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Effects of Moisture Content on Binderless Cross bonded jute stick board

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Effects of Moisture Content On

Binderless Cross Bonded Jute Stick Board

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Dedicated

To

My Family

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Abstract

This work describes the effects of moisture content on the mechanical and physical properties of cross bonded binderless board made from jute stick (*Corchorus capsularis*). All the boards were compressed at a pressing temperature 180^{0}C and pressing pressure was 2.5 MPa. The target density of all board was 0.8 g/cm^3. Board made at 15-20% moisture content exhibited higher physical and mechanical properties. The Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) of jute stick cross bonded board at 15-20% moisture content board were 10359.4 N/mm^2 and 76.49 N/mm^2 respectively. Thickness swelling and water absorption of the board sealed with epoxy resin were at 15-20% moisture content were 24.05% and 18.02% respectively. Hence it can be concluded that by controlling moisture content high performance cross bonded binderless board can be manufactured successfully.

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Chapter One

Literature review

General Information about jute

1.1 Introduction

Bangladesh has a total land area of 14.39 million hectares, of which 9.12 million ha is cultivated, 2.14 million ha public forests, 0.27 million ha village groves, and 1.64 million ha constantly under water. The remaining land area (1.22 million hectares) is occupied by tea gardens, uncultivable areas, rural and urban houses and ponds (Kibria *et al.* 2000). The area covered by government and village forests is about 16% of the total land area; however only 0.93 million ha (6.5%) is under tree cover, which is about 40% of the forests controlled by the government.

The population of world is increasing rapidly day by day. There is a greater awareness of the need for materials in an expanding world population and increasing affluence (Pijus*et at*, 2011). The raw material cost is also increasing. Considering the circumstances the technology is advancing to produce cheaper materials from residues. New raw materials that reduce the production cost and which do not damage the environment have been an important aspect. Jute plants have carbon dioxide assimilation rate and it clean the air by consuming large quantities of carbon dioxide. This is why jute is used as a raw material worldwide. They are abundant, renewable and recyclable.

Jute is the second most important vegetable fiber. The word 'jute' is probably coined from the word jhuta or jota. Jute is one of the most affordable natural fibers. Jute fibers are composed primarily of cellulose and lignin. The industrial term for jute fiber is raw jute. The fibers are off white to brown, and 1-4 meters (3-13 feet) long. Jute is also called the golden fiber. The primary source of the fiber is *Corchorus olitorius.*It is considered inferior so *Corchorurs capsularis* was used for this research. The jute plant is easily grown in tropical countries like Bangladesh and India. India is the largest producer of jute. Jute is less expensive than cotton, but cotton is better for quality clothes. Jute is used to make various products: packaging materials jute bags, expensive carpets, sweaters etc. it is obtained from the bark of the jute plant. Jute plants are easy to grow, have a high yield per acre and, unlike cotton, have little need for pesticides and fertilizers. Jute has many environmental advantages. It is an annually renewable resource. The synthetic materials are being considered as the root of global warming, the natural fiber products are proven to be absolutely harmless. Jute bast fibers are using as automotive nonwoven material (Moreau *et al.* 1995; Parikh et al. 2002a; Parikh *et al.* 2002b).

Fig: 1.1 Jute Plant

1.2. Features of Jute stick

Jute has low pesticide and fertilizer needs. It is a natural fiber with golden and silky shine. It is the cheapest vegetable fiber. It has high tensile strength, low extensibility, and better breathability of fabrics. Therefore, jute is very suitable in agricultural commodity. Jute has the ability to be blended with other fibers, both synthetic and natural. As the demand for natural comfort fibers increases, the demand for jute and other natural fibers will also increase. Some manufactures in the natural fiber industry plan to modernize processing with the Rieter's Elitex system to meet this demand. Jute stick contain a higher amount of hemicelluloses and lignin. It makes jute stick more preferable to wood industry. The main elements of jute sticks are Cellulose, hemicelluloses and lignin. Hemi cellulose works as supporting matrix agent of cellulose. Lignin is amorphous and hydrophobic in nature.

