative products such as furniture and paneling. The modulus of elasticity (MOE) and modulus of rupture (MOR) of RH particleboards with PF as binder are 2.6GPa and 13MPa (Leiva et al., 2007). In the case of ground maize cob, the modulus of elasticity is 1.6GPa and its modulus of rupture 7MPa (Ndazi, 2007).

Phenol formaldehyde, a thermosetting resin, is used to impregnate web in order to produce water and heat resistance web products. The resin application method utilized is similar to dip and scrape method. By passing the paper through pinch rollers, excess resin is removed; thereby passing the paper through pinch roller controls the resin content of the paper. To polymerize the resin, heat is applied to the impregnated paper. The web is removed from the oven when it is tack free but not fully polymerized. The unreacted liquids such as formaldehyde, solvents and moisture are evaporated and exhausted to the incinerator. Finally, the web is rewound as it exits the oven and stored. Furthermore, this resin is used as high performance abrasive products, in the insulator materials, for bonding and lamination. It should be easily applied and firmly adhere to the web. Other properties should include well penetration and improving the wet-strength of web similar to or better than the phenol-HCHO resin. For curing it may need curing agent or catalyst. The catalyst used to initiate the curing and polymerization at minimum heat, preferably in two stages similar to phenol formaldehyde resin that would meet the process requirement. Although, phenol-HCHO may be one of the less expensive resins, and its ingredient polymerize easily and form insoluble coating when cured, it is, nonetheless, associated with serious environmental problems.

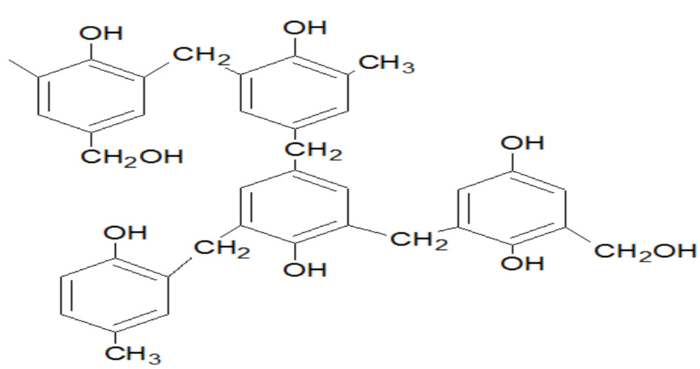


Figure 2.5 Phenol formaldehyde (Pizzi and Mittal, 2003)

2.8.1.2 Urea Formaldehyde (UF)

Urea formaldehyde resins are relatively high molecular weight polymers of urea and formaldehyde dispersed in a water medium (Maloney, 1977). They were developed in the early 1930's. Urea formaldehyde resins have undergone many improvements which, together with the reduction in their cost, have kept them in the leading position among adhesives used in particleboard manufacture in the past several decades (Moslemi, 1974). They are usually synthesized by condensation in aqueous, basic media. Depending on the ultimate application of the product, a 1.5 to 2 fold excess of formaldehyde is employed. Suitable catalysts are all basic compounds, provided they are water soluble to some extent. The most widely used catalysts are the alkali hydroxides. The pH of the reaction mixture should not exceed 8-9 to prevent occurrence of the Cannizzaro reaction of formaldehyde. The pH must be kept constant by buffering or by repeated addition of base. The reaction takes place 10-20 minutes under a temperature of 50 - 60^0C. Catalytic cross linking is carried out with free acids (acid hardening). Large amounts of acid (pH = 2) cause the cross linkage to occur at room temperature. At least 90% of particleboard is produced with urea formaldehyde in central Europe (Kollmann et al., 1975), because urea formaldehyde resin is comparatively cheap and easy to apply (Moslemi, 1974). Urea formaldehyde normally requires the addition of a hardening agent to initiate the final state of curing (Rayner, 1965). These hardeners are either acidic themselves or capable of liberating acids when mixed with the adhesives (Moslemi, 1974).

Resin viscosity is affected by a number of variables including temperature. Increased ambient temperatures result in lower viscosities for both urea and phenolic resins. It is generally recommended that the resin viscosity ranges between l00 – 500Centipoise at 21^oC for particleboard production. The urea and phenolic formaldehyde resins contain a certain percentage of solids in a water medium.The solid content on the other hand cannot be excessively high since the resin becomes too viscous, causing problems associated with resin viscosity already mentioned(Moslemi, 1974).

UF resin is inexpensive and used where surface smoothness is required but not high water resistance. UF is extensively used in particleboard manufacturing for interior applications such as furniture and cabinetry. However, it has a disadvantage of formaldehyde emissions at high temperature. Chemical bonds between urea and formaldehyde are weaker than PF and are easily cleaved by moisture. The MOE and MOR of RH particleboards made with UF are 1.9GPa and 10MPa respectively (Leiva, 2007).

Figure 2.6 Urea formaldehyde molecular structure (Frihart et al., 2005)

2.8.2 Natural Adhesives

In early 1900s, adhesives were derived from agricultural resources until the introduction of petroleum resins in the early 1930s. In recent times, the term ‘biodegradable’ is commonly used to denote environmentally friendly products which, in plastics, describe all degradable plastics through microorganisms such as bacteria, fungi and algae. The main challenge with the use of biodegradable adhesives is that they are predominantly water soluble. This limitation limits their outdoor applications or in a moisture rich environment. Two natural adhesives discussed here in the manufacture of MC particleboards are soybean protein and starch.

2.8.2.1 Soybean Adhesive

Soybean is inexpensive and is a widely available food material. Soy protein concentrate as such or modified with alkali can be used as an adhesive. The cure schedule followed is similar to the RH boards made from synthetic resins. The MOE and MOR of soy protein based boards are 2GPa and 8MPa respectively (Leiva, 2007).

2.8.2.2 Starch Adhesive

Starch is a high molecular mass carbohydrate $(C_6H_{10}O_5)_n$. Because of this starch is usually made up as a percentage solution rather as a molar strength. Starch is a white powder which is typically tasteless and odourless. Starch grains are fine crystals or lumps depending on their origin within the plant kingdom. Available starches include corn starch, potato starch, sago and tapioca.

Starches are modified to increase their stability against excessive physical conditions, to change their texture, to vary gelatinization time or to modify their characteristics for particular applications. Modified starch is prepared by treating starch or starch granules with modified agents, causing the starch to be partially degraded. Modified starch is normally used as an adhesive, stabilizer or emulsifier. Modified starch may be converted into instant starch which thickens and gels without heat or a cook-up starch which must be cooked like regular starch. Modified starch may, therefore, be specifically formulated to be used as a resin for adhesives in particleboards production.

Among the above listed adhesives I was used starch adhesives for my experiment because Starch is an easily available and inexpensive biodegradable material.

Advantage of modified starch adhesive:

- Good availability
- Relative low cost
- Good adhesive to cellulose and many porous substrates
- Insoluble in oils and fats
- Nontoxic and biodegradable
- Heat resistant

Disadvantage of modified starch adhesive:

- Poor water resistance
- Slow drying process
- Poor storage stability
- Need pretreatment to improve the water resistance.

2.9 Additives

It was shown that the use of a special hardener and additives in glue mix for particleboard production can result in boards of increased weather resistance, while the level of formaldehyde emission is kept low with the use of a catcher. Furthermore, results from biological tests have proved that boric acid added to the glue mix improves the boards biological resistance. Therefore, a glue mix formulation for particleboards that provides improved weather and biological resistance with low formaldehyde emission levels has been developed. It was also shown that the presence of an agent is not necessary in order to avoid leaching of boric acid, presumably because the resin itself acts as an agent. This is significant from the financial point of view since the cost of the preservative system is in this way greatly reduced. In particleboard manufacture, a number of additives are often incorporated in the structure to enhance its performance under certain circumstances. Additives include sizing agents, fire retardants, insect repellents, and fungicides. It is therefore, essential that the adhesives properties and curing mechanism not be adversely disturbed when these compounds are added (Abdallah, 2006).

2.10 Wax

Wax products, prepared from petroleum and synthetic waxes, are highly useful in the particleboard manufacturing process. By applying these products, the following characteristics are given to the particleboard products:

- Water repellency.
- Decreased water adsorption.
- Resistance to swelling caused by water.

The purpose of the wax emulsion in the manufacture of various board products is to make the boards moisture resistant to a certain degree. This emulsion is made of two parts, one part paraffin wax and the other part water. In the process, the wax is melted and in molten form passes into hot water. A dispersing agent is added and the whole mix is passed through a high pressure homogenizer. A large amount of pressure is exerted on one side of the material while the other side is atmospheric. The material expands passing through the machine and this expansion tears all the particles into tiny droplets. That gives a stable dispersion of wax in water. From there it is stored and passed through the particleboard manufacturing line. The quality of the equipment used in manufacturing particleboard emulsion will determine the quality and stability of the end product (Abdallah, 2006).

2.11 Factors Affecting the Properties of Particleboard

The typical structure of wood-based particleboard is three-layered, with rough particles in the core, while the top layers consist of finer particles. Single layer particleboard do exist, but they constitute a smaller proportion of the particleboard production. Besides the distribution of the particles, particleboards possess a gradient of density along their thickness direction, called density profile, emerging from the interaction of moisture, pressure and heat during hot pressing. It is of special interest for this research because of its marked impact on the mechanical properties of particleboard. Depending on the size and shape of the particles as well as multiple process parameters, the density profile cannot be considered in isolation. Therefore, the following sections are arranged according to the logic that the density profile affects the mechanical properties of particleboard, while being formed by the particle size and shape and the process parameters. Firstly, the density profile is introduced with its characteristics and its impact on the panel properties without outlining its generation in depth. Size and shape of the particles as well as process parameters are treated thereafter, addressing the density profile formation in particular plus their influence on the panel properties not being related to the density profile. The following considerations are mainly oriented towards the mechanical properties of the panel's focus of this research, with some aspects on the swelling behavior (Wong et al. 1999).

2.11.1 Density Profile

For a better understanding of the impact of the density profile on the mechanical panel properties, it is useful to start from the density in general. Most properties that can be assessed at particleboard are in one way or another interlinked with the density (Dunky and Niemz, 2002). At increasing density, more material is present in the same volume of the panel. At first, pores in the structure are reduced without stronger deformation of the particles. As compaction advances, the pores are eliminated to a large extent along with deformation and partial solid compaction of the particles to close the pores between them. During these phases, the bonded surface area between the particles grows, as resonated surface area bordering on pores is reduced. The third phase is solid compaction of the material, along with considerably higher press pressure compared to the previous phases. Deformation and compaction are supported by the plasticization of the particles which is promoted by heat and moisture (Kelly, 1977). As these possess gradients over the panel thickness, different degrees of compaction emerge. The specific control of these parameters to generate the desired shape of the density profile is treated in the section of the process parameters. While the swelling behaviour and the water uptake hold strong correlations with the overall density, it is the density of the respective layer charged in the mechanical tests that accounts for the panel properties. The density profile of common particleboard typically resembles a U-shape with the highest density near the panel surfaces and the lowest density in the core. Ideally, it should be symmetrical with the peak densities having identical values and positions relative to the panel center line (Wong et al., 1999).

