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MANUFACTURING OF BINDERLESS PARTICLE BOARD FROM JUTE STICK

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Dedicated to........

My beloved parents

DECLARATION

I, Shaila Sharmin Piya, declare that this thesis is the result of my own works and it has not been submitted or accepted for a degree in any other university.

I, hereby, give consent for my thesis, if accepted, to be available for photocopying and for inter-library loans, and for the title and summary to be made available to outside organizations only for research and educational purposes.

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Shaila Sharmin Piya

ABSTRACT

This study was conducted to make binderless particle board from jute stick. We have succeded to make binderless particle board from jute stick by using hot pressing system at 180^0C temperature and 9 min pressing time. The density of the board was 0.74 g/cm^3, the modulus of rupture (MOR) was 10.15 N/mm^2 and modulus of elasticity (MOE) was 1625 N/mm^2. These values satisfy the standard value of ANSI. The thickness swelling and water absorption capacity of jute stick binderless board was comparatively higher. It can be improved by further study. Thus, it can be concluded that jute stick can be an alternative raw material for manufacturing of binderless particle board.

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ABBREVIATIONS

FAO	Food and Agricultural Organization
ASTM	American Society for Testing and Materials
JBPB	Jute Stick Binderless Particle Board
MDPB	Medium Density Particle Board
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
TS	Thickness Swelling
WA	Water Absorption

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).

The feasibility of using fast-growing trees and agricultural residues as alternative raw materials for particleboard or binder less board production has been explored by a number of researchers. 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 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, jute etc. and they are abundantly available (Markessini *et al.*,1997).

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 as a raw material of binderless particle board. 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 (Rowell *et al.*, 2002): 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, 2000).

1.2: Objectives of the study

The objectives of this research were

- To study the potentiality of jute stick as a raw material for binderless particle board production.
- To evaluate the physical and mechanical properties of jute stick binderless particle board.

Chapter 2
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: Introduction:

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 bast fibre 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 MiddleEastern 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: PROPERTIES OF JUTE

Table 2.1.1: Shows the chemical composition of jute sticks. (Handbook of Pulp and Paper Processing).

Constitutes	Jute stick
Alphacellulose	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.

Physical Properties of jute fibre

Table 2.1.2: Shows the physical properties of jute fiber (Sur and Amin, 2010).

Macro and micro structure

Ultimate Cell Length (L)	2.50 mm
Ultimate Cell Breadth	18 μm
Density	1.46 g / cc
Moisture Regain at 65% RH	13.8 %
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.

2.5 Major Drawback of Uses of Jute:

The major disadvantages of jute sticks are to their coarseness, stiffnes, 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)

Chapter 3

Materials and methods

3.1 Collection and preparation of raw materials

Jute (*Corchorus capsularis*) sticks were collected from Gollamari and Gopalganj 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

3.2 Binderless board manufacture

3.2.1 Mat Formation

The weight of the 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.

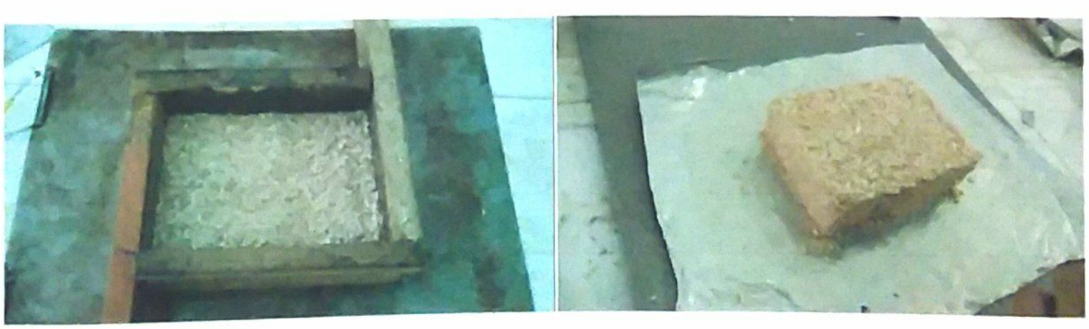


Fig 3.2.1: Mat formation

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 180^{0}C. The mat was covered with steel sheet and then inserted into the hot press for pressing. The pressure (4.5 KPa) was remained for 9 minutes. After 9 minutes the machine was switched off. So, the temperature was dwindled gradually but retained the pressure for 9 minutes. The mat was allowed to cool for 30 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 sizes to test the boards in the laboratory.