1.3 Types of Jute

White Raw Jute *(Chorchorus capsularis)*

White raw jute originated centuries ago in the poorer regions of India. It was first used to make clothing for villagers and farmers. It is also known as "Bangla white." Since then, white raw jute has grown in personal and industrial use. White raw jute is used to make products such as yarn, twine and rope. Historical documents (*including Ain-e-Akbari* by Abul Fazal in 1950) state that the poor villagers of India used to wear cloths made of jute.

Tossa Raw Jute *(Chorchorus olitorius)*

Tossa raw jute and white raw jute are the most commonly found types of jute. They are grown where climate permits in India. Tossa raw jute is silky. It is much stronger than white raw jute; because of its extra strength. It is also used to make bags such as gunny sacks and clothing. Bangladesh is the largest global producer of the tossa raw jute.

Mesta Raw Jute

Mesta is a blend of the mesta plant. Mesta became a part of jute production in 1947, when India had to partition its land. Since that time, mesta has become a more important part of this blend. Mesta is capable of growing in areas where the climate is not appropriate for raw white or tossa jute.

1.4 Jute Cultivation

Farmer scatter the seeds on cultivated soil to grow jute. First thinning is done when the plants are about 15-20cm tall. Harvesting begins after four months. The stalks are cut off close to the ground. They are allowed to soak for about 20 days to soften the tissues. It also helps to break the hard pectin bond between the bast and jute hurd. The fibers then separated and washed in water. They are finally hung up to dry. The fibers are tied into bundle after 2-3 days of drying jute plant needs a plain alluvial soil and standing water. The suitable climate for growing jute (warm and wet) is offered by the monsoon climate. Temperatures ranges from 20˚C to 40˚C and relative humidity ranges from 70%–80% are favorable for successful cultivation. Jute requires 5–8 cm of rainfall weekly. Soft water is necessary for the jute production.

1.5 Properties of Jute

Physical Properties of Jute fibres

The major physical properties of jute fibre presented in the following table.

Table: 1.5.1 Physical Properties of jute fibre

(Macro & Micro Structure)		
Ultimate Cell Length (L)	Average	2.50 mm
	Range	0.8 – 6.0 mm
Ultimate Cell Breadth (B)	Average	18 µm
	Range	10 – 25 µm
L / B Ratio	Average	110
Fibre Fineness		1.3 – 4.0 tex
Fibre Length (after Carding)		2 – 50 cm
Density	True	1.46 g / cc
	Apparent	1.10 – 1.34 g / cc

Bulk Density		0.4 – 0.5 g / cc
Degree of Crystallinity (X-ray)		55 – 60 %
	Moisture Absorption	
Moisture Regain	at 65% RH	13.8 %
	– at 100% RH	36.0 %
Transverse Swelling in water	Diameter-wise	20%
	Cross-sectional areawise	45%
Water holding Capacity		500 %
	Thermal Properties	
Specific Heat		1.36×10^3 J kg^{-1} K^{-1}
Thermal Conductivity		427.3 mW m^{-1} K^{-1}
Heat of Combustion		17.5 J / g
Ignition Temperature		193 °C
Heat of Wetting		18.2 calories

Chemical Properties of Jute Fibre

The chemical composition of jute fibres and sticks are given in the following tables

Table: 1.5.2 Chemical composition of jute fibre

Constituents	Jute

(in % of Bone Dry Weight of the Fibre)	*C. capsularis*	*C. olitorius*
Alpha cellulose	60.0 – 63.0	58.0 - 59.0
Hemicellulose	21.0 – 24.0	22.0 – 25.0
Lignin	12.0 – 13.0	13.0 – 14.0
Fats & Waxes	0.4 – 1.0	0.4 – 0.9
Pectin	0.2 – 1.5	0.2 – 0.5
Proteins / Nitrogenous matter, etc.	0.80 – 1.9	0.8 – 1.6
Ash	0.7 – 1.2	0.5 – 1.2