2.11.2 Effect Moisture Content on the Particleboard Process and Properties

Furnish moisture content exerts much influence both on the manufacture and the properties of particleboard. Too high or low levels of furnish moisture result in troublesome operation and produce a poor quality board. The optimum moisture content depends on many factors such as geometry, and wood density, among others, making generalizations difficult. The maximum board strength occurs when the moisture content ranges between 8 to 12 percent at the particle interface. Generally, it is advisable that the boards made from low density woods possess a relatively lower moisture content compared to boards made from denser woods. To make a board of a given density and volume using a low density wood species will require a large number of particles. This is conducive to compaction. Thus excessive moisture in mat made up of low density particles is likely to lead to low board strength or, in extreme cases, results in blows and blisters.Moisture differentiation can result in a number of advantages during the hot pressing operation with such as rapidly consolidating the mat surfaces into a dense, strong layer. In order to create a moisture differential, either surface particles with higher moisture are used or, just prior to hot pressing, the mat surface is sprayed with a given quantity of water per unit surface area. An optimum exists in the amount of water sprayed, depending on such factors as shape and size, and mat moisture content (Moslmi, 1974).

Short, thick particles normally used in the core layer require a greater amount of resin per unit surface area as compared to long, thin particles or very fine granular particle used for surface layers. Longer and thinner particle, everything else being the same, produce aboard with higher bending strength and dimensional stability. Shorter and thicker particles produce aboard with lower bending strength and dimensional stability but higher internal bond strength .The placing of particles to produce a board with high bending and internal bond strength the thick and short are used in core layers while the thin and long are used on the surface layers. (Moslemi, 1974).

2.11.3 Effects of Size, Shape and Orientation of the Particles

According to Hansel et al., (1988) who investigated the ratio of particle thickness in the middle layer over particle thickness in the surface layer for its effect on the formation of the density profile of three-layered particleboard. A high ratio, indicating that the middle layer consists of thick particles, leads to higher density of the surface layer, as thick particles generate higher restoring forces, while the fine particles in the surface layers can be plasticized and formed more easily, leading to higher compaction in these zones. The use of thick particles in the panel core thus enhances both, the IB strength. A further benefit from this strategy is the generation of a smooth panel surface for downstream laminating or coating works (Dunky and Niemz, 2002). According to Hänsel et al., (1988) reports that the variation of the mass ratio of the fine surface to the rough core layer is also a means of shaping the density profile. At higher ratio, which means an increase in the proportion of surface layer, the zone of higher density grows which due to the conservation of mass leads to a decrease in core density. In this configuration, the core layer gets thinner and lighter at the same time. While particle length and thickness have been identified as decisive factors for the mechanical properties in extensive research, particle width has merely been assessed. From the above considerations it can be assumed to be of minor importance (Rackwitz, 1963).

The orientation of the particles in relation to the test direction has a high impact on the mechanical properties of particleboard. Kelly, (1977) refers to research proving that the alignment of the particles in the long axis of bending specimen's yields considerably higher MOR compared to perpendicularly aligned particles. The differences between the load directions however are less pronounced than for solid wood. In the weak load direction, i.e. perpendicular to the fibre direction, the bending properties of aligned particles exceed the ones of solid wood. Effects of particle orientation on the IB strength are not reported. The size of the particles influences the resin load (RL), which is most commonly referred to as the ratio of dry resin applied on dry particles, as the surface area relevant for adhesive application varies at different particle sizes. Referring to particle sizes typical for particleboard production. According to Dunky and Niemz, (2002) cite the example whereby 100gm of rough particles possess a surface area of $1m^2$ whereas 100gm of fine particles have a surface area of $10m^2$. Thus, for fine particles the RL must be chosen at higher level. The RL requires special attention in the case of adhesive application on a particle mix of different sizes. The roughness of the particle surface also influences the resin load. The smoother the particle surface is and the better its natural structure is preserved, the higher the shear strength of the bond between the particles gets. Rough particle surface hence implies the need for more resin to achieve satisfactory bonds (Rackwitz, 1963).

Particle geometry (shape and size) is a prime consideration affecting both the board's important properties and its manufacturing process. Indeed, the performance of particleboard is, in large part, the reflection of particle characteristics Mechanical strength is an important property of the board and is greatly affected by particle geometry. Particle geometry affects the face and edge appearance significantly. Thin and small particles with their pliability and gap filling ability generate gap- free-surface. In recent years, most commercial operations have utilized fine, dust like particles and pressure- refined fibers on board surfaces. Particle geometry indirectly influences the finishing, gluing, and overlaying characteristics of particleboard. Further, the behavior of particleboard to machining (i.e. sawing, routing, shaping, planning, and sanding) is also affected by the type of particle used in manufacturing the product. The shape and size of particles have a direct influence on the amount of heat required for the particles to reach a certain level of moisture content. An increase in particle size of any specific shape necessitates a greater amount of heat to remove a given weight of water (Brumbaugh, 1960).

2.11.4 Effect of Resin Content

It has been indicated that resin content is an important factor in improving the strength properties and dimensional stability of particleboard. It has been calculated by that particle geometry was much more significant than adhesive content with (UF) on MOR values. Adhesives with different levels; 8, 10 and 15% were used by Kimoto et. al. (1964) and found that only a slight improvement in strength properties with 15% as compared to 10% adhesive content. Lehmann, (1970) used UF at 2, 4 and 8% resin contents and found only a small increase in MOR and MOE when adhesive content increased from 4% to 8%. Shuler (1974) used seven levels of UF resin ranging from 2 to 12% has no improvement was evident to him in MOR and MOE when the adhesive level was increased above 5%. The 12% adhesive content was below the 10% level at all particleboard densities. Lehmann, (1978) indicated that the increases in strength properties were directly related to resin content. Price and Lehmann, (1979) also reported that properties increased with an increase in resin content and decreased with a decrease in resin content with the use of either phenol-formaldehyde (PF) or urea-formaldehyde (UF) resins.

Hann et al., (1963) indicated that the particleboard durability was improved when the adhesive levels were increased from 3% to 6% and from 4% to 8% for PF and UF adhesives, respectively. Shuler, (1974) used seven levels of UF adhesive ranging from 2 to 12%, and concluded that thickness swelling (TS) after 2, and 24 hours water soaking tests attained a minimum at 10% resin content and thereafter, no improvement in TS took place. The effect of resin may also depend on the raw material used wood or non-wood materials.

2.12 Maize in Ethiopian Agriculture

Shahidur et al., (2017) reports that reaffirms that maize continues to be a significant contributor to the economic and social development of Ethiopia. As the crop with the largest smallholder coverage at 8 million holders (compared to 5.8 million for teff and 4.2 million for wheat), maize is critical to smallholder livelihoods in Ethiopia. In addition, maize is the staple crop with the greatest production at 4.2 million tons in 2007/08, compared to teff at 3.0 million tons and sorghum at 2.7 million tons. Moreover, maize plays a central role in Ethiopia’s food security. It is the lowest cost source of cereal calories, providing 1½ times and two times the calories per dollar compared to wheat and teff respectively. An effective maize sector could propel Ethiopia's food production to quickly reduce the national food deficit and keep pace with a growing population. However, the maize cobs are organic wastes and deplete environmental pollutions, there is no processing industries maize cob organic wastes in Ethiopia.

2.13 Ethiopian Particle Board Manufacturer Companies

Ethiopian Chipwood and Furniture Share Co (ECAFCO S. CO) was established in 1966. The company is located at Debre Zeit Road. The annual plant capacity is 15,000m^3 of wood and a pioneer for making particleboard from *Eucalyptus* particles. The products ranges in thickness from 08 up to 16mm. (Dun and Bradstreet, 2010).

Maichew Particleboard Factory PLC (MPF) was established in 2007. The factory is located southern zone of Tigray region, at Maichew town. The annual production capacity of the plant is 40,000m^3 of wood. The company employs state-of-the-art technology and couples its with large production capacity, quality control panels, laboratories and all the necessary facilities. The company are manufactures various marketable three layered particleboard and products thicknesses ranging from 08 up to 40mm in accordance to international German DIN standard with particleboard size, 1.22mx2.44m.

Hawassa Chipwood Factory PLC was established under MIDROC investment group and operating in 2012. The factory is located at South Nation, Nationality and Peoples of Ethiopia (SNNPR), in Hawassa . The annual production capacity is 40,000m^3 of wood. The company is manufactures the various marketable products; a single layered particleboard and products thicknesses ranging from 08 up to 40mm in accordance to the international German DIN standard with particleboard size, 1.22mx2.44m.

Table 2.5 Ethiopian particle board producer companies

Company Name	ECAFCO S. CO	Maichew Particleboard	Hawassa Chipwood Factory
Annual production (m^3)	15,000	40,000	40,000

Source: The data taken from the companies and their websites

As shown in the above Table 2.5, almost 95,000m^3 woods are required for making of 3,545,940.46 number of board annually. Approximately, 316.67m3 wood is used in each day for the production of particleboard. This indicates, how much of tree is deforesting and imagine the environmental effect in the country. The weight of boards is differing from factories to factories. The main reason is the technology that used for manufacturing particleboard. Both factories are used the latest and efficient technology for production while ECAFCO is used very old compared to them. It weighs 30 and 40 kg respectively.

Table 2.6 Import particleboard from abroad

Year	Quantity (tonnes)
2007	1876.40
2008	3694.60
2009	2124.70
2010	2771.20
2011	3709.90
2012	3128.50
2013	4638.80
2014	4938.40
2015	5295.30
2016	5522.10

Source: Ethiopian revenue and custom authority

As shown in the above Table 6, the import particleboard has shown a general increase in the past 10 years with some fluctuation. During 2007-2009 the annual average quantity imported was about 2,565.23 tonnes. In the following three years i.e. 2010-2012, annual average has increased to 3,203 tonnes. A sharp increase has been observed in recent four years. The annual average amount imported during 2013- 2016 has reached to a level of 4,078.92 tonnes. This sharp increase is mainly due to the boom of construction sector and furniture industry in the past few years, but the inability of domestic production to satisfy the growing demand in the country. Subsequently import is one of the indicators for unsatisfied demand, currently unsatisfied demand is estimated at 6,000 tonnes.

2.14 Disadvantage of the Use of Wooden Products

Cutting plants for particle board production and the use of synthetic adhesives for particle board productions have a number of negative effects on soil, water, the climate, and the ecosystems the Potential Gab of Literature listed below

Loss of biodiversity - With so many of the world's plants and animals live in forests, that a significant reduction in that habitat, whether tropical rainforest or northern evergreen forest has an impact on biodiversity. Worse, many endangered plants and animals live only in a certain kind of forest habitat. Those species can be lost entirely or can become extinct in the wild very easily.

