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UTILIZATION OF MAIZE COB (Zea mays) FOR THE PRODUCTION OF BINDERLESS PARTICLEBOARD

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DECLARATION

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Khan Md. Masudur Rahman

Dedicated

To

My Beloved Father Late Khan Md. Aminuddin

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ABSTRACT

Agricultural residues are materials generated in large quantities in Bangladesh. Among agricultural residues, maize cob (*Zea mays*) is one worthy of notice, and an alternative use for maize cob would be to produce binderless particleboard panels in association with jute stick (*Corchorus capsularis)*. This study aimed to evaluate the feasibility of using maize cob for production of binderless particleboard panels. The following maize cob percentages were used: 0%, 25%, 50%, 75% and 100%, in association with the particles of jute stick. For compressing the panels, a pressure of 10MPa was applied at a temperature of 190° C, for 10 minutes. Increased replacement of jute stick by maize cob residue promoted significant improvements to the properties water absorption, thickness swelling after half and two hours of immersion. Mechanical properties had a decreasing correlation with the maize cob percentage being incorporated.

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List of abbreviations

Anon	Anonymous
ANOVA	Analysis of Variance
LSD	Least Significant Difference
ASTM	American Society for Testing and Materials
AWPA	Australian Wood Panels Association
BBS	Bangladesh Bureau of Statistics
FAO	Food and Agricultural Organization of United Nations
gm/cm^3	Gram per cubic centimeter
Ha	Hectare
kg/m^3	Kilogram per cubic meter
KN	Kilo Newton
lb/ft^3	Pound per cubic feet
cm	Centimeter
m	Meter
mm	Millimeter
µm	Micro meter
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MPa	Mega Pascal
N/mm^2	Newton per square millimeter
rpm	Rotor per minute
SD	Standard deviation
UTM	Universal Testing Machine
WP	Wood particle

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The world population is increasing rapidly day by day. As a result the natural resources of world mainly forest resources is decreasing continuously to meet the demand of increasing population. The inexorable increase in population together with shifting climatic pattern will put more pressure on the land to sustain local communities, which rely on forest products of various kinds. To meet the demand of expanding pressure, alternative raw materials are major concern of the world (Adger and Brown, 1994).

A number of researchers has explored the feasibility of using fast-growing trees and agricultural residues as alternative raw materials for particleboard or binder less board production. Particles or fiber of lignocellulosic material bonded together with each other and produce in panel form are gradually gaining importance in a number of countries in the world. Worldwide economic growth and development have generated unprecedented needs for converted forest products such as pulp and paper, composite boards, plywood and lumber (Youngquist *et al.*, 1993). According to Adger and Brown (2000) this global demand is the main reason of aggressive deforestation across the world.

Bangladesh is a small country but also faces the same problem because of its vast population and the demand of growing population. To meet the demand of vast population the forest resources of Bangladesh is decreasing day by day. On the other hand, the wood-based industries in Bangladesh faced boldly a hard situation of great lacking of available raw materials. Due to heavy industrial development, these wood-based composites such as hardboards, fiberboards, binderless board etc. are in high demand and have to be supplied successively. So, it is now very much essential to find out alternative raw materials for these industries, not only to meet the demand but also to reduce the pressure on the presently used tree species by these industries (Adhikary *et al.*, 2007).

Nowadays, environmental and economic concerns are stimulating research in the development of new materials for construction, furniture, packaging, and automobiles industries. Particularly, many research studies have conducted on composite panels from non-wood lignocellulosic materials in which most are based on natural renewable resources. Non-wood lignocellulosic materials have been considered to produce various composite products. These resources are abundantly available in many countries; including residues from annual growth plants. Most of non-wood lignocellulosic materials have very low densities, which make them extremely bulky.

The collection, transportation and storage of these materials call for special attention, due to the bulky nature of bagasse, cereal straw, maize cob, jute etc. and they are abundantly available (Markessini *et al*., 1997).

Maize cob is worthy of special mention due to its high volume productivity, with corn (*Zea mays* L.) being ranked third among the most widely cultivated cereals worldwide, after wheat and rice. It is a neglected but a novel source of renewable ligno-cellulosic raw material. But due to little knowledge about the technical feasibility of making binderless particleboard from these novel sources of ligno-cellulosic raw material, these are now being underutilized. Maize cob are using as fuel wood. If the study for finding the technical feasibility to convert them into binderless particleboard, a new avenue can be opened to the particleboard manufacturing industries. Jute, as a natural fiber, has many inherent advantages like luster, high tensile strength, low extensibility, moderate heat and fire resistance and long staple lengths. It is a biodegradable and eco-friendly. It has much advantage over synthetics and protects the environment and maintains the ecological balance. (International Jute Study Group, 2011).

In this study, we use jute stick and maize cob as a composite raw material of binderless particleboard. Binderless board is a wood panel made without the use of synthetic adhesive. It is prepared by hot pressing of wood particles that involves a self-bonding process (Workshop on Technology Transfer: 15 July, 2014).

It is well known that wood-based fragments can be converted into boards by steam/heat treatments without using any adhesive (Shen, 1991). This phenomenon, called self-bonding, is improved by activating chemical components of the board constituents during steam/heat treatment. These reactions may include degradation of both the hemicelluloses and part of the cellulose to produce simple sugars and other decomposition products (Shen, 1991; Rowell *et al.*, 2002; Widyorini *et al.*, 2005); thermal softening of the cell wall matrix (Inoue *et al.*, 1993); crosslinking between carbohydrate polymers and lignin (Suzuki *et al.*, 1998), and an increase in cellulose crystallinity (Tanahashi *et al.*, 1989).

1.2 Objectives of the study

Considering the above context, the objective of this study is to evaluate the feasibility of using maize cob for production of binder-less particleboard.

- To study potentiality of maize cob (*Zea mays*) as a raw material for the production of binderless particleboard.
- To evaluate the physical and mechanical properties of maize cob binderless particleboard.

CHAPTER TWO

LITERATURE REVIEW

2.1 Scientific classification

Corchorus capsularis L.

Kingdom: Plantae

Unranked: Angiosperms

Unranked: Eudicots

Unranked: Rosids

Order: Malvales

Family: Malvaceae

Genus: Corchorus

Species: C. capsularis

Botanical name: *Corchorus capsularis* L.

Figure 2.1 Jute Plantation

2.2: Brief about jute stick

The word 'jute' is probably coined from the word jhuta or jota, an Oriya word. Jute is one of the most affordable natural fibers and is second only to cotton in amount produced and variety of uses of vegetable fibers. Jute fibers are composed primarily of the plant materials cellulose and lignin. It falls into the bastfibre category along with kenaf, industrial hemp, flax (linen), ramie, etc. The industrial term for jute fiber is raw jute. The fibers are off-white to brown, and 1–4 metres (3–13 feet) long. Jute is also called "the golden fiber" for its color and high cash value. Jute is a long, soft, shiny vegetable fiber that can be spun into coarse, strong threads. It is produced from plants in the genus Corchorus, which was once classified with the family Tiliaceae, more recently with Malvaceae, and has now been reclassified as belonging to the family Sparrmanniaceae.

Jute is a natural fibre with numerous environmental advantages. It is an annually renewable resource with a high biomass production per unit land area, and jute products being biodegradable decompose in the soil at the end of product life-cycle. Towards global warming, a concern of much importance in the present world, while the synthetic materials are being considered as the root of many problems, the natural fibre products are proven to be absolutely harmless (International jute study group, 2011)

The worldwide awareness on environment is the reason for the opportunities of Jute, due to environment friendly characteristics. Jute, a natural fiber that can be used in many different areas, supplementing or replacing synthetics, has been receiving increasing attention from the industry. The usages of jute are not only traditional uses, but also on the production of other value –added products such as, pulp and paper, geo-textiles, composites and home textiles. Jute is an annually renewable energy source with high a biomass production per unit land area. It is biodegradable and its products can be easily disposed without causing environmental hazards. The roots of jute plants play a vital role in increasing the fertility of thy soil. Jute plants have carbon dioxide assimilation rate and it clean the air by consuming large quantities of carbon dioxide. So, the research aims are to evaluate and review the impacts of jute in Bangladesh in the context of Bangladesh (International jute study group, 2011).