Table: 1.5.3 Chemicl composition of jute sticks

Constituents	Jute Stick (in % of Bone Dry Weight of the Fibre)
Alpha cellulose	40.8-47.5
Hemicellulose	23.0-23.6
Acetyl Content	3.6-4.7
Lignin	22.2-23.5
Fats & Waxes	1.7-2.4
Pectin	0.5-0.7
Ash	0.6-0.8

Source: Sur and Amin (2010).

1.6. Jute Production in Bangladesh

About 62% of the total raw jute is produced in Faridpur, Jessore and Kushtia regions of Bangladesh. Prices of raw jute and jute goods increased substantially over the previous decade. Bangladesh Jute Spinners Association has found the pioneer exporters of jute goods in which about 64% of the total jute goods were exported by them. Raw jute and jute goods export earnings increased significantly in 2010-11 compared to the last decade. The share of Bangladesh in raw jute and jute goods production has increased significantly around 42% and 31% in 2010-11 respectively of world production.

1.7 Uses of Jute Stick

Bangladesh produce large quantity of Jute in the world. We used to separate the jute fiber and jute stick. The jute stick is mainly used to produce board, charcoal and cooking purpose. Jute helps to make top quality industrial yarn, fabric, net etc. It is one of the most versatile natural fibers that has been used in raw materials for textiles, non-textile, construction, and agricultural sectors.

1.8 Objective of the study

- To know the effects of moisture content of binderless cross bonded board from jute stick.
- To evaluate the mechanical and physical properties of binderless cross bonded board at different moisture content

Chapter Two

Information about Binderless board

2.1 Binderless Board

Binderless board is a wood panel made without the use of synthetic adhesive. It is manufactured by hot pressing of wood particles. A process which converted the lignocellulosic materials into panel boardswithout using of synthetic resin binders, has been developed and patented by shen in the mid eighties. It is a self bonding board. Studies on manufacturing process of binderless board have been conducted for years.

2.2 Binderless board manufacturing process

Non-wood raw materials which are usually rich in hemicellulose are supposed to be suitable materials for binderless board manufacture.

Table 2.2 Properties of Binderless Boards Made of Various Natural Fiber

Process	Author	Natural fiber	Density (g/cm3)	MOR (Mpa)	IB (Mpa)	TS (%)	WA (%)
Hot press	Hashim et al.(2010)	Oil palm	0.8	24.95	0.95	41.6	80.0
Hot press	Okuda and Sato (2004)	Kenaf	1.0	36.10	5.70	19.6	40.9

Hot press	Saadaoui et al. (2013)	Date palm	1.0	12.90	0.03	150.0	275.0
Hot press	Vam Dam et al. (2004)	Coconut husk	1.3	50.00	-	8.0	8.0

There are two processes for binderless board production: wet forming and dry forming. Wet forming process is the distribution of cellulosic materials into water. It forms hydrogen bonds and create thermosetting adhesive behavior of lignin during heating and drying process. Dry forming is the basic for industrial manufacturing process that reducing moisture content of cellulosic materials by drying and it distribute into mat by pre-pressing finally undergoes hotpress (Lee and Hunt, 2013).

2.3 Self bonding mechanism of Binderless board

The self bonding strength is improved only by activating the chemical components of the board during water treatment. The main reason of self bonding mechanism is mainly activation of chemical components of the board constituents, mainly hydrolysis of hemicellulose, degradation of part of cellulose to produce simple sugars and other decomposition products and thermal softening of cell wall matrix, crosslinking between carbohydrate polymers and lignin andan increase in cellulose crystallinity (Vam dam *et al.* 2004, Laemask and Okumura 2000; Ellis and Paszner 1994; Rowell *et al.*,2002; Inoue *et al.*, 1993).