Climate change - Cutting down the trees also removes a mechanism to regulate the temperature in forested areas. Hotter days and cooler nights put additional strain on the remaining plants and animals. Growing trees trap a good deal of carbon dioxide. That function cannot be fully replaced by planting single crops, like soy or hemp. The plants are good at holding moisture, trees in particular.

Loss of soil fertility - Forested land can be attractive for agriculture because it seems so fertile. In fact, this often isn't so. The seeming fertility of a rainforest depends on the complex relationships between a variety of plant species. Clearing an area to plant soy or hemp just exposes soil that is high in nutrients at first.

Flooding - Forests absorb heavy rains that otherwise could run directly into rivers and streams. After a storm, or after several rainy days, a local river can rise to flood stage, even with forests taking up much of the water.

Water pollution - Clearing a forest also causes runoff into the water. The soil carries away nutrients and may pollute the water with agricultural chemicals.

Formaldehyde emission: The formaldehyde emission is main contributor to indoor air pollution which is also known as volatile organic compounds (VOCs). The VOCs are gases release either from solids or liquid form. Generally, the gases release comprises of various types of chemicals that significantly gives negative effect for both short and long term exposure.

2.15 Advantages of Agricultural Wastes and Starch Adhesives

Computability: Composting biodegradable which can improve water and nutrient retention and help grow healthier plants with less need for chemical fertilizers and pesticides.

Less Pollution: Manufacturing biodegradable maize cob consumer products produces far less pollution. Because the products can break back down into nontoxic components, they don't cause dangerous chemical leachate that can poison water or off gassing that can pollute the air.

Functionality: Biodegradable plastics are completely freezer safe, microwavable and can typically withstand heated.

Non Toxin: Most biodegradable plastics--excluding those made from potato starch--contain no allergens and are safe for atopic consumers. On a whole biodegradable products non-toxic. They are made from natural elements therefore contain no chemicals to exude toxic and poisonous wastes while breaking down in compost.

Energy Conservation: Because biodegradable products are composed of natural ingredients that break down easily into the earth, it requires far less energy to recycle them providing faster and more efficient production.

Marketing Advantages: Recycling and green living, many people are restricting their purchases of household products, groceries and even fast foods only to products and proprietors that use biodegradable packaging products.

In summary the potential gab of literature review, almost all particle board manufacturer including Ethiopian particle board manufacturers use wood chips this may cause forest deforestation that leads to environmental depletion. Based on literature search, there is no currently commercial utilization of maize cobs in lignocellulosic composite production. In addition to this, almost all manufacturer use expensive adhesives i.e. phenol and urea formaldehyde but this study find an alternative solution to substitute wooden products by agricultural wastes and natural adhesives because starch and maize cob which can be broken down into carbon dioxide, water, methane or simple organic molecules by micro-organisms and other living things by composting, aerobic digestion, anaerobic digestion or similar processes.

2.16 Uses and Applications of Particle Board

It is used in furniture making where cost economy is the main factor. It is used both for movable and built in furniture particle boards can manufactured in various densities, thickness and grades to suit wide range of applications. Some of them are: door paneling, furniture ,table top, speaker box, flooring, low budget home, cabinet making, roofing, sound proofing, exam pad, photo lamination, flush door, building partition, packing box, false ceiling and insulation.

2.17 Advantage of Particle Board

The property of this board can be controlled, it has got better acoustic properties and hence better sound absorption, it does not support combustion, thus it is safe to use as it is fine safety measure, it is insect and termite resistant, it is water resistant and it is more economical.

2.18 Disadvantage of Particle Board

Particleboard will sag under load; e.g. book shelves. It needs to be braced its full length or the shelves be limited to a maximum span of 900mm. particle board requires edge treatment with solid timber or edge banded with a veneer strip. Particleboard will disintegrate when exposed to high levels of moisture and this problem is somewhat mitigated by laminating the board on both sides with melamine resin to reduce the moisture ingress and the use of moisture resistant resins.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Raw Materials

The main raw material required for this work was agricultural waste (maize cob) and sourced locally.

3.1.2 Chemicals

The chemicals used to prepare maize cob particle board were listed below

- ✓ Starch soluble
- ✓ Wood glue (top bond)
- ✓ Distilled water
- ✓ Sodium hydroxide (NaOH)
- ✓ H_2SO_4
- ✓ Acetone
- ✓ Decaline.

3.1.3 Equipments

The lab equipment used in this study were indicated below:

- ➢ Dryer (oven dryer)
- ➢ Material handling (plastic bag)
- ➢ Grinder machine (attrition mill)
- ➢ Electronic beam balance
- ➢ Moisture analyzer
- ➢ Measuring cylinder (plastics)
- ➢ Sieve analysis
- ➢ Plastic stirrer
- ➢ Spoon or wood stirrer

- Metal mould
- Temperature reader
- Resin impregnation unit (mixer)
- Heating mantle (stove)
- Mortal
- Manually hydraulic press
- Thermostat water bath
- Caliper
- Knife
- Crucible
- Descanter
- Furnace
- Fiber flask
- Spread sheet metals and
- Metal plates

3.2 Methods

3.2.1 Collection of Samples

Maize cobs are available in most parts of Ethiopia including Addis Ababa and for this study samples were collected from Addis Ababa and this research has been carried out in the laboratories of School of Chemical and Bio Engineering and School of Mechanical and Industrial Engineering, Addis Ababa Institute of Technology, Addis Ababa University.

3.2.2 Raw Material Analysis

3.2.2.1 Moisture Content of Maize Cop Particles

The water absorption capacity and moisture content of maize cob particle were determined using the result obtained as follows: a quantity of the maize cob particles retained on below 2mm sizes and 250gm was weighed. The size cob sample were then surface dried by spreading it on a metallic sheet and gently blowing air from a ceiling fan. The weight of the saturated surface dry sample was determined. This was then dried for 24h in an oven at 100°C, cooled and re-weight.

Weight of maize cob in its natural state, a

Weight of oven dry sample, c

Moisture content, mc = $\left(\frac{a-c}{c}\right)*100$ ……………………………………….Equation 3.1

3.2.2.2 Determination of Ash Content

Ash content is determined using the ASTM D 2017 (1998). A 3gm of MC sample placed in a pre-weighted crucible is incinerated in a muffle furnace at 900^0C until a complete ashing was achieved. The crucible is then transferred into a desiccator for cooling. Three replicate was made and taken the average samples that was taken. The cooled sample weighed was 0.08gm. The ash content is calculated by using the equation 3.2 as follows

Ash content of MC (%) = $\frac{W2-W0}{W1-W0}*100$ …………………………...…….Equation 3.2

Where, W0 = the weight of the crucible,

W1 = the weight of the crucible + sample before incineration,

W2 = the weight of the crucible + sample after incineration

3.2.2.3 Determination of Cellulose Plus Lignin

1g of dried MC ground sample is weighed into a 250ml fiber flask and 100ml of cold Sulphuric acid (H_2SO_4) solution and 2ml of decaline were added. The mixture is gently boiled for 1hrs. The mixture is filtered while still hot and the residue is washed with boiling water and acetone. The crucible and content are dried in an oven dryer at 105^0C for 12 hours and allowed to cool in a desiccator and the weight was 0.631gm. Percentage MCL is calculated using the formula:

%MCL = $\frac{dry\ MCL}{Wt\ of\ sample}*100\%$ …………………………...………………Equation 3.3

Where, Wcr = weight of crucible

MCLdry = the dry sample of MCL

MCL = the measure of the sum total by percent of cellulose and lignin.

3.2.2.4 Determination of Lignin Content

The MCL value (0.631gm) residue as obtained in the above preceding experiment is soaked in cold Sulphuric acid (H_2SO_4). The mixture is stirred to a smooth paste to break all lumps. The residue is washed with hot water until free from acid. The residue in the crucible is dried for 24hrs at 110^0C and then cooled then weighed (W_1). The crucible plus oven dried residue was transferred to a muffle furnace set at 750^0C to ash for three hours till a white grayish ash is obtained, cooled in a desiccator and weighed (W_2). % ML is calculated using the following formula:

$$\%ML = \frac{(W1-W2)}{Wt\ of\ sample} * 100 \quad \text{...Equation 3.4}$$

3.2.2.5 Determination of Cellulose

Percent of cellulose was determined in accordance with ASTM D 2017– 98 with the following formula.

%Cellulose = %MCL − %ML ....Equation 3.5

Where, MCL= the measure of the sum total by percent of cellulose and lignin

ML= the measure of the percentage of lignin only.

3.3 Experimental Design

Data analysis was carried out by DESIGN EXPERT version 6.0 software (general factorial design) to evaluate the effects of the process variables; temperature (130ºC, 155ºC and 180ºC), pressure (3MPa, 5MPa and 7MPa) and starch ratio (15.4%, 17.9% and 20.3%). A GFD experimental design prepared 27 experiments with one replicate was employed, based on the pattern generated through software. The response variable was yield internal bonding after fabrications. This design of the experiment helps us to optimize the process parameters, used for more than three levels and minimize experimental errors that is increase experimental accuracy. Significance of the result was set from analysis of variance (ANOVA). Table 3.1shows the preparation of experiment using design experts v.6.0.8 with three level and three factors.

Table 3.1 Experimental levels and factors with design expert version 6.0.8

Run No.	Factor 1 Temperature (^{0}C)	Factor 2 Pressure (MPa)	Factor 3 Starch Ratio (gm)
1	130	3	10
2	155	3	10
3	180	3	10
4	130	5	10
5	155	5	10
6	180	5	10
7	130	7	10
8	155	7	10
9	180	7	10
10	130	3	12
11	155	3	12
12	180	3	12
13	130	5	12
14	155	5	12
15	180	5	12
16	130	7	12
17	155	7	12
18	180	7	12
19	130	3	14
20	155	3	14
21	180	3	14
22	130	5	14

23	155	5	14
24	180	5	14
25	130	7	14
26	155	7	14
27	180	7	14

3.4 Preparation of Maize Cob Particle Board

The size of maize cobs were reduced by using knife and expose to sun dry until its moisture content was reduced below 4.5% (Zubairu,1989). Maize cobs particles were placed in industrial oven at 100^{o}C for 24 hour and was achieved 3.52% moisture content. After that the reduced sample were grounded by using mortal. In preparation of particleboards from maize cobs were grinding in to fine particle size. Cobs were grounded by using attrition mill machine since fine particles were obtained by attrition mill. The obtained fine particles was screened by using sieving with 2.0 and 1.0 mm mesh opening and the particles size were below 2mm. Sieving was done to obtain maize cobs particles of uniform size. It is done to avoid swelling of maize cobs. The variable in this work, the percentage binders or hardeners were used, while the mass of the milled cobs hold constant throughout.