2.3: Major types of jute in our country

2.3.1: White jute (*Corchorus capsularis*)

Corchorus capsularis, commonly known as white jute is a shrub species in the family Malvaceae. It is one of the sources of jute fibre, considered to be of finer quality than fibre from *C. olitorius*. The leaves, unripe fruit, and the roots are used in traditional medicine.

2.3.2: Tossa jute (*Corchorus olitorius*)

Tossa jute (*Corchorus olitorius*) is a variety thought to be native to India, and is also the world's top producer. It is grown for both fibre and culinary purposes. It is used as a herb in Middle Eastern and African countries. On the other hand, it is used mainly for its fiber in Bangladesh, in other countries in Southeast Asia, and the South Pacific. Tossa jute fiber is softer, silkier, and stronger than white jute. Along with white jute, tossa jute has also been cultivated in the soil of Bengal where it is known as paat from the start of the 19th century. Bangladesh is the largest global producer of the tossa jute variety. In this study white jute (Corchorus capsularis) is used as raw material for manufacturing of binderless board. I tried to make binderless board using white jute stick in eco-friendly way. It is possible to make binderless board using jute stick because jute stick contains higher amount of hemicelluloses and lignin that is the main component of binderless board.

2.4: Chemical constitution of jute stick

Table-2.4 Shows the chemical composition of jute sticks. (Handbook of Pulp and Paper processing)

Constitutes	Jute stick
Alpha cellulose	40%
Hemicellulose	34%
Lignin	23%

Binderless board prepared by hot pressing of wood particles that involves a self-bonding process. The mechanism of self-bonding during steam/heat treatment has not been completely elucidated. However, the degradation of hemicelluloses during stem/heat treatment is believed to play an important role in self-bonding. Therefore, binderless boards are usually prepared from non-wood raw materials, which are rich in hemicelluloses (Jianying, 2005). Jute stick is rich in hemicelluloses and very light in weight, it seems to be a good raw material for making binderless particle board.

2.4.1 Physical Properties of jute fibre

Table -2.4.1: Shows the physical properties of jute fiber (Sur and Amin, 2010).

Ultimate Cell Length (L)	2.50 mm
Ultimate Cell Breadth	18 μm
Density	1.46 g / cc
Moisture Regain at 65% RH	13.80%
Transverse Swelling in water (Diameter-wise)	20%
Water holding Capacity	500%
Heat of Combustion	17.5 J / g
Ignition Temperature	193° C

Jute absorbed the Carbon dioxide from the air, which helps the ozone layer from destruction. It also emits oxygen to the atmosphere, which is helping the livelihood. Jute as a fibre crop is a fast-growing one that takes only 4 to 5 months to mature. The production of the fastest growing wood plant necessitates at least 10 to 14 years from the plantation to harvest. The usages of jute in place of wood to make binderless board will reduce the cost of production(International jute study group).So following this feasibility of jute I tried to make binderless board to reduce the cost of wood.

2.4.2 Major Drawback of Uses of Jute:

The major disadvantages of jute sticks are to their coarseness, stiffness, low extensibility, wash shrinkage, ready susceptibility to microbial attack and poor abrasion resistance. In order to minimize or even eliminate some of the major disadvantages attempts have been made to reduce such problem (Sarkar and Adhikari, 2001)

2.5 Brief about Zea mays

2.5.1 Scientific classification:

Kindom: Plantae

Unranked: Monocots

Unranked: Commelinids

Order: Poales

Family: Poacae

Sub Family: Panicoideac

Genus: Zea

Species: *Zea mays*

2.5.2 Botanical Description of *Zea mays*

Zea mays, corn or maize, is a annual grass in the Poaceae (grass family) that originated in Central America and is one of the top three cereal crops grown in the world, along with rice (*Oryza sativa*) and wheat (Triticum spp.). with 2010 global commercial production of dried corn totaling 844.4 million metric tons, harvested from 161.9 million hectares.

Corn was domesticated in Mexico and Central America more than 7,000 years ago from teosinthe or wild maize (Z. mays subsp. mexicana). The corn plant may grow 1–4 m (3 to 13 ft) tall, with leaf blades 50 to 90 cm (19 to 35 in) long. Corn is used fresh ("green") for human consumption, or may be dried and ground into flour or meal, important in Central American dishes, or popped and eaten as a snack. In addition to use as a human food, the seed head and whole plant are used forage and silage, an important source of feed for livestock. Corn has become an increasingly important biofuel, both in the form of corn oil (used as bio-diesel) and ethanol (an alcohol fermented and distilled from the processed kernels), which is blended with petroleum-based gasoline in various proportions, With Although grown in temperate and tropical countries worldwide, the U.S. alone produces more than one third of the global total of dried corn (316.2 metric tons), with China, Brazil, Mexico, and Argentina also producing significant amounts. Corn production increased by 42% worldwide over the past decade, associated with the increased demand and prices for corn as biofuel.

2.5.3 Chemical analysis

Table-2.5.3: provides percentage values of chemical components present in maize cob (ASTMD-1037, 2002)

Constitutes	Maize cob
Alphacellulose	44%
Hemicellulose	36%
Lignin	14-27%

2.5.4 Utilization of maize cob:

Maize cob is worthy of special mention due to its high volume productivity, with corn (*Zea mays* L.) being ranked third among the most widely cultivated cereals worldwide, after wheat and rice. It is a neglected but a novel source of renewable ligno-cellulosic raw material. But due to little knowledge about the technical feasibility of making binderless particleboard from these novel sources of ligno-cellulosic raw material, these are now being underutilized. Maize are using as fuel wood. If the study for finding the technical feasibility to convert them into binderless particleboard, a new avenue can be opened to the particleboard manufacturing industries.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Collection and preparation of raw materials

Maize cob was used as the raw material for manufacturing the binderless particleboards in association with jute stick particles. Maize cob and Jute (*Corchorus capsularis*) sticks were collected from Jhenaidha District of Khulna division. Jute (*Corchorus capsularis*) stick about 1.2 m long and 10-12 mm in diameter was used as raw material. First, the jute stick was cut into chips about 3-4 cm in length. Then the chips were entered into grinding machine with the mesh size of 0.25-0.50mm.

Figure 3.1: Raw material (Jute stick & Maize cob)

3.1.2 Preparation of particles

To obtain binderless particleboards with good strength, smooth surfaces, and equal swelling, manufacturers ideally using a homogeneous material with a high degree of slenderness (long, thin particles), no over-size particles, no splinters, and no dust are needed.

3.1.3 Screening

For preparing samples, the particles were screened through a mesh screen to separate the dust.

3.1.4 Particle Drying:

After processing, the raw materials was kept in an electrically heated lab scale oven (Model NO: DHG-9101-ISA and S.N.-5054) at 80^0C for 24 hours to dry them. At this stage, the particle moisture content was measured to 12-14 %.

3.2 Binderless board manufacture

3.2.1 Mat Formation

The weight of the maize cob and jute stick particles was measured according to their target densities, after which the particles were hand-formed using a forming box. The mats were pressed again and again during formation. Particles are evenly spread in the frame to allow equality in shape. The mat was formed seven times higher than the particleboard thickness. So the mat was 35mm as the target board thickness was 5mm.

Fig 3.2.1: Mat formation

3.2.2 Hot pressing

In hot press machine, time and temperature had to set. Temperature was allowed to raise up to the desired limit and the desired limit was 190^{0}C. The mat was covered with steel sheet and then inserted into the hot press for pressing. The pressure (10Mpa) was remained for 10 minutes. After 10minutes, the machine was switched off. Therefore, the temperature was dwindled gradually but retained the pressure for 10 minutes. The mat was allowed to cool for 20 minutes after switched off. Then the pressure removed and brought out the board. The board was then allowed to cool.

3.2.3 Trimming

After the board was manufactured, the edges of the board were trimmed with the fixed type circular saw. The well-pressed boards were then cut into reasonable size to test the boards in the laboratory.