Chapter Three

Materials and Method

3.1 Materials

Jute (*Corchorus capsularis)* stick was used as raw materials for this work.

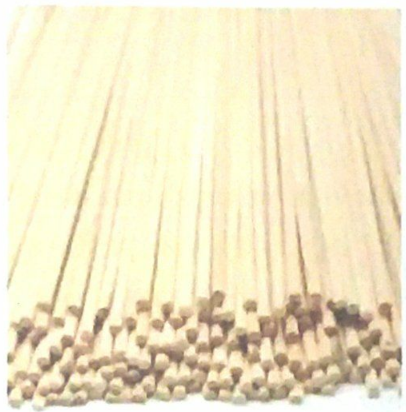

Fig: 3.1 Jute Stick

3.2 Experimental

Dipping into water

Jute sticks were collected from Gopalganj district. Raw materials were air dried for seven days after collection. Fibers on the stick were separeted manually. Then sticks were cut into desirable size by using conventional hand tool.

At first some water were taken in a stainless steel tray. Then one layer stick were taken and dipped into water just for few seconds. Immediately after dipping those sticks were gently shaken just to avoid extra moisture on it.

Fig: 3.2.1 Dipping into water

Assembling of jute sticks

31 cm sized sticks were assembled one after another the length wise to make the face layer. I used the moisure meter and took the moisture of the face layer. Then 21 cm sized sticks were assembled one after another with the width wise to make alternate layer. Alternate layer moisture was also taken using the moisture meter. Again 31 cm sized sticks were assembled to make another layer and simultaneously assembled the other width wise layer by 21 cm sized sticks. Finally the other face layer was made by 31 cm sized sticks. Using moisture meter I took the each of the five layer moisture. Then I made an average of the moisture and got the exact moisture. Through this process I controlled the moisture and manufactture board of different moisture.

The sticks were assembled into a rectangular of iron mould on a stainless steel plate. There we placed a teflon sheet on the stainless steel plate to prevent the consolidated mat from sticking to the platen during pressing.

Fig: 3.2.2 Assembling of jute stick

Hot Pressing

After assembling the assembled sticks were hot pressed at a fixed temperature 180^{0}C at air dried condition at 2.5 Mpa pressure for 10 minutes. Then press was switched off but pressure was not released at that time. Then the board is allowed to cool for 10 minutes. Then the pressure was removed and brought the board out. Boards were hot pressed at different moisture 0-5%, 5-10%, 10-15%,15-20% and above 20%.

Fig: 3.2.3 Hot press

Trimming

All boards were trimmed at edges with the fixes type circular saw. The dimensions of each type of boards were 30×20×0.7cm.

Fig: 3.2.4 Board after trimming

3.3 Board Evaluation

3.3.1 Preparation of sample for testing

Two replications of each type of boards were manufactured for testing physical and mechanical properties; four samples were collected from each board of each type. The dimension of samples for testing the physical properties was approximately (5 cm × 5 cm) and for testing the mechanical properties was approximately (21cm × 5 cm).

3.3.2 Determination of Mechanical Properties

All the samples were cut into required dimension for testing mechanical properties. The laboratory test for characterization of mechanical properties was carried out in the laboratory of Forestry and Wood Technology Discipline, Khulna University, Bangladesh.

3.3.3 Determination of Physical Properties

All the samples are cut into (5cm × 5cm) dimension for testing physical properties. At first all the specimens were weighted and green dimension are taken at room temperature were measured. Next the samples were soaked into water for 2 hour. Then weight and dry dimension were taken. Next the samples were soaked into water for 24 hours. Then wet dimension was taken and all the physical properties are calculated by using following formula,

Water Absorption

Water absorption was calculated by the following formula-

$$A_w(\%) = \frac{m_2 - m_1}{m_1} \times 100$$ (ASTM, 1997)

Where,

Aw=Water absorption (%) m_1=Weight of the sample before

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

immersion in water (gm.)