To produce the particleboard, the weight scale is used to weigh fine particle cobs, starch and wood glue (Top Bond). The mixture ratio adopted for this work were 69.2% MC particle : 15.4%, 17.9%, and 20.3% modified starch adhesive : 15.4% glue. Then thoroughly mixed manually by using wooden stirrer and metal spoon. The mixture is then poured into a wooden mould or mat measuring 100mm × 100mm × 15mm with steel plate placed at the bottom.

Mould **Plate**

Figure 3.1 Metallic mould and plates

Oil was used as a releasing agent on mould surface to achieve easy composites removal from the mould after curing of the composites. After pre pressing with metal block a forming was removed and another steel plate was placed on the top the formed mat. The entire mat was later transferred to the laboratory press. The mould was a manually separated operated hydraulic press with electrically heated plate. The mixture is allowed to flow on its own inside the mould.

Then 3MPa, 5MPa and 7MPa pressure were applied on mould with a temperature of 130^0C, 155^0C and 180^0C for 12 minutes by using manually press machine. After that the particle board was removed carefully from the mould, the next step was allowed the particleboard to dry naturally in free air for 6 days.

Figure 3.2 Manually hydraulic press machine

Curing is the process by which glue/starch adhesive penetrate into the particleboard.

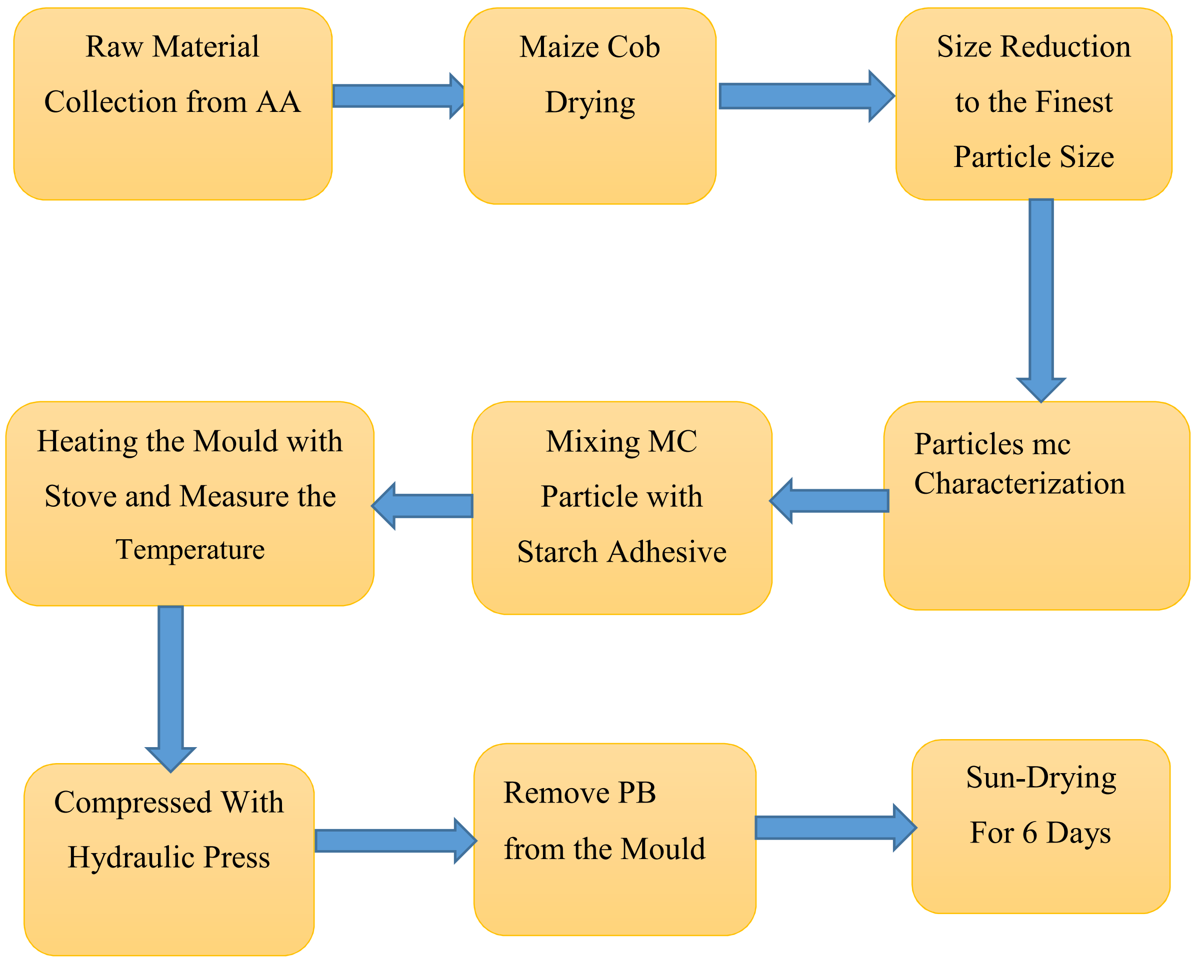


Figure 3.3 Experimental flow sheet diagrams of maize cob PB preparation.

Figure 3.4 Experimental products of maize cob particle board

From figure 3.4 all maize cob particle board product were produced by using hot pressing technique is a vital for manufacturing of maize cob particleboards. Particle dis-integration was occurred at very low moisture content and at high moisture content. .

3.5 Characterization of Physico-mechanical Properties of Particleboard

3.5.1Characterization of Physical Property of Particle Board

3.5.1.1 Thickness of Particle Board

The thickness of particleboard is determined by as follows. Fistful the samples size of maize cob particle board thickness with clean and sharp-edge with deviation of 0.1mm and give name for each sample. Make sure that thickness gauge and is at normal condition. Measure a thickness of each sample using thickness gauge and record.

3.5.1.2 Determination of Moisture Content

The MC of particleboard is determined by the following procedures. Cut 4.5*4.5cm slabs from board of equal size busing a cutter machine and give a name for each slab. Measured the weight of each block and recorded. Put each piece inside the oven for 24hrs at the temperature of 100^0Cand recorded the time of the in and out. Take out the samples after the specified time and put it inside desiccators for 2 minutes and measure the weight of dried particleboards, and to put the result. Finally, calculate the moisture content of the particleboard using the following formula:

$$WA = \frac{(Wwet - Wdry)}{Wwet} * 100 \quad \text{..........3.6}$$

Whereas, Wwet = the weight of wet sample

Wdry = the weight of dry sample

3.5.1.3 Determination of Density Particleboard

The density of particleboard is determined by as follows. First, measured the weight of particleboard in weighing balance, second measured the dimension in length and width of particleboard by using flexible meter or the graduated steel meter, and third measured the thickness using the thickness gauge (analog or digital) at the 4 points and taken the mean values. Then, calculate the gross density of the particleboard using the following formula:

$$\text{Density } (Kg/m^3) = \frac{Wa}{Va} \quad \text{..........Equation 3.7}$$

Wa air dried weight

Va air dried volume

Volume of PB = l x h x w……………………………………………..………….…Equation 3.8

Whereas, l = length

h = height

w = width

3.5.1.4 Water Absorption

Cut the samples of 2.5*2.5cm*board thickness with clean and sharp-edge with deviation of 0.1mm and give name for each sample. Make sure that the precision weight balance is at normal condition. Measure the mass of each sample by using a precision balance and record. Insert each specimen in water bath and record the time in 30min. The particleboard was observed to sink so that it was rested at the base of the water container. After the specified time is reached, take out the specimen from the water bath and measure mass of each specimen according to the designation given record. The weight of the particleboard was tested and obtained with the aid of a weighing scale. After 30 minutes, the particleboard were reweighed and the quantity of water absorbed is calculated as follows:

$$WA = \frac{(Wf - Wi)}{Wi} * 100 \qquad \text{Equation 3.9}$$

Where, W_f final weight

W_i initial weight

3.5.1.5 Determination of Internal Bonding Strength

The IB of particleboard is determined by as follows. Cut test pieces with a dimension of 4.5*4.5cm*board thickness and with sharp edge from the board. Measure the weight of each test pieces and calculate the density. Sanding the test pieces and glued each test piece between the two prismatic yokes by pulling the trigger of the glue gun and wait at least 20min in standard atmosphere. Connect two gimbals– mounted clamping device in the WOLPERT St.6 testing machine. The preparation of the specimen does not allow assuring that the adhered wooden braces are perfectly parallel. After the specimen breaks, the tests evaluate to register the result and record the value of internal bending.

3.5.1.6 Hardness Test

Hardness measurement is the resistance of sample of MC particle board to denting and wear it measures the force required to embed steel ball halfway into the sample size of 4.5x4.5mm or at the center of maize cob particle board by using ASTM Roell, M.FOS.013.

CHAPTER FOUR

RESULT AND DISCUSSION

For this section a result and discussion for production and evaluation of particleboard using maize cob and modified starch adhesive were analysed.

4.1 Raw Material Characterizations

4.1.1 Moisture Content of Maize Cop Particles

The moisture content of maize cop particle was calculated using the above equation 3.1 and the result was 3.52%. According to Zubairu, (1989) the moisture content of particles described below 4.5% which is an acceptable value but after 5 days storage in normal atmospheric temperature it absorbed less moisture because maize cob have unique property to absorb fluid.

4.1.2 Determination of Ash Content

The ash content of maize cob particle was calculated by using the above equation 3.2 and the result was 2.67%. According to Chow *et al.* (2008), the standard range in ash content of wood is 2 -5%, in the case of soft wood, the ash content of maize cob sample was between the range i.e an acceptable value.

4.1.3 Determination of Cellulose Plus Lignin

Percentage of cellulose and lignin were calculated using the above equation 3.3 and the result was 63.1%

4.1.4 Determination of Lignin Content

Lignin of maize cob binds to cellulose fibers to harden and strengthen cell walls of plant and percentage of measurement of lignin was 24.5% nearest to 25% that is an acceptable range. According to According to Chow *et al.* (2008), the standard value of lignin content of wood is 25 -35%.

4.1.5 Determination of Cellulose

Percent of cellulose was determined in accordance with ASTM D 2017 – 98 with the following formula. According to Zubairu, (1989), the maize cobs average percent of cellulose is 45%.

%Cellulose = %MCL − %ML = 63.1 – 24.5 = 38.6%

Where, MCL = the measure of the sum total by percent of cellulose and lignin

ML = the measure of the percentage of lignin only.

4.2 Physical Property Tests of Particle Board

4.2.1 Thickness of maize cob particle board

The average measured value thickness of maize cob particle board was found to 6.75mm. The maximum and the minimum value were 6 and 7.5 respectively. It was an accepted value, according to the result and variation of thickness was occurred to the variation of control parameters like impregnation ration and pressure.

4.2.2 Density of particle board

It was noted that difference in experimental composition and the addition of impregnation ratio was making some effect on the board density. From experimental result the minimum density was 6840kg/m^3, the maximum density was 9083.33kg/m^3 and the average density found to be 7828.16kg/m^3. Experimental MC Particle Boards would be high density boards. The value of WA could be the high density of the material compared with *Pinus* and *Eucalyptus.* Therefore, a higher amount of particles per area is needed to form panel mattress of predetermined density, which increase the availability of sorption sites. According to Zumbairu (1989), above 800kg/m^3 are high density particle boards Board density is having lot of impact on properties like, IB, TS and WA. So, according to a results obtained from the experiment, there were some significant difference in density among industrial panels.