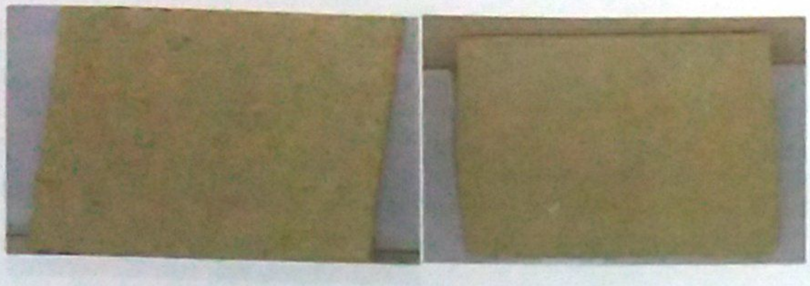
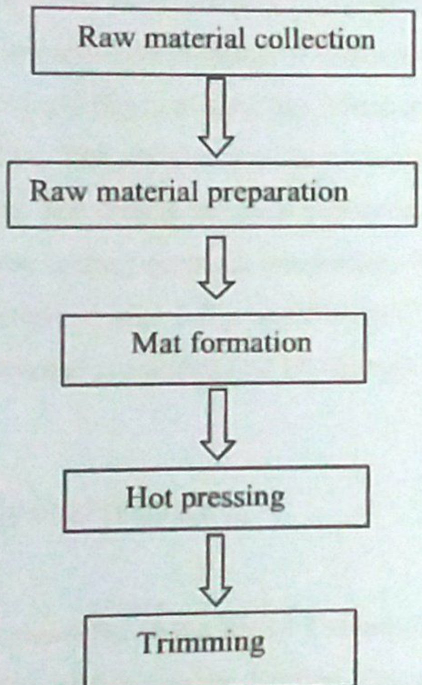


Fig. 3.2.4- Finished Board

3.2.5 Flow Diagram of Binderless Particle Board Production



3.3 Experimental Design

Table-4: The experimental design consisted of five treatments, in which four percentages of maize cob residues were used in replacement of jute stick, as is illustrated in table-

Treatment	Maize cob (%)	Jute stick (%)
1	0	100
2	25	75
3	50	50
4	75	25
5	100	0

3.4 Manufacturing and Laboratory Test

The particle board was manufactured at Pulp and paper Technology Laboratory and Wood science lab that are controlled by Forestry and Wood Technology Discipline, Khulna University, Khulna. All physical tests for its quality were also done there, and MOE, MOR, IB were tested from Akij Particleboard Mills Ltd. The properties were tested according to the procedures defined in the Japanese standard for particleboards.

3.5 Preparation of samples for testing

The properties of the particleboard were evaluated according to the Japanese Industrial Standard (JIS A 5908 2003). Mechanical tests like modulus of elasticity (MOE), modulus of rupture (MOR), internal bonding strength (IB) and physical tests like, Density, moisture content, water absorption (WA), thickness swelling(TS),. The samples were prepared at a dimension of 300mm x 200mm x 5 mm for static bending test. For testing physical properties, four samples were collected from each board of each type for testing physical properties. Moisture content, water absorption, thickness swelling were determined after 1/2hr. and 2 hours of soaking under water. The dimension of samples for testing the physical properties and IB strength was approximately 50 mm x 50 mm x 5 mm.

3.6 Determination of physical properties

3.6.1 Density

Density of each sample was measured in the Wood Technology Laboratory of Forestry and Wood Technology Discipline of Khulna University, Khulna. Density was calculated by the following formula-

$\rho = \frac{m}{v}$ (Desch and Dinwoodie, 1996)

Where, m= Mass of the sample in gm and v= Volume in cm^3

3.6.2 Moisture content

The moisture content was determined, from the differences in weights before and after the sample has been drying in the oven. Initial and final weight of the samples was measured by electric balance. It was calculated by the following formula-

$$MC\ (\%) = \frac{\text{Green Weight} - \text{Oven Dry Weight}}{\text{Oven Dry Weight}} \times 100$$ (Desch and Dinwoodie, 1996)

Where,

MC= moisture content (%)

3.6.3 Water absorption

Water absorption is expressed in percentage and defined as the difference in weight before and after immersion in water. The water absorption was calculated by the following formula-

$$A_w = \frac{m_2 - m_1}{m_1} \times 100$$ (Desch and Dinwoodie, 1996)

Where,

Aw= Water absorption (%)

m_2= The weight of the sample after (24hr.) immersion in water (gm)

m_1= The weight of the sample before immersion in water (gm)

3.6.4 Thickness swelling

Thickness swelling was expressed in percentage and calculated by the following formula-

$$G_t = \frac{t_2 - t_1}{t_1} \times 100$$ (Desch and Dinwoodie, 1996)

Where,

Gt= Thickness swelling (%)

t_2= Thickness of sample after immersion (24hr.) in water (mm)

t_1=Thickness of sample before immersion in water (mm)

3.7 Static Bending Strength Test

3.7.1 Modulus of rupture (MOR)

The MOR was calculated from the following equation-

$MOR = \frac{3PL}{2bd^2}$ (Desch and Dinwoodie, 1996).

Where,

MOR= Modulus of rupture (MOR) in N/mm^2

P= Load in N

L= Span length in mm

b= Width of test sample in mm

d= Thickness of test sample in mm

And the specific MOR was calculated from the following equation-

$$\text{Specific MOR} = \frac{MOR}{Density}$$

3.7.2 Modulus of elasticity (MOE)

The Modulus of elasticity (MOE) was calculated from the following equation-

$$MOE = \frac{pl^3}{4\Delta bd^3}$$ (Desch and Dinwoodie, 1996).

Where,

MOE is the modulus of elasticity in N/mm^2

P= Load in N at the limit of proportionality

L= Span length in mm

Δ= the deflection in mm at the limit of proportionality

b= Width of sample in mm

d= Thickness/depth of sample in mm

And the specific MOE was calculated from the following equation-

$$\text{Specific MOE} = \frac{MOE}{Density}$$

3.7.3 Internal bonding strength (IB)

Adhere a test piece to steel or aluminum blocks, apply a tension load vertically to the board face, measure the maximum load (P') at the time of failing force (breaking load of perpendicular tensile strength to the board), and calculate the internal bond from the formula below:

Internal bond (N/mm^2) = $P'/2bL$ (JIS A 5908, 2003)

Where,

P': maximum load (N) at the time of failing force

b: width (mm) of sample

L: length (mm) of sample

3.7.4 Surface Soundness test

Strength or quality of bonding between the particles or fibres at the surface of a board and the layer below (unfaced panels) or between the coating material and the underlying board (overlaid panels). Measurement of the tensile load required to pull off a defined surface area of overlaid or unfaced panel.

To carry out the test in accordance with EN 326-1, each sample is cut into 50 mm × 50 mm.

The surface soundness SS for each test piece in newton's per square millimeter shall be calculated from the equation

SS = F/A (JIS A 5908, 2003)

Where,

F, is the maximum force in Newton's;

A, is the surface area given in mm^2.

Express the result to the nearest 0,01 N/mm^2.

3.8 Analysis of Data

It is important to characterize the significance of all the samples of binderless board. In the laboratory, the data was analyzed by using Microsoft Office Excel. and Minitab-18, software to assess the physical and mechanical properties of binderless boa

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical Properties of Binderless Board

4.1.1 Density

Density is an important parameter and it virtually affects all the properties of binderless board. It has been found that the density of binderless particleboards, Maize cob (100%), M+J (75+25%), M+J (50+50%), M+J (25+75%), and Jute stick (100%) are 0.66, 0.68, 0.72, 0.73 and 0.72 g/cm3 respectively. From the analysis of variance, it has been found that there was significant difference (F= 8.92, df=4 and $p<0.05$) among the density of five different binderless particleboards.