Thickness Swelling

Thickness swelling was calculated by the following formula-

$$G_t = \frac{t_2 - t_1}{t_1} \times 100$$ (ASTM, 1997)

Where,

Gt=Thickness swelling (%) t_1= Thickness of the sample before immersion in water (gm.) t_2= Thickness of the sample after (24 hours) immersion in water (gm.)

Boards were tested according to the Japanese Industrial Standards for particle board (JIS A 5908, 2003). The boards are ready for testing physical properties after conditioning for one week at a room temperature 20^{0}C. The MOE and MOR were evaluated by conducting a three point bending test on a 200 x 30 x 9 mm specimen of each board under dry conditions. The loading speed and effective span were 10 mm/min and 150 mm, respectively. The thickness swelling (TS) and water absorption (WA) values of each board after water immersion at room temperature for 24 hours.

Chapter four

Result and Discussion

4.1 Mechanical Properties

Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)

Fig.4.1.1 showed the modulus of elasticity of cross bonded binderless board at different moisture content. At 0-10% moisture content it is not possible to produce any sorts of board as no bonding occured between the jute stick layer. It may be due to the fact that The moisture content was too low to degrade or hydrolyze the hemicellulose that produce simple suger. Literature showed that the cellulose and hemicelluloses are partially hydrolyzed to simple soluble sugars that contribute to self-bonding (Shen 1991; Rowell *et al.* 2000; Widyorini *et al.* 2005a;). However 10-15% and 15-20% moisture board showed the result of Modulus of Elasticity (MOE) (8566.69 N/mm^2 and10359.4 N/mm^2). Because the moisture was enough to enable hemicellulose to hydrolyze.15-20%,moisture showed the better result as this amount of moisture is enough to make strong bonding. It may be due to self bonding ability of the boards increased by degradation of hemicellulose and transformed into hydroxyl methyl furfural which creates stronger bonding (Cerman,2015). However in case of 20-25% moisture there was excess moisture which went inside the inner portion of the jute stick and explosion causes. Literature showed that degradation of chemical components for the hot-press process has been found to be much less effective than a steam treatment (Laemsak and Okuma 2000; Okamoto *et al.* 1994; Widyorini *et al.* 2005a).

Fig. 4.1.2 showed the modulus of rupture of cross bonded binderless board at different moisture content. Modulus of rupture is better at 15-20% moisture content than 10-15% moisture content.. It may be due to self bonding ability of the boards increased by degradation of hemicellulose and transformed into hydroxyl methyl furfural which creates stronger bonding (Cerman,2015). Hemicelluloses are partially hydrolyzed to simple soluble sugars that contribute to self-bonding at this moisture perfectly. When the moisture of the board was 20% or above there was explosion.).

However in case of 20-25% moisture there was excess moisture which went inside the inner portion of the jute stick and explosion causes. Angles *et al.* (2001) discovered that the hygroscopicity characteristics of hemicelluloses are responsible for moisture absorption.