4.2.3 Volume of Particle Board

The Volume of the particle board was varied between $6x10^{-5}m^3$ and $7.5x10^{-5}m^3$ because of the impregnation ratio and the pressing pressure but the average volume the maize cob particle board found to be $6.75x10^{-5}m^3$.

4.2.4 Moisture Content

Percentage of moisture content, mc was calculated by using equation 3.6. The minimum moisture content for the Particle board found to be 7.41% at 180^0C, 3MPa and 15.5% SR and the maximum was 13.84% at 130^0C, 3MPa and 20.3% SR. Average moisture content of all boards was 11.43%. Equilibrium moisture content is mainly depends on relative humidity. Measurement of moisture content can be achieved by weighing or by using electric moisture meter. Linear dimensions and thickness were changed when there was changed the moisture content. According to Moslmi, (1974) the moisture content ranges between 8 to 12 percent at the particle interface which was an acceptable value.

4.2.5 Water Absorption Test

The water absorption was 37.44% at a temperature of 130^0C, 5MPa and 20.3% SR have highly water absorbed and almost all samples after 30 minutes were soluble. The particle board water absorption was high since it absorbed much water due to this, it can be used for indoor application for dry seasons. From the experiment, average value of WA times (30 minute immersion) was 29.54%. In the case of particle board made by phenol formaldehyde resin have low water absorption that is the lowest water absorption values whereas maize co boards showed the highest average of WA values.

Table 4.1 Physical property summary result of the product (maize cob particle board)

Run No	T (^{0}C)	P (MPa)	SR (gm)	Th (mm)	M (Air dry) gm	M (Oven dry) gm	ρ (kg/m^3)	mc (%)	WA (%)
1	130	3	10	7	52.3	47.2	7457.14	10.8	34.4
2	155	3	10	7.5	55.2	51.1	7360	8.02	26.6
3	180	3	10	7	52.2	48.6	7471.42	7.41	30.87
4	130	5	10	6.5	49.4	44.3	7600	11.5	40.37
5	155	5	10	7	53.8	49.6	7685.71	8.47	24.65
6	180	5	10	6	51.9	46.7	8650	11.13	33.77
7	130	7	10	7	48.1	43.2	7300	11.37	29.57
8	155	7	10	6.5	50.1	46.3	7707.69	8.21	30.24
9	180	7	10	6	51.1	46.5	8016.67	9.9	25.06
10	130	3	12	7.5	51.3	45.6	6840	12.5	29.78
11	155	3	12	7	53.8	47.6	7685.71	13.02	35.67
12	180	3	12	6	50.8	45.2	8466.67	11.95	32.38
13	130	5	12	7	53.4	47.5	7628.57	12.42	22.34
14	155	5	12	7	54	48.8	7714.29	10.66	24.48
15	180	5	12	6	48.3	43.3	8050	11.55	22.57
16	130	7	12	6.5	52.2	46.5	8030.76	12.26	30.95
17	155	7	12	6	49.7	43.7	8283.33	13.7	25.7
18	180	7	12	6.5	45.5	40.3	7000	12.9	28.97
19	130	3	14	7	55.9	49.2	7628.57	13.84	34.81
20	155	3	14	7	53.7	47.4	7985.71	12.66	23.59
21	180	3	14	6.5	51.5	45.9	7923.07	12.2	34.86
22	130	5	14	7.5	52.2	46.1	7093.33	13.2	37.44
23	155	5	14	6	53.2	47.4	8700	12.24	22.56
24	180	5	14	6.5	53.6	48.1	8246.15	11.43	23.57
25	130	7	14	7	52	46.8	7428.57	11.11	28.73
26	155	7	14	6	51.5	45.6	8583.33	12.94	22.45
27	180	7	14	6	54.5	49	9083.33	11.22	26.84

4.3 Mechanical Property Determination of Particle Board

4.3.1 Internal Bond Test

The IB test shows a correlation between the density and the IB strength of the particle board. Having a length of 100mm, the bending specimens can have variations of the density over their length. According to, ASTM WOLPERT St.6, the minimum internal bonding was 0.12N/mm^{2}, the maximum internal bonding was 0.142N/mm^{2} and the average internal bonding was 0.132 N/mm^{2} relatively low internal bonding compared with urea and phenol formaldehyde resin made PB.

At least from a theoretical point of view, the whole cross section is stressed uniformly in the IB test. The preparation of the specimen does not allow assuring that the adhered wooden braces are perfectly parallel. The adhesive application and the joining of the braces are both manual processes, involving some impreciseness.

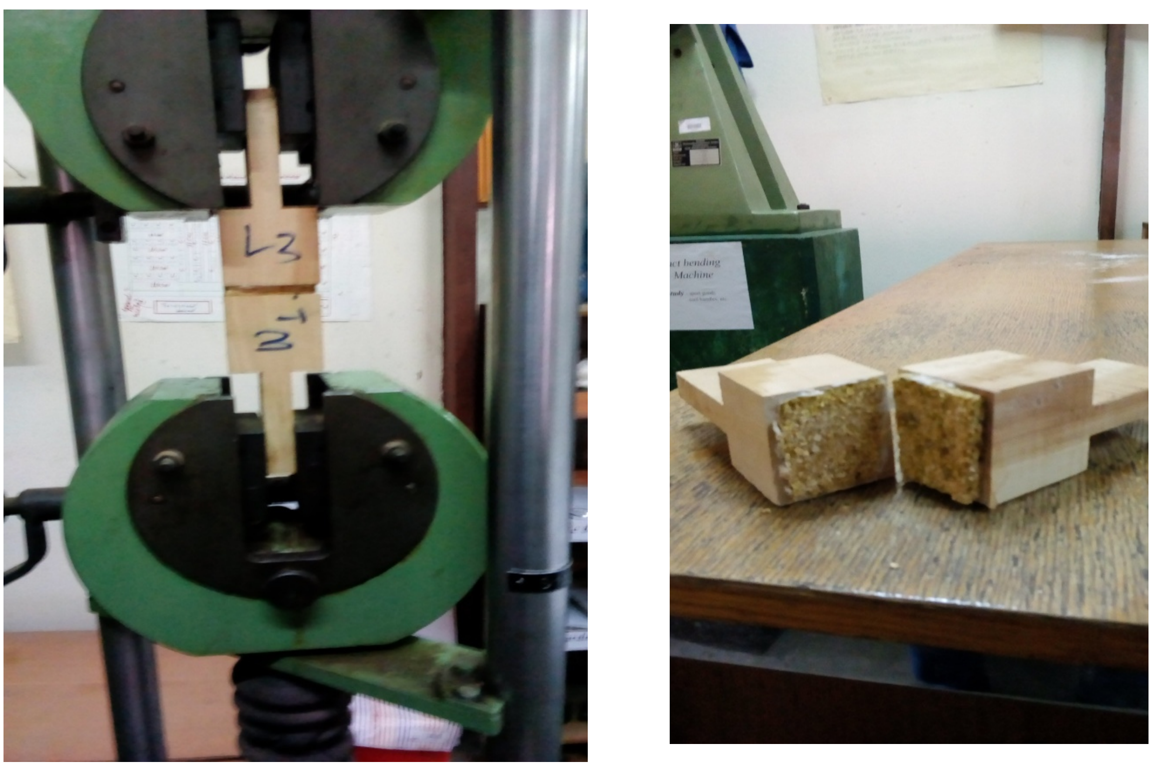


Figure 4.1 Test setup of IB test MC particle board (WOLPERT St.6)

Charged parallel, the stress does not distribute uniformly over the specimen area with the result that it starts breaking in the area of the highest charge. Thus, the test piece starts failing at one side and breaks like a zip. In this case, the IB strength is influenced by both, the density and the degree of parallelism of the braces which is slightly different for every specimen. Compared to common wood based panels, the results of IB of these PB are relatively low. The reason for this is starch by nature soluble in water. The IB strength generally correlates highly with the pressing pressure in the PB core.

Common wood based panels possess more pronounced density profiles with comparably low densities in the panel core. Thus the relevant density for the IB strength is significantly lower than the average density of the specimen. As the MC PB tested in this research possess flat density profiles and comparably high overall densities, the relevant density for the IB strength is much higher than the one of common wood based panels. Also the compact particle shape which is unfavorable for the bending behavior may give rise to the high IB strength of the panels.

According to ASTM WOLPERT St.6, fraction PB of 130° C press temperature, and 15.4% SR have considerably lower IB strength than the ones of higher press temperatures, whereas, at 155^0C, pressing pressure 7MPa and 20.3% SR had relatively high IB. For MC particle board of 130°C press temperature, the adhesive probably cross links less whereas at 155°C the degree of curing was higher with no significant increase in terms of bond strength when temperature is further raised to 180°C.

4.3.2 Hardness Test

Hardness measurement is the resistance of sample of MC particle board to denting and wear it measures the force required to embed steel ball halfway into the sample size of 4.5x4.5mm, to determine whether the board is suitable for ceiling roof. On the side of MC, most materials show increasing hardness at increasing density, fitting well with the impact of density on hardness (ASTM Roell M.FOS.013). Furthermore, increasing press temperature leads to higher hardness.

Figure 4.2 Hardness measuring setup of particle board (ASTM Roell, M.FOS.013)

Possibly, their higher compression during pressing has weakened the compound. At 155°C press temperature, 7MPa and 20.3% SR found to be a good hardness i.e. 83 shore. According to ASTM Roell, M.FOS.013, a hardness was nearest to 80 shore since above 80 shore of particle board has a good hardness. For a precise comparison, more factors such as the mc, the panel thickness and the density profile were needed to be considered in more depth.

Table 4.2 Experimental particle board internal bonding and hardness results

Run No.	Temperature (^0C)	Pressure (MPa)	Starch Ratio (gm)	IB (N/mm^2)	Hardness (shore)
1	130	3	10	0.125	75
2	155	3	10	0.129	74
3	180	3	10	0.122	76
4	130	5	10	0.132	78
5	155	5	10	0.133	77
6	180	5	10	0.127	81
7	130	7	10	0.135	76
8	155	7	10	0.134	79
9	180	7	10	0.131	79
10	130	3	12	0.127	74
11	155	3	12	0.134	75
12	180	3	12	0.130	80
13	130	5	12	0.129	76
14	155	5	12	0.128	75
15	180	5	12	0.125	80
16	130	7	12	0.130	80
17	155	7	12	0.131	81
18	180	7	12	0.128	79
19	130	3	14	0.131	77
20	155	3	14	0.130	76
21	180	3	14	0.133	79
22	130	5	14	0.124	71
23	155	5	14	0.127	85
24	180	5	14	0.128	80
25	130	7	14	0.136	76
26	155	7	14	0.142	83
27	180	7	14	0.129	81

4.4 Statistical Analysis for Internal Bonding of Particleboard

A = Mould and plate temperature

B = Pressure

C = Starch Ratio (SR)

AB = The interaction between muold, and plate temprature and pressure.