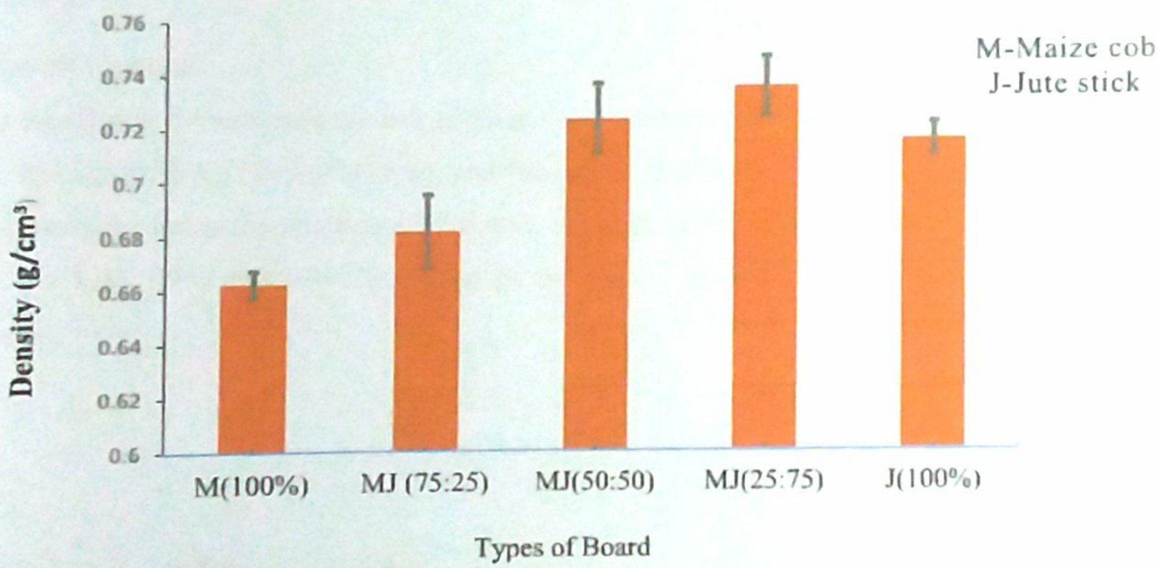


Fig 4.2 Density of binderless particleboards

Medium density particle board density was 0.75 g/cm^3 (ANSI A208.1–1993). The steam-exploded fibers of oil palm frond binderless board had density lower than 0.70 g/cm^3. The density of binderless board made with palm date tree without stem injection was 0.97 g/cm^3. (Saadaoui *et.al.*, 2013). The variation in density between maize cob and jute stick composite binderless board and medium density particleboard may be due to the variation of the raw materials itself.

In this study density of the boards were ranges from 0.65-0.73 gm/cm^3. The variation of densities was due to mat thickness and pressing time variation and it was done intentionally to observe different physical and mechanical properties of board at different densities. Different ratio of jute stick and maize cob, temperature and pressure may affect the board density. Bending properties of the board are greatly influenced by density. Density depends on the density of raw materials used, hot pressing conditions and other factors (Hsu *et al.*, 1988; Sekino, 1999; Volasqueze *et al.*, 2003). Pressing temperatures or press pressures may have important effect on board density. Arias (2008) emphasized four factors that are significantly important for the density and these factors are pretreatment temperature, pretreatment time, pressing temperature and initial pressing pressure. Density also may depend on the proper distribution of lignin between the particles during pressing process. To allow a good distribution of lignin between the particles during the pressing process, it is necessary to apply enough heat and pressure to melt the lignin through the whole board (Arias, 2008).

4.1.2 Moisture Content

It has been found that the moisture content of binderless particleboards, Maize cob (100%), M+J (75+25%), M+J (50+50%), M+J (25+75%), and Jute stick (100%) are 9.23, 9.12, 8.72, 8.61 and 8.87 % respectively. From the analysis of variance, it has been found that there was significant difference ($F= 8.01$, $df=4$ and $p<0.05$) among the moisture content of five different binderless particleboards.

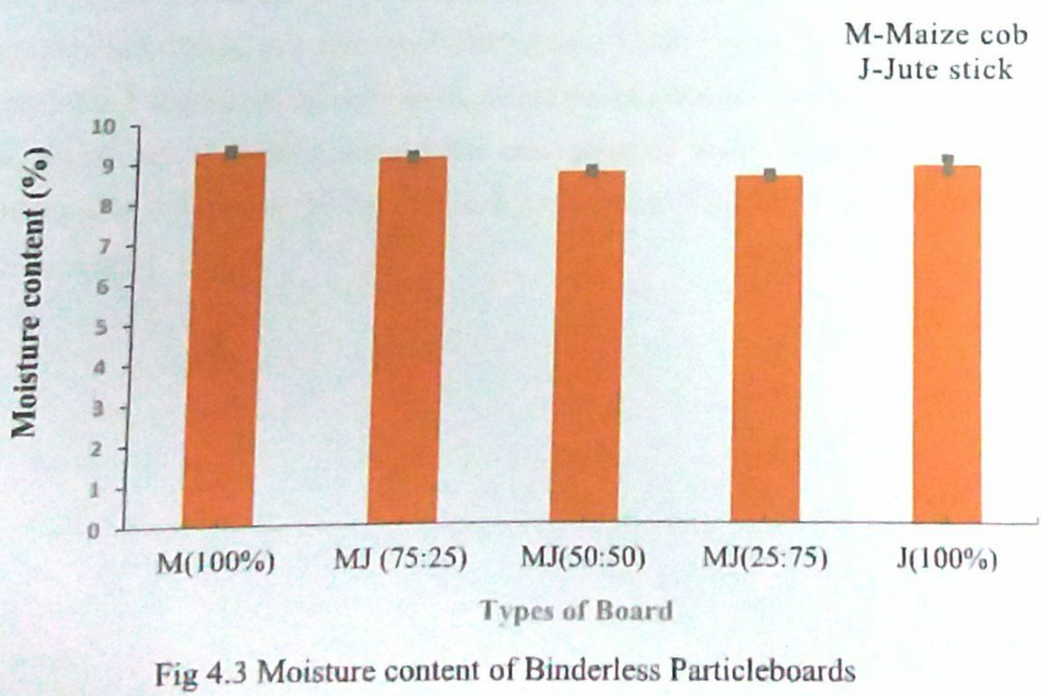


Fig 4.3 Moisture content of Binderless Particleboards

The moisture absorption in particleboard is mainly due to the gaps and flaws at the interfaces, and the micro-cracks in the matrix formed during the manufacturing process. The moisture content ensures good physical and mechanical properties and dimensional stability.

The moisture content of the medium density particle board was 9 %(ANSI A208.1–1993). The variation of moisture content among different types of binderless boards may be due to the variation in moisture content of raw materials itself or other parameters like chemical behavior of the particles or variation of temperatures during pressing time. Temperature has direct impact on moisture content as temperature is related to the melting of lignin. If any board is produced by higher temperature, it absorbs less moisture content. At the elevated temperatures, the moisture is removed from the board and melted lignin distributed equally in the board and sealed the lumen of the particles (Mancera *et al.*, 2011).

4.1.3 Water Absorption

It has been found that the absorption of water of binderless particleboards of, Maize cob (100%), M+J (75+25%), M+J (50+50%), M+J (25+75%), and Jute stick (100%) are 109, 102.54, 91.07, 87.14 and 96.30% respectively after 1 hour immersion in water.. It has been also found that the absorption of water of binderless particleboards of Maize cob (100%), M+J (75+25%), M+J (50+50%), M+J (25+75%), and Jute stick (100%) are 137.84, 130.66, 123.13, 117.81 and 125.78 respectively after 2 hours immersion in water. From the analysis of variance, it has been found that there was significant difference among the absorption of water of five different binderless particleboards after 1 hour ($F= 30.55$, $df=4$ and $p<0.05$) and 2 hours ($F=68.43$, $df=4$and $p<0.05$) immersion in water.