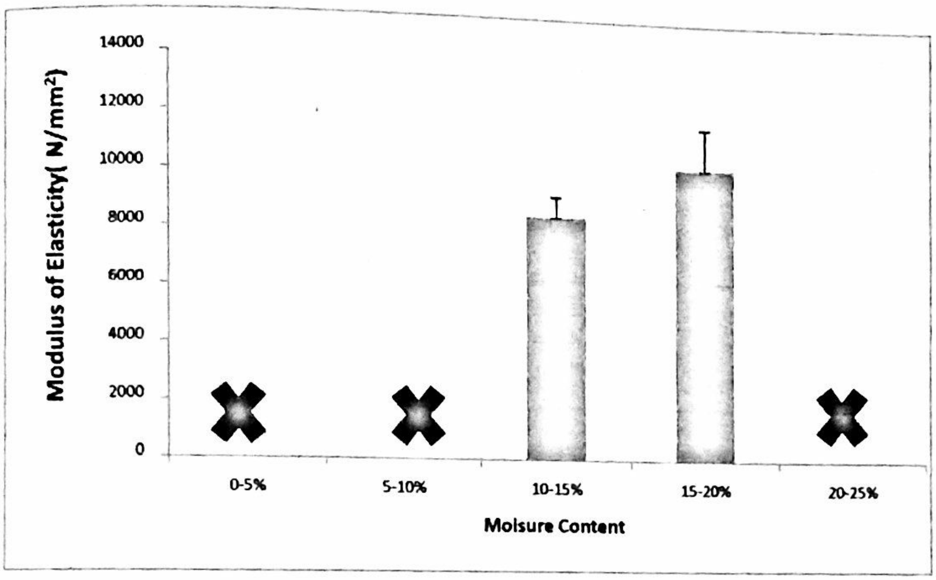

Fig. 4.1.1 Effects of moisture content on Modulus of Elasticity of binderless cross bonded board.

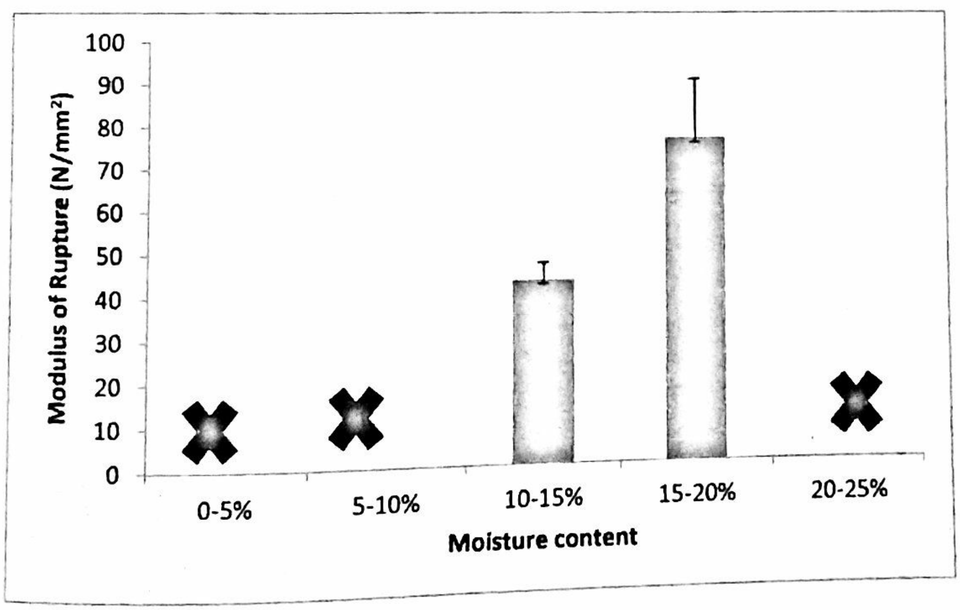

Fig. 4.1.2 Effects of moisture content on Modulus of Rupture of binderless cross bonded board.

4.2 Physical Properties

Water absorption

Fig: 4.2.1 Effects of moisture content on water absorption.

Fig 4.2.3 showed water absorption of cross bonded board at 10-15% and 15-20% moisture content. Since 0-5%, 5-10% and 20-25% moisture content there was not possible to develop any board there was no result. Board made at 10-15% and 15-20% moisture showed water absorption 51.85% and 28% respectively after 2 hours. To get better result the edges of the samples were sealed with epoxy so that the water can not penetrate easily. After epoxy sealing water absorption was 40.52% and 24.05% respectively after 2 hours. It may be due to hemicellulose degradation. During dipping into water hemicellulose reduces the amount of free reactive hydroxyl groups and decrease the ability to bind water. Board made at 10-15% moisture was completely delaminated after 24 hours without epoxy sealing. But with epoxy sealing it was not delaminated and water absorption was 95.27%. Without epoxy sealing and with epoxy sealing, board made at 15-20% moisture water absorption was73.53% and 54.905% respectively. Hence it can be concluded that board made at 15-20% moisture showed lower water absorption and thickness swelling.