AC = The interaction between mould, and plate temperature and starch ratio.

BC = The interaction between pressing pressure and starch ratio.

Table 4.3 ANOVA of fitted model for the yield of internal boding

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	*4.016E-004*	*18*	*2.231E-005*	*3.40*	*0.0411*
A	*4.956E-005*	*2*	*2.478E-005*	*3.78*	*0.0699*
B	*2.142E-004*	*2*	*1.071E-004*	*16.34*	*0.0015*
C	*5.400E-005*	*2*	*2.700E-005*	*4.12*	*0.0589*
AB	*2.956E-005*	*4*	*7.389E-006*	*1.13*	*0.4085*
AC	*3.111E-006*	*4*	*7.778E-007*	*0.12*	*0.9720*
BC	*5.111E-005*	*4*	*1.278E-005*	*1.95*	*0.1957*
Residual	*5.244E-005*		*86.556E-006*	-	-
lack of fit	*0.08*	-	-	-	-
pure error	*0*	-	-	-	-
Cor Total	*4.540E-004*	*26*	-	-	-

Std. Dev.	*2.560E-003*	*R-Squared*	*0.8845*
Mean	*0.13*	*Adj R-*	*0.6246*
C.V.	*1.97*	*Pred R-*	*-0.3158*
PRESS	*5.974E-004*	*Adeq Precision*	*7.708*

Table 4.3 showed that the starch ratio, the interaction between mould and plate temperature and pressing pressure, the interaction between pressing pressure and starch ratio but the

main effects the interaction between mould and plate temperature, pressure and starch ratio affects the internal bonding. From these statistical tests, it was found that the model was adequate for predicting internal bonding of maize cob particleboard within the range of variables.

The "Model F-value" of 3.40 implies the model is significant relative to the noise. There is a 4.11 % chance that a "Model F-value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case pressure is a significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

A negative "Pred R-Squared" implies that the overall mean is a better predictor of your response than the current model. "Adeq Precision" measures the signal to noise ratio is greater than 4 is desirable. A ratio of 7.708 indicates an inadequate signal and we should not use this model to navigate the design space.

Final equation in terms of coded factors:

IB = 0.13 - 1.222E-003 * A - 6.667E-004 * A^2 - 3.556E-003 * B + 3.333E-003 * B^2 - 1.000E-003 * C + 2.000E-003 * C^2 + 4.444E-004 * AB - 7.778E-004 * A^2B - 1.444E-003 * AB^2 + 0.000 * A^2B^2 - 4.444E-004 * AC+ 0.000 * A^2C + 2.222E-004 * AC^2 - 3.333E-004 * A^2C^2 + 5.556E-004 * BC - 1.000E-003 * B^2C - 2.444E-003 * BC^2 + 2.000E-003 * $B^2 C^2$.

Table 4.4 Actual and predicted values of internal bonding of particleboard

Run No	Temperature	Pressure	Starch ratio	Internal bonding	Actual value	Predicted value	Residual
1	130	3	10	0.125	0.13	0.12	2.222E-003
2	155	3	10	0.129	0.12	0.12	2.556E-003
3	180	3	10	0.122	0.13	0.13	3.333E-004
4	130	5	10	0.232	0.13	0.13	-1.222E-003
5	155	5	10	0.133	0.13	0.13	1.333E-003
6	180	5	10	0.127	0.14	0.14	-1.111E-004
7	130	7	10	0.135	0.13	0.13	-1.000E-003
8	155	7	10	0.134	0.13	0.13	1.222E-003
9	180	7	10	0.131	0.13	0.13	-2.222E-004
10	130	3	12	0.127	0.13	0.13	-4.444E-004
11	155	3	12	0.134	0.12	0.12	-2.222E-004
12	180	3	12	0.130	0.13	0.13	6.667E-004
13	130	5	12	0.129	0.13	0.13	-8.889E-004
14	155	5	12	0.128	0.14	0.14	-3.333E-004
15	180	5	12	0.125	0.14	0.14	1.222E-003
16	130	7	12	0.130	0.13	0.13	1.333E-003
17	155	7	12	0.131	0.13	0.13	5.556E-004
18	180	7	12	0.128	0.13	0.13	-1.889E-003
19	130	3	14	0.131	0.13	0.13	-1.778E-003
20	155	3	14	0.130	0.13	0.13	2.778E-003
21	180	3	14	0.134	0.13	0.13	-1.000E-003
22	130	5	14	0.124	0.12	0.13	2.111E-003
23	155	5	14	0.127	0.13	0.13	-1.000E-003
24	180	5	14	0.128	0.13	0.13	-1.111E-003
25	130	7	14	0.136	0.13	0.13	-3.333E-004
26	155	7	14	0.142	0.13	0.13	-1.778E-003
27	180	7	14	0.129	0.13	0.13	2.111E-003

The general factorial design response, and the statistical analysis of ANOVA are given in Table 4.4 is a multiple regression coefficients are obtained by employing a least square technique to predict a quadratic polynomial model for MC particle board . The actual and the predicted internal bonding of the PB at different process parameters were calculated. The model was tested for adequacy by analysis of variance (ANOVA).

4.5 Model Adequacy Check

A line of unit slope, i.e. line of perfect fit with points corresponding to zero error between predicted values and actual values are also shown in Figure 4.3. This plot therefore, shows the performance of the correlation in an obvious way. The results in Figure 4.3 demonstrated that the regression model equation provided a very accurate description of the experimental data, in which all points are very close to the line of perfect fit. This result indicates that it was successful in capturing the correlation between the three particleboard production process variables to the bending strength.

The adequacy of the model was further checked with the analysis of variance (ANOVA) as shown in the Table 4.3. Based on a 95% confidence level, F-value is a test for comparing model variance with residual (error) variance. If the variances are close to the same, the ratio will be close to one and it is likely that any of the factors have a significant effect on the response with the P-value greater than 0.05. It was calculated by model mean square divided by residual mean square. Here the model F-value of 3.40 implies the model is not significant. The "Model F-value" of 3.40 implies the model is significant relative to the noise. There is only 4.11% chance that a "Model F-value" this large could occur due to noise.

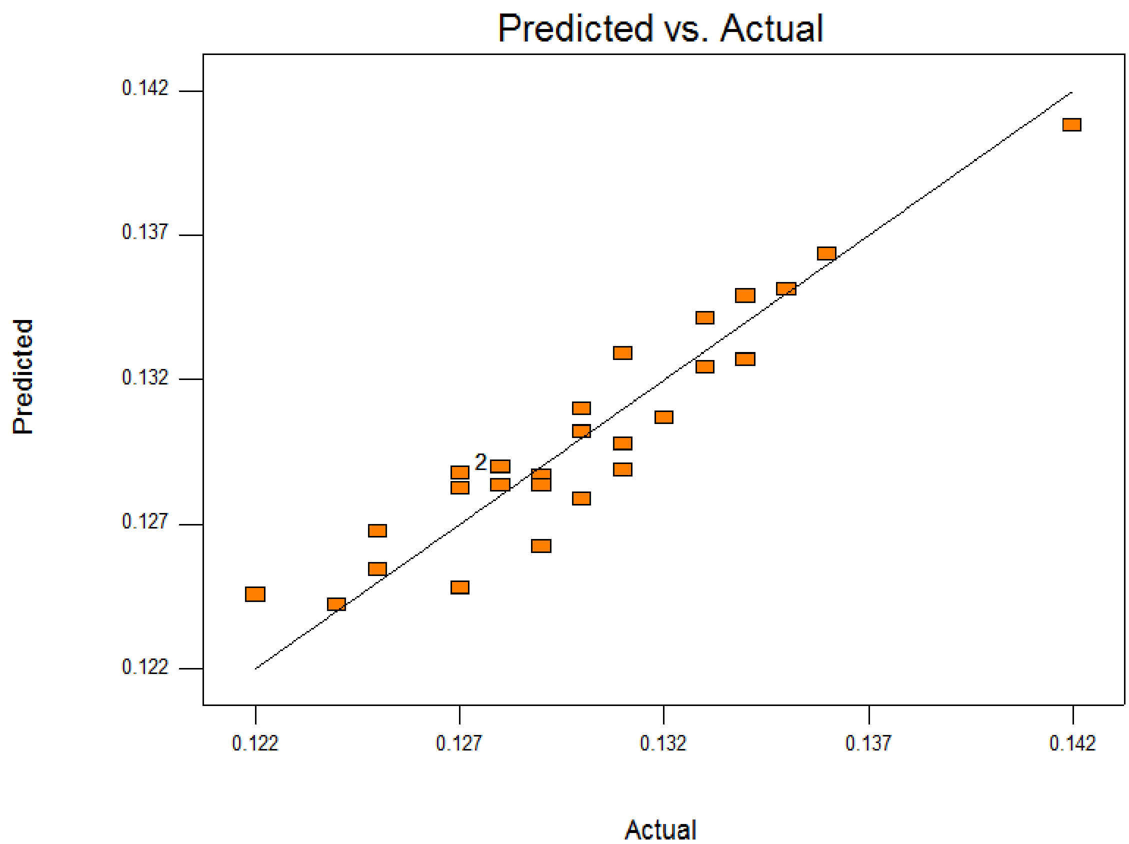


Figure 4.3 Predicted versus the actual internal bonding of MC particleboard

A line of perfect fit with points corresponding to zero pure error between predicted values and actual values of internal bonding were. This plot therefore, shows the performance of the correlation in an obvious way. In the above Figure 4.3 demonstrated that the regression model equation provided the actual and predicted values were the same description of the experimental data, in which all points are the same close to the line of perfect fit.