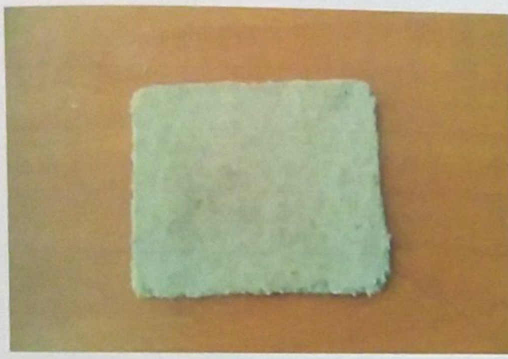


Fig. 3.2.2: Board before trimming

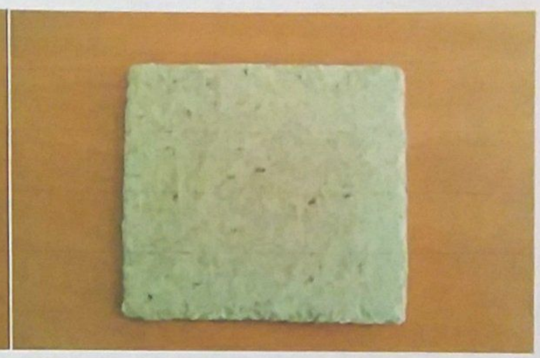
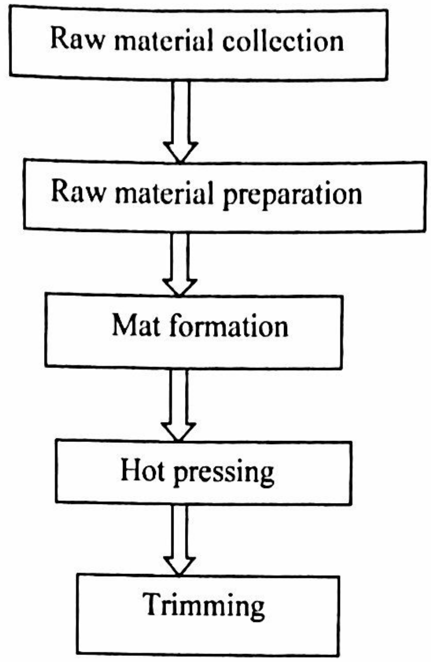


Fig. 3.2.3: Board after trimming

3.2.4 Flow Diagram of Jute Stick Binderless Particle Board Production



3.3 Laboratory test

The physical properties of the binderless boards were assessed in the Wood Technology Laboratory, Pulp and Paper Laboratory of Forestry and Wood Technology Discipline in Khulna University, Khulna, Bangladesh. The mechanical properties were tested in the laboratory of Khulna University of Engineering and Technology (KUET), Khulna, Bangladesh.

3.3.1 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

3.3.2 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-

$$MC\ (\%) = \frac{\text{Green Weight} - \text{Oven Dry Weight}}{\text{Oven Dry Weight}} \times 100$$

Where,

MC= moisture content (%)

3.3.3 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-

$$A_w = \frac{m_2 - m_1}{m_1} \times 100$$

Where,

A_w= 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)

3.3.4 Thickness swelling

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

$$G_t = \frac{t_2 - t_1}{t_1} \times 100$$

Where,

G_t= Thickness swelling (%)

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

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

3.3.5 Static Bending Strength Test

3.3.5.1 Modulus of rupture (MOR)

Modulus of rupture (MOR) was expressed in N/mm^2 and measured with the Universal Testing Machine (UTM), model: WE- 100, made by Time Group Inc. in the Laboratory of .... Engineering Department of Khulna University of Engineering and Technology (KUET), Khulna. 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