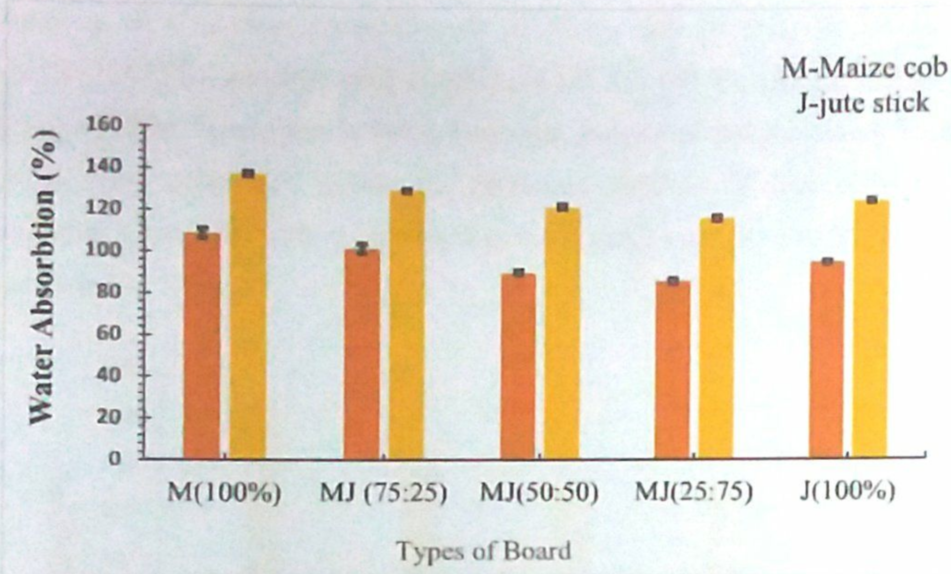


Fig 4.2.3 Water absorption of Binderless Particle Board.

Water absorption capacity is an important factor in the case of binderless particleboard. Physical and mechanical properties of binderless board also influenced by water absorption capacity of samples (Kumar, 2008). Binderless board made with spruce and pine showed water absorption 45% and 75% (Angles *et al.*, 1999). Due to presence of hydroxy and other polar groups in various constituents of maize cob and jute particles, the moisture uptake is high (approx. 12.5% at 65% relative humidity and 20°C) (Basak *et al.*, 1998). All this leads to weak interfacial bonding between maize particle and the relatively more hydrophobic matrices. Board density has a significant effect on the water absorption. Water absorption decreased with increasing board density in the case of kenaf core binderless board. Low-density board had high water absorption compared to medium density particle board (Widyorini *et al.*, 2005). The higher amount of hemicelluloses content in maize cob may lead to the higher affinity to moisture. In the case of fiberboards, the dimensional stability of the fiberboards is related to partial hemicelluloses hydrolysis because hemicelluloses are very hydrophilic (Arias, 2008).

4.1.4 Thickness Swelling

It has been found that the thickness swelling of binderless particleboards of, Maize cob (100%), M+J (75+25%), M+J (50+50%), M+J (25+75%), and Jute stick (100%) are 71.39, 68.59,61.70, 55.12 and 63.33 respectively after 1/2 hour immersion in water. It has been also found that the thickness swelling of binderless particleboards of Maize cob (100%), M+J (75+25%), M+J (50+50%), M+J (25+75%), and Jute stick (100%) are 165.19, 143.29, 131.13, 128.69 and 139.32 respectively after 2 hours immersion in water. From the analysis of variance, it has been found that there was significant difference among the thickness swelling of four different binderless particleboards after 1 hour (F= 125.41, df=4 and $p<0.05$) and 2 hour (F= 195.22, df=4and $p<0.05$) immersion in water.

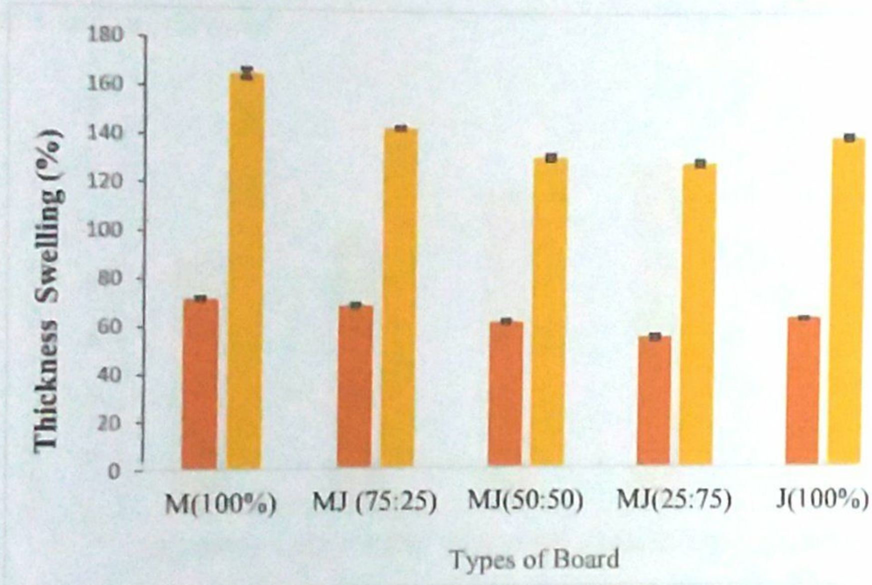


Fig 4.2.4 Thickness swelling of Binderless Particle board.

Thickness swelling is related to the dimensional stability of the boards. This property gives us an idea of how the boards will behave when used under conditions of severe humidity and are especially important regarding boards that are to be used externally (Mancera *et al.*, 2011). Thickness swelling varies between 5.8 and 14.7% in the case of particleboard (JIS A 5908). In the case of medium density particle board thickness swelling of the board was 8% (ANSI A208.1–1993). Binderless boards made from spruce and pine showed thickness swelling 12 % and 37% (Angles *et al.*, 1999). So, thickness swelling of maize cob and jute stick binderless board was higher than other boards. The factors affecting water absorption are responsible for the thickness swelling of maize cob and jute stick binderless particleboard. The thickness swelling value is believed to relate with density. In the case of kenaf core binderless board the thickness swelling values showed a trend to increase with increasing density. This may be due to the high spring back (Widyorini *et al.*, 2005).

4.2 Mechanical Properties

4.2.1 Modulus of Rupture (MOR) N/mm^2

It has been found that the modulus of rupture of binderless particleboards of, Maize cob (100%), M+J (75+25%), M+J (50+50%), M+J (25+75%), and Jute stick (100%) are 8.82, 9.66, 11.23, 12.15 and 11.07 N/mm^2 respectively. From the analysis of variance, it has been found that there was significant difference ($F= 34.67$, $df=4$ and $p<0.05$) among the modulus of rupture of five different binderless particleboards.