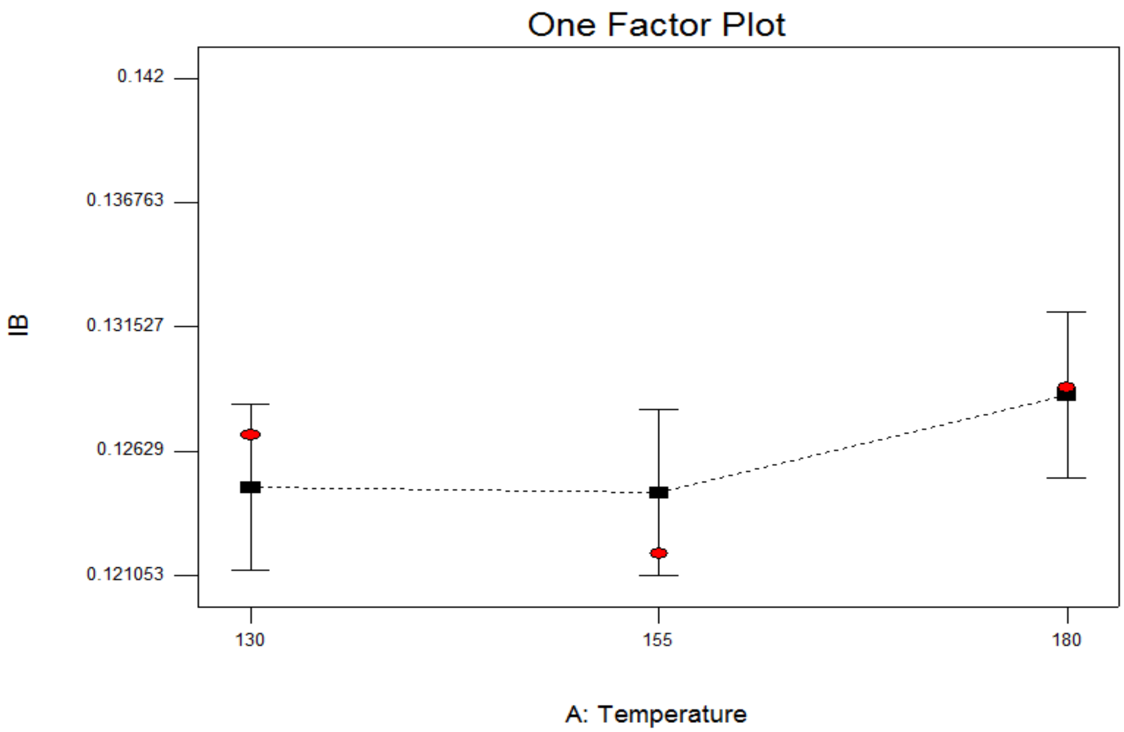


Figure 4.4 The effect of temperature in the internal bonding of particleboard

On the figure 4.4, the red color point indicated the design pints of a model. The temperature affects the internal bonding of MC particle board as the temprature goes from 130^{0}C to 155^{0}C the inerna bonding slightly constant after 155^{0}C the IB and the temperatures were directly proportional to the internal bonding.

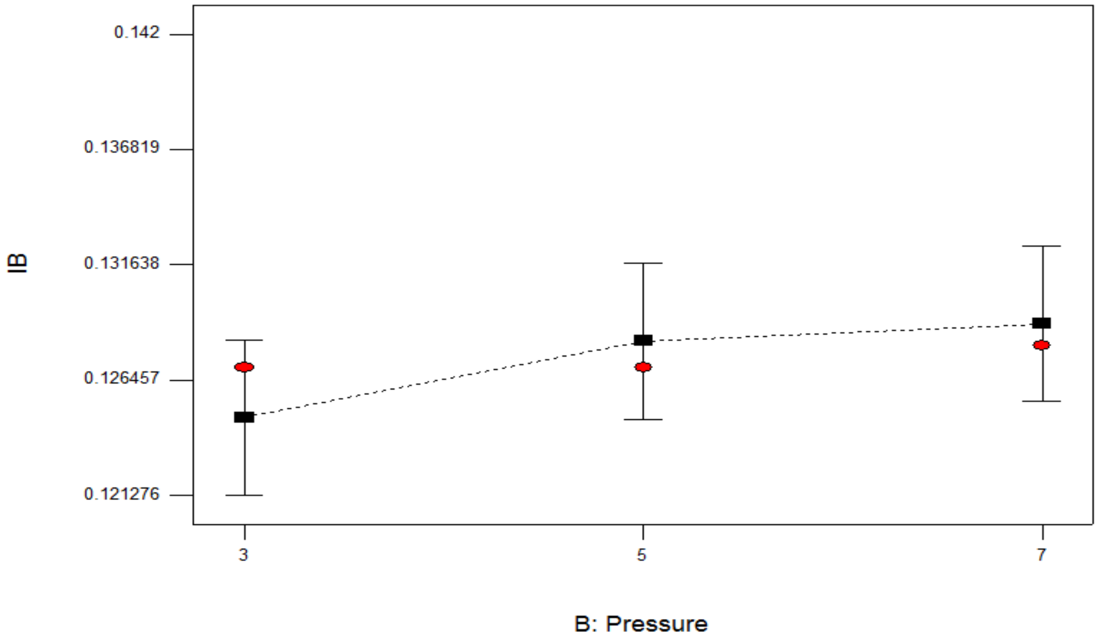


Figure 4.5 The effect of pressure in the internal bonding of particleboard

On figure 4.5, the red color point indicated the design pints of a model. When the pressure was increased, the internal bonding also increased but after 5MPa pressure the internal bonding was constant when the pressure was increased.

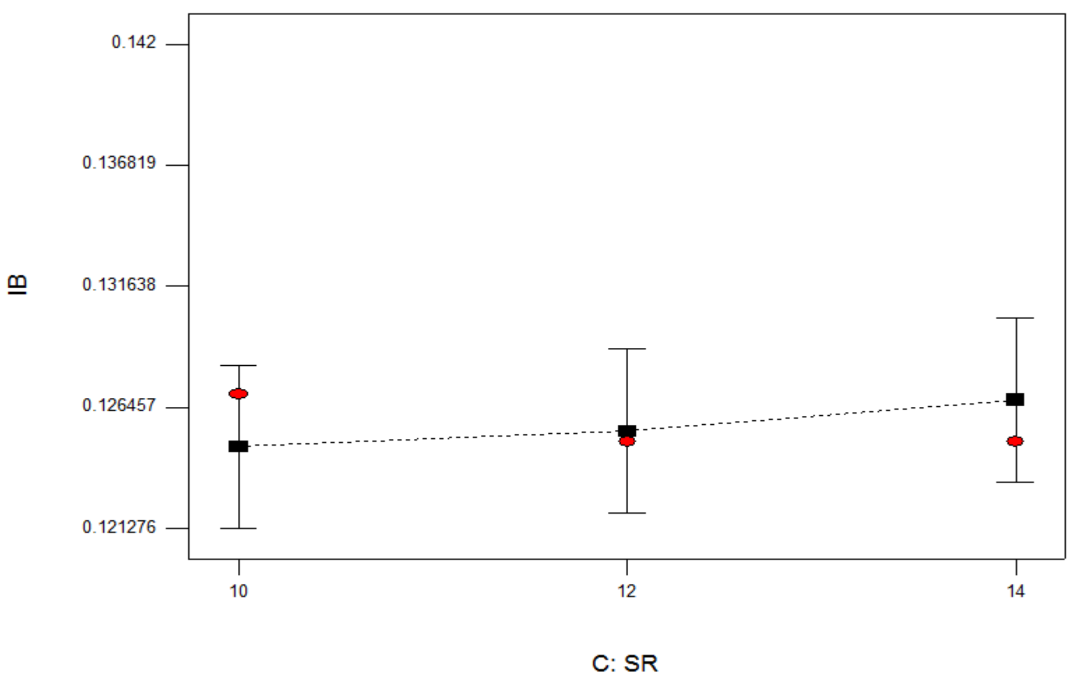


Figure 4.6 The effect of starch ratio in the internal bonding of particleboard

From the above figure 4.6, the red color point indicated that the design pints of a model. The starch ratio 15.4% to 17.9% the internal bonding is slightly constant but after 17.9% SR the IB was increased as increasing and SR also increased, due to affected by other control parameters like plate and mould temperature and pressing pressure the internal bonding was increased within increasing starch ratio.

4.6 Effects of Factors in Maize Cob Particle Board Production

4.6.1 Effect of Moisture Content

The mc of the MC particles played an important role in producible densities and strength. If the moisture content of the particle board is high, the stability and strength would be decreased. The minimum moisture content for the Particle board found to be 7.41% at 180^0C, 3MPa and 15.4% SR and the maximum was 13.84% at 130^0C, 3MPa and 20.3% SR. Average moisture content of all boards was 11.43%. According to Moslmi, (1974) refers the mc is between 8% to 12%. While at 11.43% mc allowed the production of panels and the density was between 6840kg/m^3 and 9083.33kg/m^3. Although the densities were specifically referenced, the actual densities of the produced panels varied within acceptable limits from the reference densities. The minimum producible densities probably resulted from the reduced starch molecule mobility at high moisture content. A possible explanation may be that moisture evaporated from the mixture thereby reducing its mc.

4.6.2 Effects of Adhesives

Relatively the moisture content low was with 15.4% modified starch ratio adhesive but 20.3% starch ratio the moisture content was increased. At 17.9% and 20.3% starch ratio relatively found to be a good internal bonding. The present investigation on the use of modified starch adhesive to prepare a natural adhesive that a particleboard panels bonded with modified starch adhesive showed lower physico-mechanical properties compared to UF resins but it was satisfied the exigencies of panels for interior fittings. Moreover, the formaldehyde emission levels obtained from boards bonded with modified starch adhesive were considerably lower to these obtained from boards made with control UF. Experimental studies have been showed that beyond at a temperature of 155^0C, 5MPa and 20.3% starch ratio, modified adhesives exhibit a good structural stability and having low water absorption relative to other factors for 30 minutes durations after 30 minutes almost all MC particle boards were soluble with water since starch by nature is soluble with water.

4.6.3 Effects of Temperature

The press time was constant for all experimental works. To study the effect of temperature was done at three different press temperatures of 180^0C, 155^0C, and 130^0C. A press temperature of 180^0C is an established temperature for industrial particleboard production; therefore, it was adopted in this work as the reference temperature. The lower temperatures of 155^0C and 130^0C also were adopted for the study bearing in mind that lower temperatures involve slower chemical and physical reactions and the PB have good stability with modified starch adhesives. After pressing, PB were degassed slowly at 180^0C relatively low moisture content rather than 130^0C press temperature.

The function of the hot press in particleboard production is to consolidate the chip mat to the desired thickness. The adhesive at the mat surface is the first to cure next to at the central region and then last. Relatively longer press cycles (7MPa) at lower temperatures of 130^0C were desirable because less water was removed from the board and the subsequent moisture adsorption from the atmosphere was reduced because less water was evaporated and the remaining water was more uniformly distributed in the finished board.

4.6.4 Effects of Pressure

At 7MPa press pressure the internal bonding was good relatively low pressing pressure. Press pressure is of minor importance in particleboard produced with press stops, once the initial mat consolidation is reached. The produced particleboards with reduced pressure at various temperature and SR intervals after the desired thickness was reached. No significant property deterioration occurred when the pressure was released after 12 minutes once stopped. The higher density boards 9083.33kg/m^3 exceeded the desired thickness and had slightly lower internal bond when the pressure was reduced.

CHAPTER FIVE

CONCLUTIONS AND RECOMMENDATIONS

5.1 Conclusions

This study presents an experimental work which investigates the potentiality of modified starch adhesives in the production of maize cob particleboard with the addition of wood glue (top bond) as a harder and manufactured under pressure and temperature by using manually hydraulic press. Almost all the characteristics property of maize cob analysis were met the requirements of American Society Testing and Materials.