3.3.5.2 Modulus of elasticity (MOE)

The Modulus of elasticity (MOE) was also measured with the Universal Testing Machine (UTM) in the Laboratory of .... Engineering Department of Khulna University of Engineering and Technology (KUET), Khulna. 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

3.4 Analysis of Data

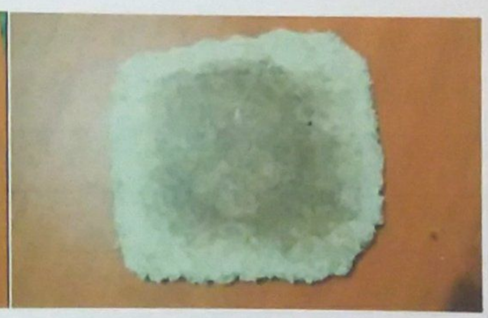
It is important to characterize the significance of all the samples of fiber boards. In the laboratory, the data was analyzed by using Microsoft Office Excel……. and SPSS (Statistical Package of Social Survey) software to assess the physical and mechanical properties of binderless boards.

Chapter 4

RESULTS AND DISCUSSION

Several attempts were taken to make board at different temperatures and times. The boards got delaminated when they were treated with 140°C and 160°C temperature with pressing time 3 min, 9 min, and 12 min. Fig 4.1 shows that it was not possible to make board at 140°C to 160°C temperature with jute stick at different times (3 min, 9 min, 12 min). This may be the result of chemical behavior of hemicellulose or hemicelluloses of jute stick do not act as binder at this temperature. According to NPCS Board of Consultants & Engineers jute stick hemicellulose is predominant in xylan and at 150-155°C temperature hemicellulose of jute stick start degrading but it doesn't act as binder at this temperature. So, this may be one of the reason of delaminating of boards that were made at 140°C and 160°C temperature. In this study it was found that at 180°C temperature and 9 min pressing time it was possible to make binderless board with the jute stick.

140°C



160°C

180°C

Fig. 4.1 Effect of temperatures on board quality

4.1.2 Density

Density is an important parameter and it virtually affects all the properties of binderless board. Fig. 4.2 shows that the density of jute stick binderless particleboard was 0.74 g/cm³.

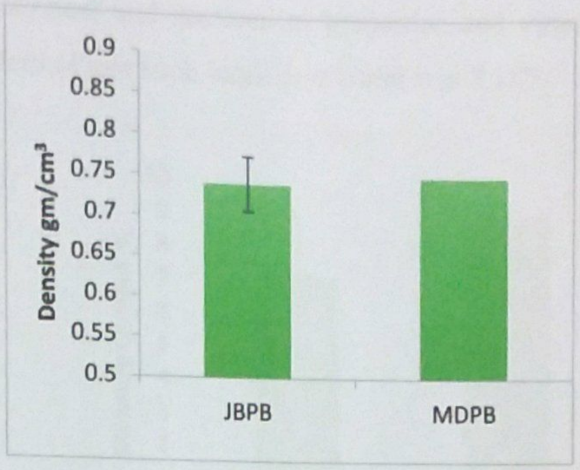


Fig 4.2 Density of Jute stick Binderless Particle Board (JBPB) and Medium Density Particle Board (MDPB).

Medium density particle board density was 0.75 g/cm³ (ANSI A208.1–1993). The steam-exploded fibers of oil palm frond binderless board had density lower than 0.70 g/cm³. The density of binderless board made with palm date tree without stem injection was 0.97 g/cm³. (Saadaoui *et.al.*, 2013). Jute stick binderless board showed density 0.74 g/cm³. The variation in density between jute stick binderless board and medium density particle board may be due to the variation of the raw materials itself. 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).

4.1.3 Moisture Content

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. Fig. 4.3 shows the moisture content of jute stick binderless board was 7.18%.