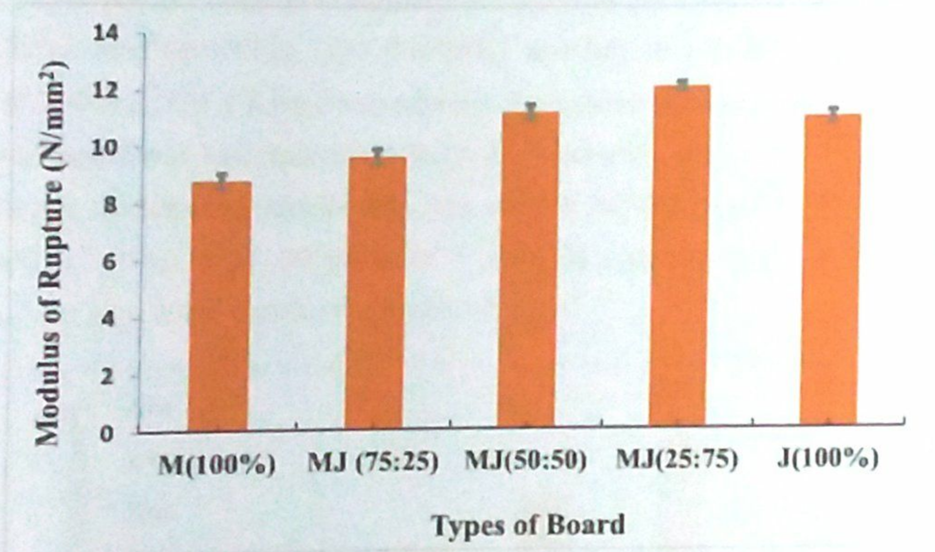


Fig. 4.3.1Modulus of Rupture (MOR) Binderless Particleboard

The specific MOR value for binderless, Maize cob (100%), M+J (75+25%), M+J (50+50%), M+J (25+75%), and Jute stick (100%) particleboards are 13.30, 14.15, 15.48, 16.48 and 15.42 N/mm^2. The MOR of medium density particle board was 11 N/mm^2 (ANSI A208.1–1993; NPA, 1993) and MOR of palm date tree binderless board was 12.9N/mm^2 (Saadaoui *et.al.*, 2013). The MOR of maize cob and jute stick binderless board was close to the MOR of medium density particle board. This variation is may be due to the variation of stem pressure. The modulus of rupture of board is believed to relate with steam pressure. To acquire high MOR, high steam pressure is needed. Compared to the density and steam pressure, the steam treatment time has less effect on MOR (Widyorini *et al.*, 2005). Arias (2009) showed that low pressing temperatures and long pressing times enhance MOR, which agrees with density behavior. Mechanical properties of boards depend on many factors. It is related to cellulose and lignin content of the material (Arias, 2008; Suschland, 1987). It may be also dependent on the behavior of chemical components of particles. Sekino *et al.*, 1999) indicated that the production in hygroscopicity, which is due to the changes in hemicelluloses during steam treatment, is one factor for improving the dimensional stability. The MOR of the binderless boards is also affected by the moisture content present in the particles (Widyorini *et al.*, 2011). The nature and the extent of natural bonding are the important parameters affect the mechanical properties.

4.2.2 MOE (Modulus of Elasticity)

It has been found that the modulus of elasticity of binderless particleboards of, Maize cob (100%), M+J (75+25%), M+J (50+50%), M+J (25+75%), and Jute stick (100%) are 916.19, 1024.54, 1250.30, 1462.69 and 1151.8 N/mm^2 respectively. From the analysis of variance, it has been found that there was significant difference ($F = 198.11$, $df = 4$ and $p < 0.05$) among the modulus of rupture of five different binderless particleboards. The specific MOE value for binderless, Maize cob (100%), M+J (75+25%), M+J (50+50%), M+J (25+75%), and Jute stick (100%) particleboards are 1382.93, 1501.16, 1724.56 , 1983.31 and 1605.3 N/mm^2 .

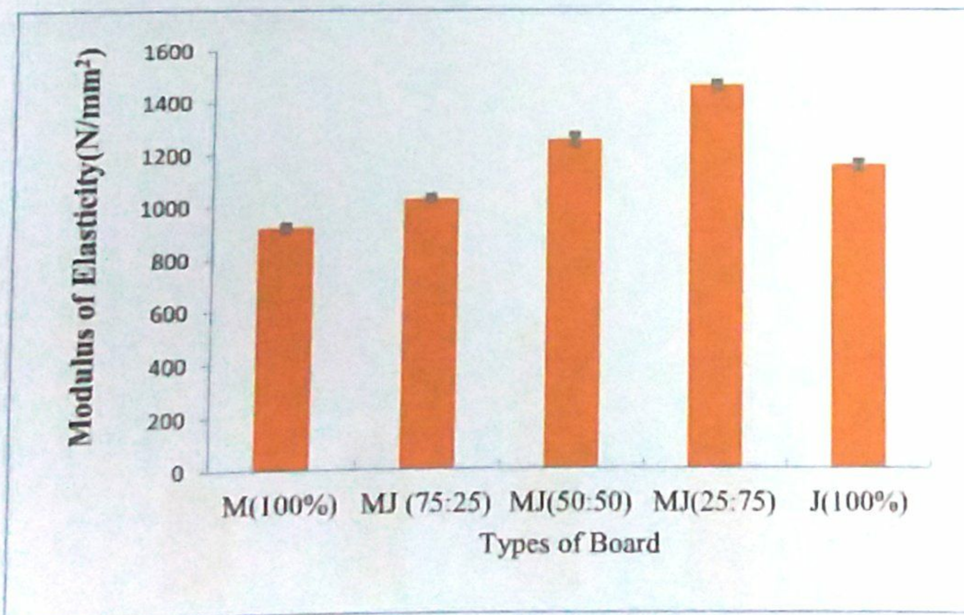


Fig 4.3.2 MOE of Binderless Particleboard

The MOE of medium density particleboard was 1725 N/mm^2 (ANSI A208.1–1993). Modulus of elasticity may depend on the nature and the extent of natural bonding among the chemical components of particles. Widyorini *et al.*, (2005) found that partial degradation of the three major chemical components of the kenaf core by mild steam injection treatment increased the bonding performance and dimensional stability of the binderless boards. Modulus of elasticity of binderless particleboard is also related with the chemical components of the particles and density of the board. It has found that mechanical properties of the boards are related to cellulose and lignin content of the materials (Arias, 2008; Suchsland, 1987). The MOE also depends on board density. Some study showed that if density is higher the MOE also gets increased. As explained earlier that four factors (pretreatment temperature, pressing temperature, initial pressing time and initial pressure) are significantly important affecting mechanical properties of the boards. A suitable combination of processing factors is the key to obtaining the desired properties.

4.2.3 Internal Bonding Strength (IB)

It has been found that the internal bonding strength of binderless particleboards of, Maize cob (100%), M+J (75+25%), M+J (50+50%), M+J (25+75%), and Jute stick (100%) are 0.2, 0.28, 0.47, 0.56 and 0.45 Mpa. respectively. From the analysis of variance, it has been found that there was significant difference ($F= 7.18$, $df=4$ and $p<0.05$) among the internal bonding strength of five different binderless particleboards.

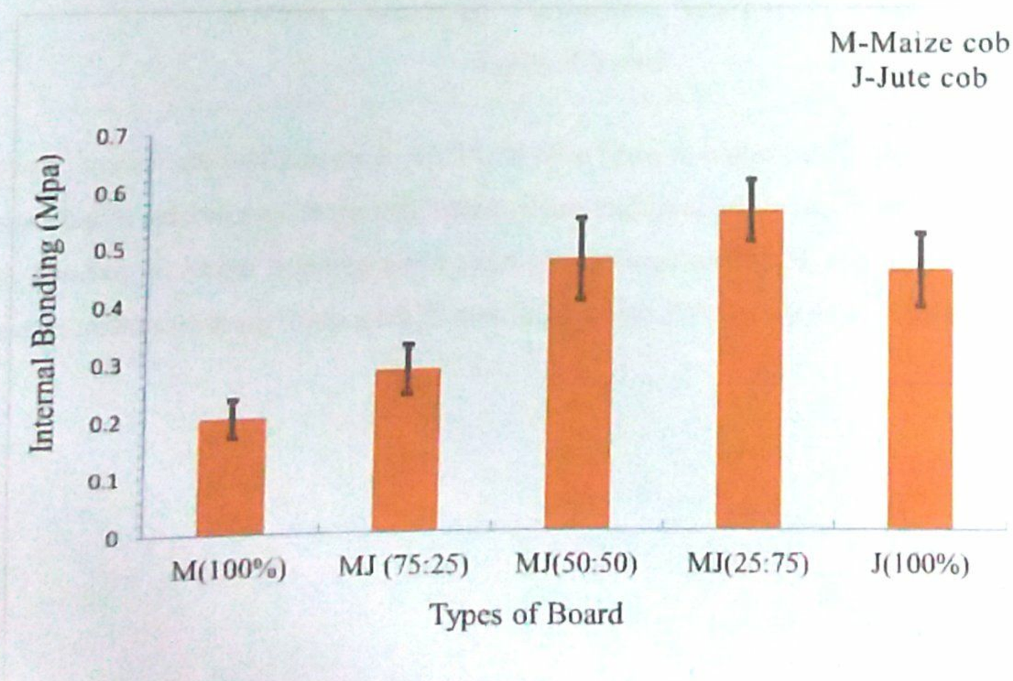
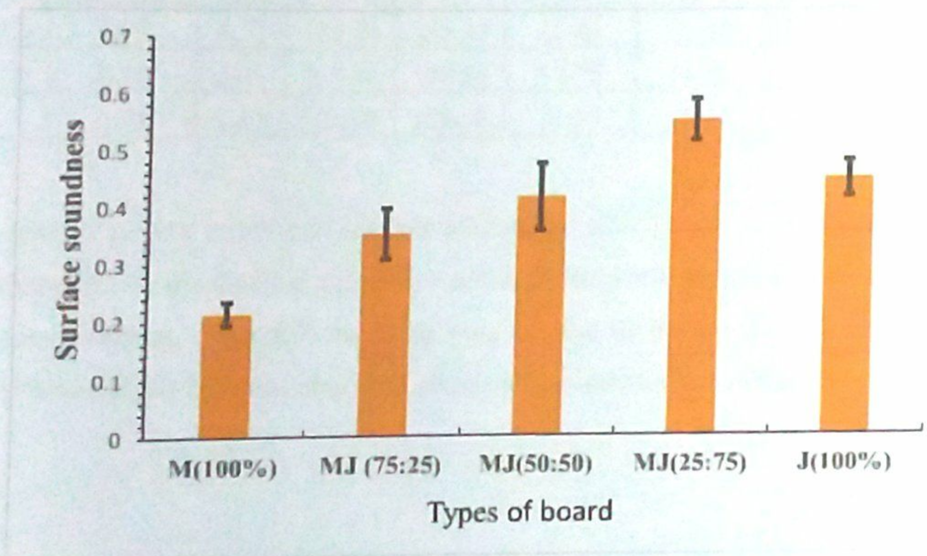