The present investigation on the use of modified starch adhesive is a natural wood adhesive that a particleboard panels bonded was showed lower physico-mechanical properties relative to the panels made with the commercial UF and UF resins. Relatively the moisture content MC particle board made with at 180^0C decreased when compared to 130^0C.The observations from the physical and mechanical results showed that the densities and the percentage water absorptions of the immersed particle board increases with increasing time of immersion. The modified starch ratio, pressing pressure and mould temperature in particleboard manufacturing were important factors to determine the internal bonding.

Experimental studies have been shown that beyond 17.9% modified starch adhesives exhibit a good structural stability. It is concluded that maize cobs can be utilized in the manufacturing of particleboard and use in summer area with long dry seasons or by panting formica and verneer, it can be used for manufacturing and in industrial purpose.

5.2 Recommendations

Create and increase an awareness to the society after using the maize, cobs put into a container.

If we used automatic hot press machine, the stability and strength of particle board will be increased due to this further studies will be required for improving the production process.

This study should be progress to further improve modified starch adhesive formulation.

Further studies necessarily required for pretreatments of modified starch adhesive in order to improve water resistance.

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APPENDIX I: Laboratory Chemicals and Equipments

Preparation of modified starch adhesives

To prepare 500 g of modified adhesive, corn starch water solution was prepared at 65% (p/v) concentration, by dissolving 130 g of cornstarch in 200 ml of deionized water and stirred at room temperature. The solution was mixed and 100 ml of sodium hydroxide (33%) was added. The resulting adhesives were mixed for 45 min at room temperature then used to bond particleboard.

Modified starch

Maize cob

Attrition mill

Thermostat water bath

Muold

Metal plate

Manually hydraulic press

Starch

Figure i: Experimental laboratory equipment’s

APPENDIX II: Design Expert Plot 6.0.8 Version interaction graph

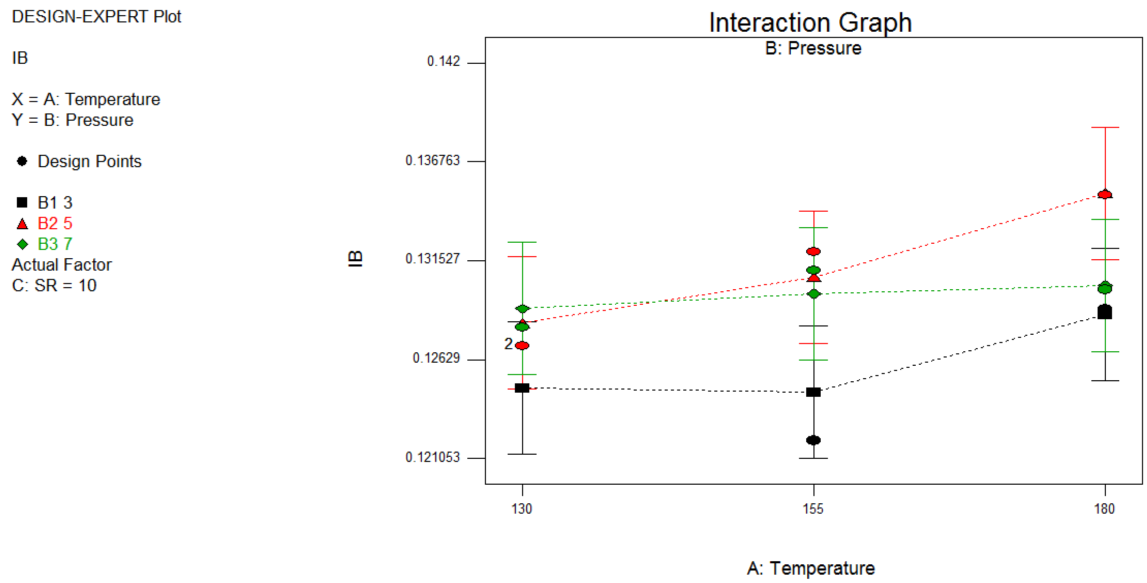

Figure i: The interaction effects of pressure and temperature on internal bonding

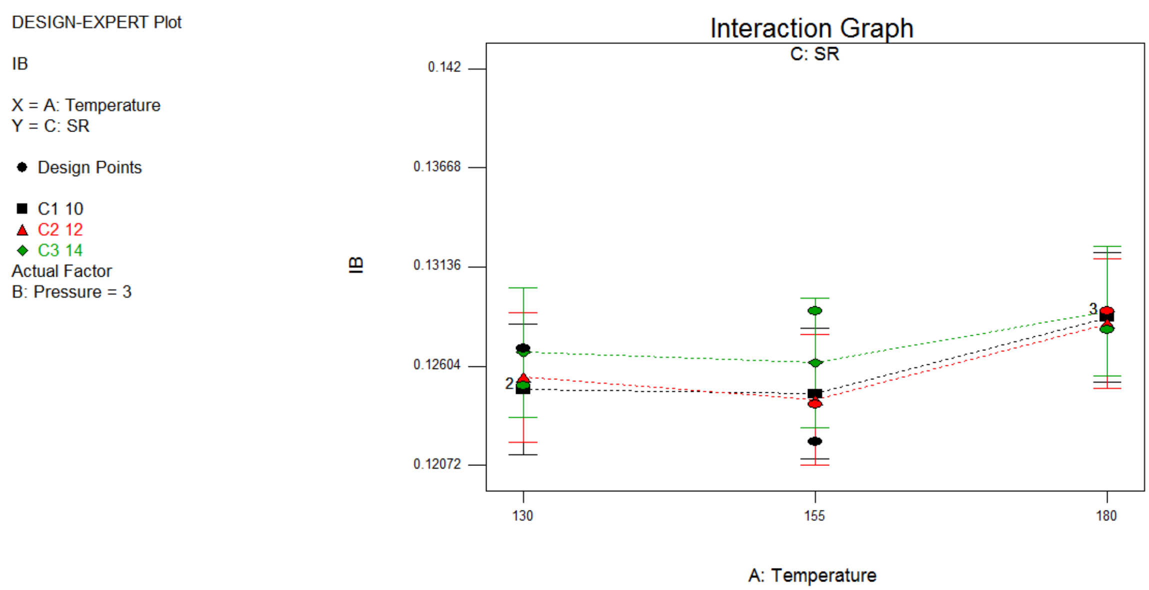

Figure ii: The interaction effects of starch ratio and temperature on internal bonding MC PB

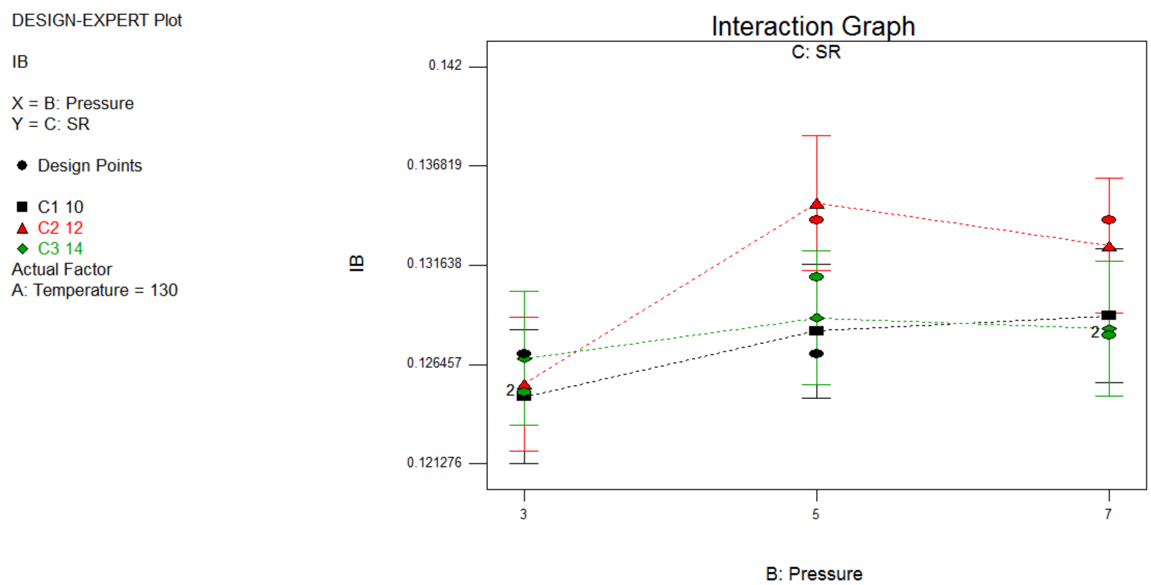

Figure iii: The interaction effects of starch ratio and pressing pressure on internal bonding MC PB

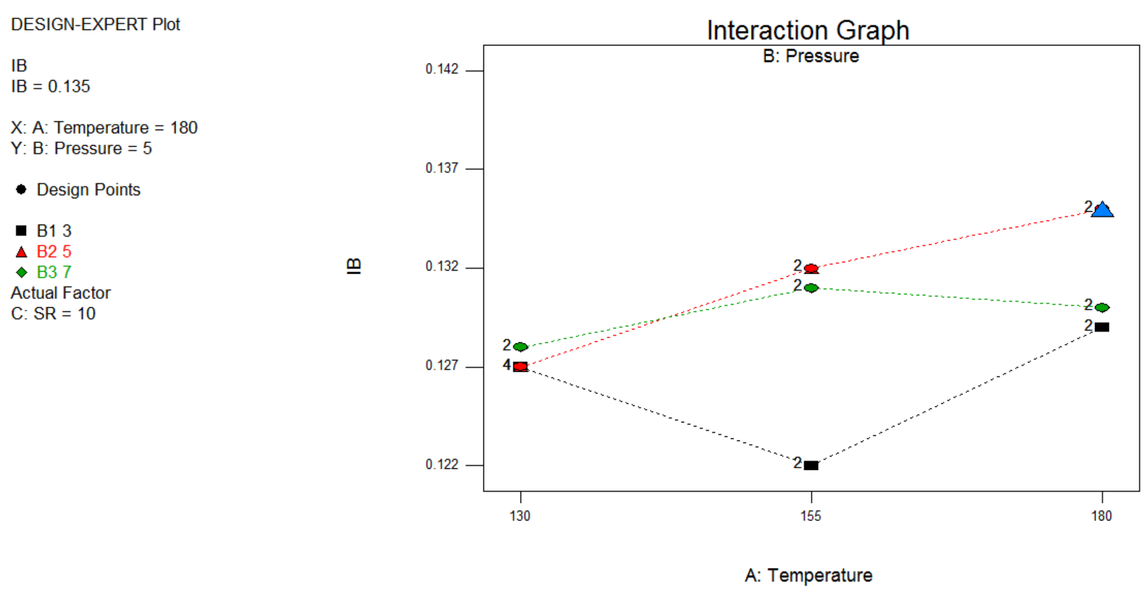

Figure v: The interaction effects of temperature, pressing pressure and starch ratio on internal bonding of MC PB