The presence of cellulose in the crystalline structure helps to prevent water from penetrating the boards and leads to an increase in dimensional stability, as it makes the structure of the boards compact without voids. At the same time, cellulose is also degraded through the dipping process, which causes a reduction in the quality of boards.

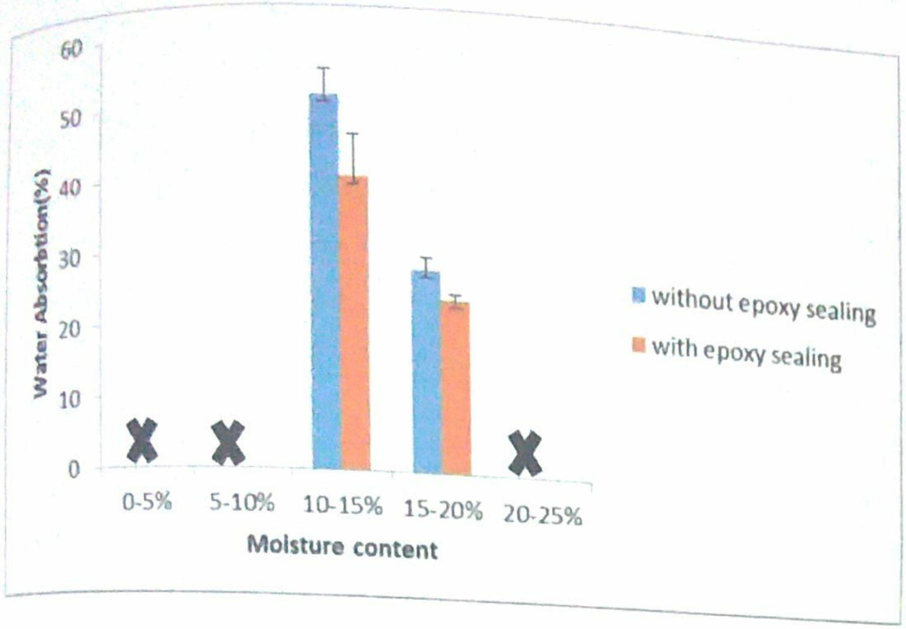

Fig. 4.2.2 Effects of moisture content on water absorption of binderless cross bonded board after 2 hours.