Figure: 4.3.3 Internal Bonding strength of binderless particleboard

4.2.4 Surface soundness (N/mm^2)

It has been found that the surface soundness of binderless particleboards of, Maize cob (100%), M+J (75+25%), M+J (50+50%), M+J (25+75%), and Jute stick (100%) are 0.22, 0.36, 0.42, 0.56 and 0.45 Mpa. respectively. From the analysis of variance, it has been found that there was significant difference ($F= 9.66$, $df=4$ and $p<0.05$) among the surface soundness of five different binderless particleboards



In this study, maize cob and jute stick (25:75) % ratio showed highest value than the other one. In this case probable reason may be the utilization of jute stick and maize cob composition. Increasing jute stick content increases bonding ability and causes increased MOE and MOR value. Surface soundness increases with increasing MOE and MOR value (Widyorini *et al.* 2014).

Comparative study of different types of board properties

Standard/ Boards	Density (gm/cm^3)	MC (%)	WA (%)	TS (%)	MOR (N/mm^2)	Specific MOR	MOE (N/mm^2)	Specific MOE	(IB) Mpa	(SS) Mpa
(ANSI A208.1–1993).	0.64-0.80	8-12	50	15	11.00	-	1725	-	0.5	1.0
M (100%)	0.66	9.23	137.84	165.19	8.82	13.30	916.19	1382.93	0.20	0.22
M:J (75:25)	0.68	9.12	130.66	143.29	9.66	14.15	1024.54	1501.16	0.28	0.36
M:J (50:50)	0.72	8.72	123.13	131.13	11.23	15.48	1250.30	1724.56	0.47	0.42
M:J (25:75)	0.73	8.61	117.81	128.69	12.15	16.48	1462.69	1983.31	0.56	0.55
J (100%)	0.72	8.87	125.78	139.32	11.07	15.42	1151.80	1605.3	0.45	0.45

From this table it is very much evident that the ratio of MJ (25:75) showed very good properties than the others and its most of the properties satisfied the ANSI standard except water absorption and thickness swelling. Here this variation may be due to the pressing time, temperature and pressure. Without it, its inherent chemical composition may influence the properties of properties

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

CONCLUSION

Increasing replacement of jute stick by maize cob residue promoted significant improvements in the properties water absorption, thickness swelling ; Mechanical properties had a decreasing correlation with the maize cob percentage being incorporated; Percentages higher than 50% drastically decreased values of mechanical properties; Overall, incorporating maize cob does not affect the physical properties of panels, despite affecting their mechanical properties.

RECOMMENDATION

Maize cob and jute stick has satisfied the physical and mechanical properties of the international standards. It would be better to use different pressure and temperature which may have the ability to enhance the physical and mechanical properties of maize cob composite binderless particleboard and also to give new variation to the binderless particleboard manufactured from maize cob in association with jute stick In this situation, the government and particleboard industry owners may take initiatives for utilizing maize cob as an alternate source of raw material for manufacturing of particleboard in future. So, further study may be conducted in future.

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APPENDIX

DATA ANALYSIS

APPENDIX

1. Analysis of Variance of Density

Data Table-1

Treatment	M (100%)	MJ (75:25)	MJ(50:50)	MJ(25:75)	J(100%)
R1	0.66	0.7	0.69	0.75	0.7
R2	0.67	0.71	0.72	0.71	0.72
R3	0.65	0.65	0.74	0.76	0.73
R4	0.67	0.67	0.75	0.73	0.72

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
M (100%)	4	2.65	0.6625	9.16667E-05
MJ (75:25)	4	2.73	0.6825	0.000758333
MJ(50:50)	4	2.9	0.725	0.0007
MJ(25:75)	4	2.95	0.7375	0.000491667
J (100%)	4	2.87	0.7175	0.000158333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0157	4	0.003925	8.920454545	0.00068	3.055568
Within Groups	0.0066	15	0.00044			
Total	0.0223	19				

Tukey Pairwise Comparisons

Factor	N	Mean	Grouping
MJ(25:75)	4	0.7375	A
MJ(50:50)	4	0.7250	A B
J(100%)	4	0.71750	A B
MJ (75:25)	4	0.6825	B C
M(100%)	4	0.66250	C

2. Analysis of Variance of Moisture content (%)

Data Table-2

Treatment	M(100%)	MJ (75:25)	MJ(50:50)	MJ(25:75)	J(100%)
R1	9.25	9.15	8.54	8.43	8.84
R2	9.46	9.28	8.88	8.56	8.93
R3	9.34	9	8.65	8.75	9.26
R4	9.1	8.99	8.79	8.68	8.45

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
M(100%)	4	37.15	9.2875	0.023025
MJ (75:25)	4	36.42	9.105	0.018967
MJ(50:50)	4	34.86	8.715	0.022567
MJ(25:75)	4	34.42	8.605	0.019767
J(100%)	4	35.48	8.87	0.111

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.25188	4	0.31297	8.011519	0.001155	3.055568
Within Groups	0.585975	15	0.039065			
Total	1.837855	19				

Tukey Pairwise Comparisons

Factor	N	Mean	Grouping
M(100%)	4	9.2875	A
MJ (75:25)	4	9.1050	A B
J(100%)	4	8.870	A B C
MJ(50:50)	4	8.7150	B C
MJ(25:75)	4	8.6050	C

3. Analysis of Variance of water absorption (1/2 hr.)

Data Table-3

Treatment	M(100%)	MJ (75:25)	MJ(50:50)	MJ(25:75)	J(100%)
R1	110.45	102.68	90.23	85.67	97.45
R2	114.67	108.45	90.56	89.43	95.98
R3	104.34	100.34	94.05	84.56	97.04
R4	106.54	98.67	89.45	88.91	94.74

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
M(100%)	4	436	109	20.67287
MJ (75:25)	4	410.14	102.535	18.25483
MJ(50:50)	4	364.29	91.0725	4.156825
MJ(25:75)	4	348.57	87.1425	5.731425
J(100%)	4	385.21	96.3025	1.468692

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1228.827	4	307.2067	30.54678	4.74E-07	3.055568
Within Groups	150.8539	15	10.05693			
Total	1379.681	19				