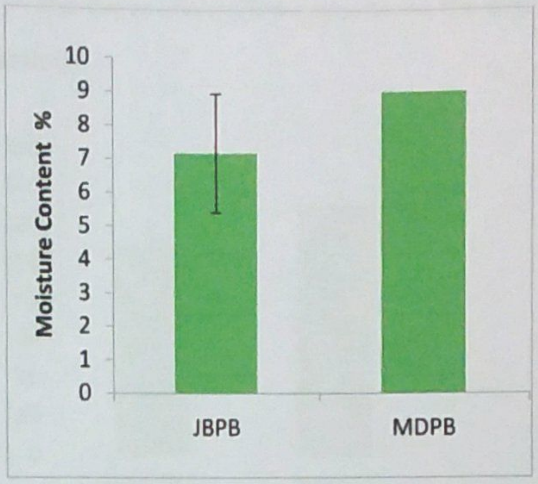


Fig 4.3 Moisture content of Jute stick Binderless Board (JBPB) and Medium Density Particle Board (MDPB).

Figure 4.3 shows that the moisture content of jute stick binderless particle board is 7.18%. The moisture content of the medium density particle board was 9% (ANSI A208.1–1993). The variation of moisture content within the two types of 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).

4.1.4 Water Absorption

Water absorption capacity is an important factor in the case of binderless particle board. Physical and mechanical properties of binderless board also influenced by water absorption capacity of samples (Kumar, 2008). In the case of jute stick binderless board after half hour soaking in water the water absorption capacity of the board was 110.83% and after two hours it was 131.68% (Figure. 4.4). We also observed the water absorption capacity of the board after 24 hours. After 24 hours the board got delaminated.

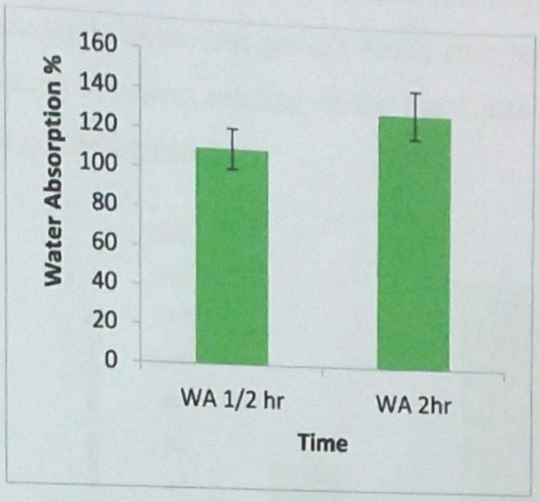


Fig 4.4 Water absorption of Jute stick Binderless Particle Board (JBPB).

Binderless board made with spruce and pine showed water absorption 45% and 75% (Angles et al.,1999). In this study we found (Fig. 4.4) that the water absorption capacity of the jute stick binderless particle board was comparatively higher. Due to presence of hydroxy and other polar groups in various constituents of jute particle, the moisture uptake is high (approx. 12.5% at 65% relative humidity & 20°C) (Basak *et al.,* 1998). All this leads to weak interfacial bonding between jute 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 jute stick 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). From the Handbook of

Pulp and Paper Processing we know that jute stick contains higher amount of hemicelluloses about 34%.

4.1.5 Thickness Swelling

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). The thickness swelling of jute stick binder less particle board after half hour soaking in water was 51.88% and after two hours thickness swelling of the board was found 141.68% (Figure 4.5). After 24 hours the board got delaminated.

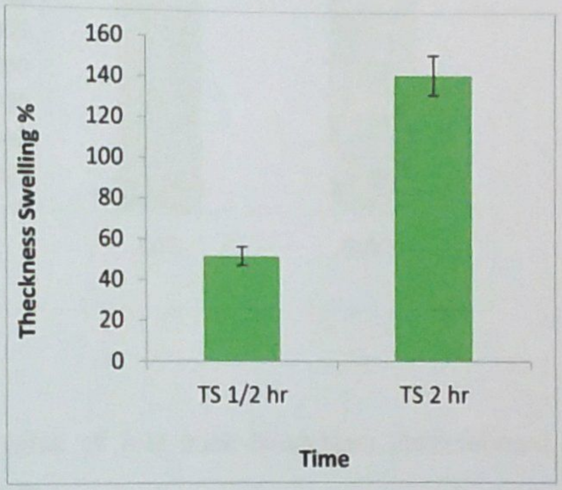


Fig 4.5 Shows the thickness swelling of Jute stick Binderless Particle board.

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). Binderlessboards made from spruce and pine showed thickness swelling 12 % and 37% (Angles *et al*., 1999). So, thickness swelling of jute stick binderless board was comparatively higher than other boards. The factors affecting water absorption are responsible for the thickness swelling of jute stick binderless particle board. 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 MOR (Modulus of Rupture)

Fig 4.3 shows the modulus of rupture of jute stick binderless particleboard and medium density particle board. The modulus of rupture of jute stick binderless board was 10.15 N/mm^2 (Fig 4.3).

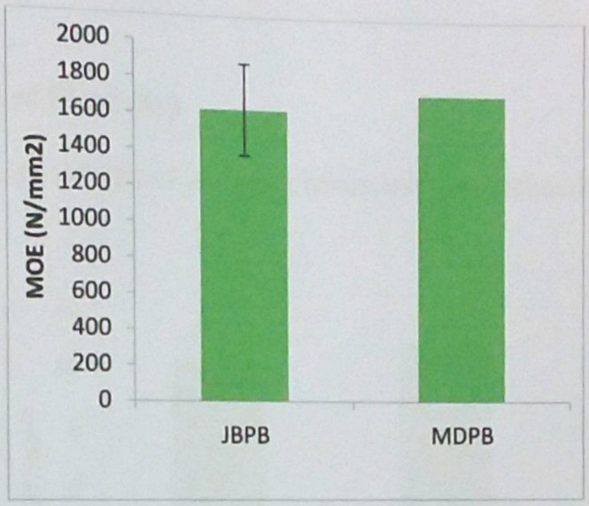


Fig. 4.2 Shows the MOR value of Jute stick Binderless Particleboard (JBPB) and Medium Density Particle Board (MDPB).

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 12.9 N/mm^2 (Saadaoui *et.al.*, 2013). The MOR of 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 jute stick particle.

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)

The modulus of elasticity (MOE) of jute stick binderless particleboard was 1625.66 N/mm^2 (Fig. 4.2).

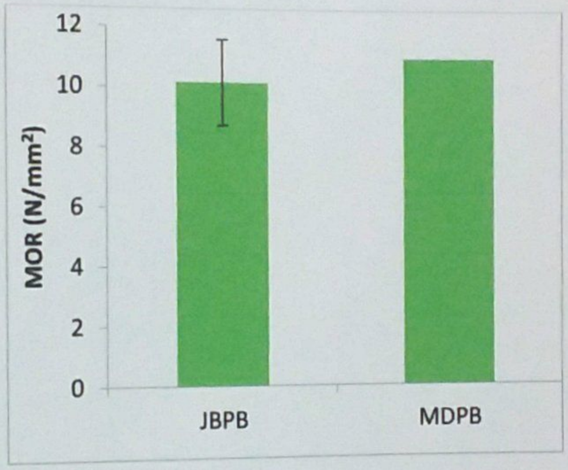


Fig 4.2 The MOE of Jute Stick Binderless Particle Board (JBPB) and Medium Density Particle Board (MDPB).

The MOE of medium density particle board was 1725 N/mm^2 (ANSI A208.1–1993). The MOE of jute stick binderless board was close to the MOE of medium density particle board. It may depend on the nature and the extent of natural bonding among the chemical components of jute stick 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 particle board 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.

CHAPTER 5

CONCLUSION

- We have succeded to develop binderless particleboard from jute stick at 180°C temperature and 9 min pressing time.
- Jute stick binderless board showed good physical and mechanical properties and these result satisfy the standard value of ANSI.
- Further study is required to improve the board properties using different parameters.

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