Tukey Pairwise Comparisons

Factor	N	Mean	Grouping
M(100%)	4	109.00	A
MJ (75:25)	4	102.54	A B
J(100%)	4	96.303	B C
MJ(50:50)	4	91.07	C D
MJ(25:75)	4	87.14	D

4. **Analysis of Variance of water absorption (2 hrs.)**

Data Table-4

M(100%)	MJ (75:25)	MJ(50:50)	MJ(25:75)	J(100%)
137.48	132.76	125.34	115.56	125.48
138.56	130.72	123.61	117.34	123.98
140.23	129.04	120.46	120.32	126.61
135.08	130.11	123.09	118.03	127.04

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
M(100%)	4	551.35	137.8375	4.659225
MJ (75:25)	4	522.63	130.6575	2.446825
MJ(50:50)	4	492.5	123.125	4.081633
MJ(25:75)	4	471.25	117.8125	3.877292
J(100%)	4	503.11	125.7775	1.868825

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	926.9607	4	231.7402	68.42533	1.89E-09	3.055568
Within Groups	50.8014	15	3.38676			
Total	977.7621	19				

Tukey Pairwise Comparisons

Factor	N	Mean	Grouping
M(100%)	4	137.84	A
MJ (75:25)	4	130.658	B
J(100%)	4	125.778	C
MJ(50:50)	4	123.13	C
MJ(25:75)	4	117.813	D

5. Analysis of variance of thickness swelling (1/2hr.)

Data Table-5

Treatment	M(100%)	MJ (75:25)	MJ(50:50)	MJ(25:75)	J(100%)
R1	70.23	67.23	60.34	56.89	64.56
R2	72.54	69.89	63.07	55.05	62.85
R3	71.82	68.23	61.39	54.47	63.87
R4	70.98	69.01	62.01	54.07	62.03

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
M(100%)	4	285.57	71.3925	1.007025
MJ (75:25)	4	274.36	68.59	1.281867
MJ(50:50)	4	246.81	61.7025	1.306225
MJ(25:75)	4	220.48	55.12	1.554267
J(100%)	4	253.31	63.3275	1.241625

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	641.1952	4	160.2988	125.4096	2.45E-11	3.055568
Within Groups	19.17303	15	1.278202			
Total	660.3683	19				

Tukey Pairwise Comparisons

Factor	N	Mean	Grouping
M(100%)	4	71.392	A
MJ (75:25)	4	68.590	B
J(100%)	4	63.328	C
MJ(50:50)	4	61.703	C
MJ(25:75)	4	55.120	D

6. Analysis of variance of thickness swelling (2 hrs.)

Data Table-6

Treatment	M(100%)	MJ (75:25)	MJ(50:50)	MJ(25:75)	J(100%)
R1	166.08	143.08	132.67	126.76	140.67
R2	160.06	142.84	132.44	130.94	137.08
R3	167.98	144.32	130.53	128.07	140.06
R4	166.64	142.9	128.89	129	139.45

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
M(100%)	4	660.76	165.19	12.33187
MJ (75:25)	4	573.14	143.285	0.4865
MJ(50:50)	4	524.53	131.1325	3.155092
MJ(25:75)	4	514.77	128.6925	3.089292
J(100%)	4	557.26	139.315	2.468167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3362.764	4	840.691	195.2288	9.69E-13	3.055568
Within Groups	64.59275	15	4.306183			
Total	3427.357	19				

Tukey Pairwise Comparisons

Factor	N	Mean	Grouping
M(100%)	4	165.19	A
MJ (75:25)	4	143.285	B
J(100%)	4	139.315	B
MJ(50:50)	4	131.132	C
MJ(25:75)	4	128.693	C

7. Analysis of Variance for MOR

Data Table-7

Treatment	M(100%)	MJ (75:25)	MJ(50:50)	MJ(25:75)	J(100%)
R1	8.89	9.08	11.45	12.38	11.63
R2	9.06	10.21	11.61	12.41	11.04
R3	8.11	9.34	10.49	11.98	10.68
R4	9.2	10.01	11.37	11.84	10.92

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
M(100%)	4	35.26	8.815	0.236967
MJ (75:25)	4	38.64	9.66	0.287933
MJ(50:50)	4	44.92	11.23	0.253333
MJ(25:75)	4	48.61	12.1525	0.081825
J(100%)	4	44.27	11.0675	0.163025

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	28.37765	4	7.094413	34.67172	2.05E-07	3.055568
Within Groups	3.06925	15	0.204617			
Total	31.4469	19				

Tukey Pairwise Comparisons

Factor	N	Mean	Grouping
MJ(25:75)	4	12.153	A
MJ(50:50)	4	11.230	A B
J(100%)	4	11.068	B
MJ (75:25A)	4	9.660	C
M(100%)	4	8.815	C

8. Analysis of Variance for MOE

Data Table-8

Treatment	M(100%)	MJ (75:25)	MJ(50:50)	MJ(25:75)	J(100%)
R1	876.34	1023.05	1198.9	1445.02	1175.58
R2	925.78	1046.24	1249.72	1478.89	1123.39
R3	934.28	1028.02	1253.23	1436.65	1184.08
R4	928.37	1000.85	1299.36	1490.21	1124.15

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
M(100%)	4	3664.77	916.1925	718.5304
MJ (75:25)	4	4098.16	1024.54	348.8122
MJ(50:50)	4	5001.21	1250.303	1685.922
MJ(25:75)	4	5850.77	1462.693	670.0336
J(100%)	4	4607.2	1151.8	1059.712

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	710519.7	4	177629.9	198.1146	8.7E-13	3.055568
Within Groups	13449.03	15	896.6021			
Total	723968.7	19				

Tukey Pairwise Comparisons

Factor	N	Mean	Grouping
MJ(25:75)	4	1462.7	A
MJ(50:50)	4	1250.3	B
J(100%)	4	1151.8	C
MJ (75:25)	4	1024.54	D
M(100%)	4	916.2	E

9. Analysis of Variance for internal bonding

Data Table-9

Treatment	M(100%)	MJ (75:25)	MJ(50:50)	MJ(25:75)	J(100%)
R1	0.14	0.24	0.63	0.67	0.33
R2	0.17	0.33	0.51	0.59	0.49
R3	0.29	0.18	0.29	0.55	0.61
R4	0.2	0.37	0.45	0.41	0.37

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
M(100%)	4	0.8	0.2	0.0042
MJ (75:25)	4	1.12	0.28	0.0074
MJ(50:50)	4	1.88	0.47	0.02
MJ(25:75)	4	2.22	0.555	0.011833
J(100%)	4	1.8	0.45	0.016

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.34168	4	0.08542	7.186203	0.001935	3.055568
Within Groups	0.1783	15	0.011887			
Total	0.51998	19				

Tukey Pairwise Comparisons

Factor	N	Mean	Grouping
MJ(25:75)	4	0.5550	A
MJ(50:50)	4	0.4700	A B
J(100%)	4	0.4500	A B
MJ (75:25)	4	0.2800	B C
M(100%)	4	0.2000	C

10. Analysis of Variance for surface soundness

Data table-10

Treatment	M(100%)	MJ (75:25)	MJ(50:50)	MJ(25:75)	J(100%)
R1	0.24	0.44	0.53	0.57	0.43
R2	0.16	0.23	0.51	0.59	0.49
R3	0.25	0.38	0.29	0.45	0.51
R4	0.21	0.37	0.35	0.61	0.37

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
M (100%)	4	0.86	0.215	0.001633
MJ (75:25)	4	1.42	0.355	0.0079
MJ(50:50)	4	1.68	0.42	0.014
MJ(25:75)	4	2.22	0.555	0.005167
J (100%)	4	1.8	0.45	0.004

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.25268	4	0.06317	9.659021	0.000453	3.055568
Within Groups	0.0981	15	0.00654			
Total	0.35078	19				

Tukey Pairwise Comparisons

Factor	N	Mean	Grouping
MJ(25.75)	4	0.5550	A
J(100%)	4	0.4500	A B
MJ(50:50)	4	0.4200	A B
MJ (75:25)	4	0.3550	B C
M(100%)	4	0.2150	C