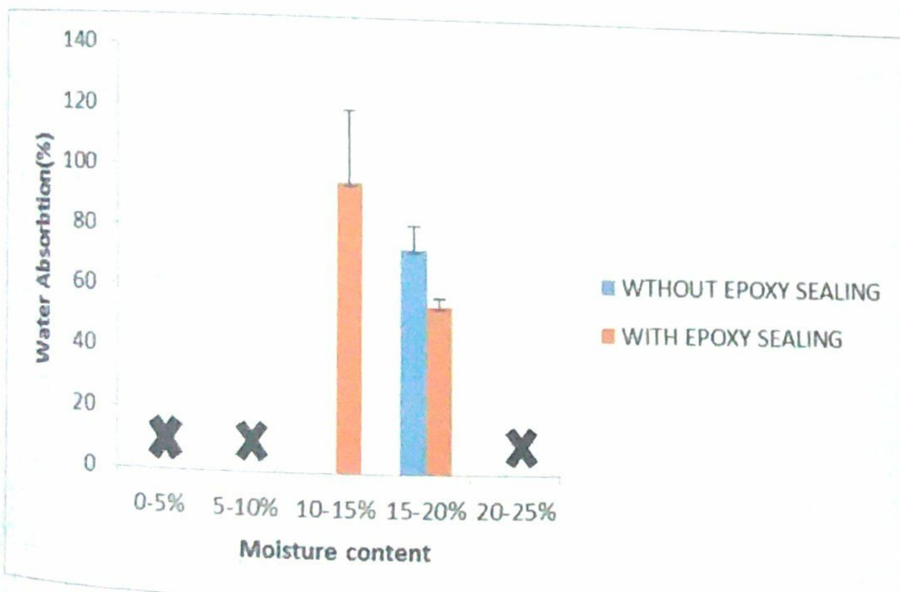

Fig. 4.2.3 Effects of moisture content on water absorption on binderless cross bonded board after 24 hours

Thickness Swelling

Fig 4.2.4 and 4.2.5 showed thickness swelling of cross bonded binderless board at different moisture, after 2 hours and 24 hours submersion in water. After 24 hours submersion in water board made at 15-20% moisture showed lower thickness swelling (22.27%) than 10-15% moisture. Due to lower water absorption thickness swelling is less. To get better result the edges of the samples were sealed with epoxy. Without epoxy sealing board made at 10-15% moisture was completely delaminated after 24 hours. But after epoxy sealing thickness swelling 44.29% after24 hours. Hence board made at 15-20% moisture content showed the better result without epoxy sealing and with epoxy sealing and the reason is same as water absorption. Literature showed that under heat, the pores start to collapse due to the action of unalterable hydrogen bonding among adjoining pore walls, which is termed as horrification (Park et al. 2006). Some authors (Angles *et al.* 2001; Widyorini *et al.* 2005a; Mancera *et al.* 2008) have attained similar results, in which decreasing hemicelluloses content leads to improved dimensional stability, but does not lead to any increase in mechanical properties.

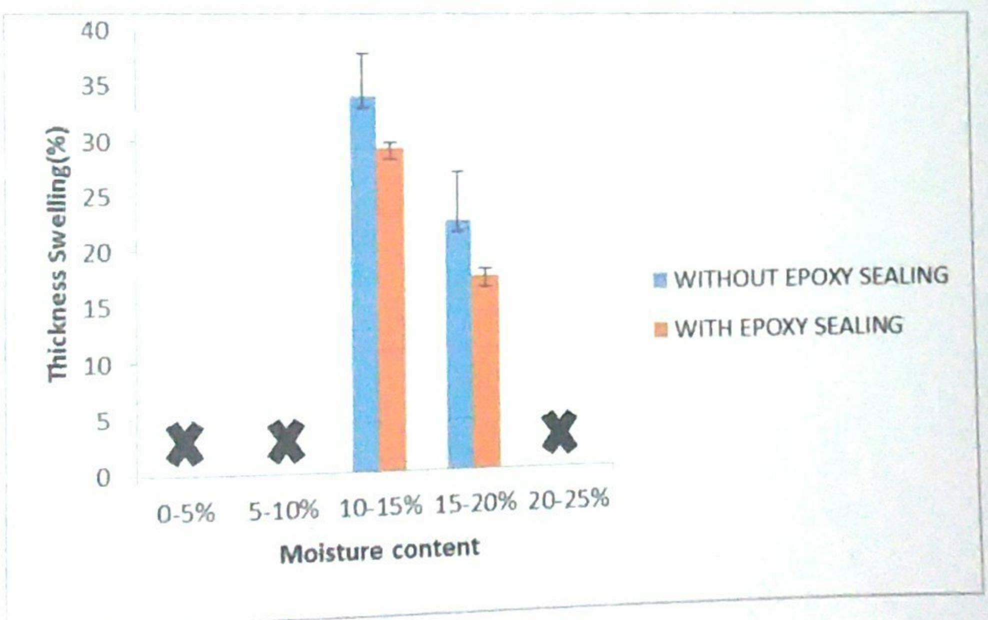

Fig. 4.2.4 Effects of moisture content on thickness swelling of binderless cross bonded board after 2 hours.

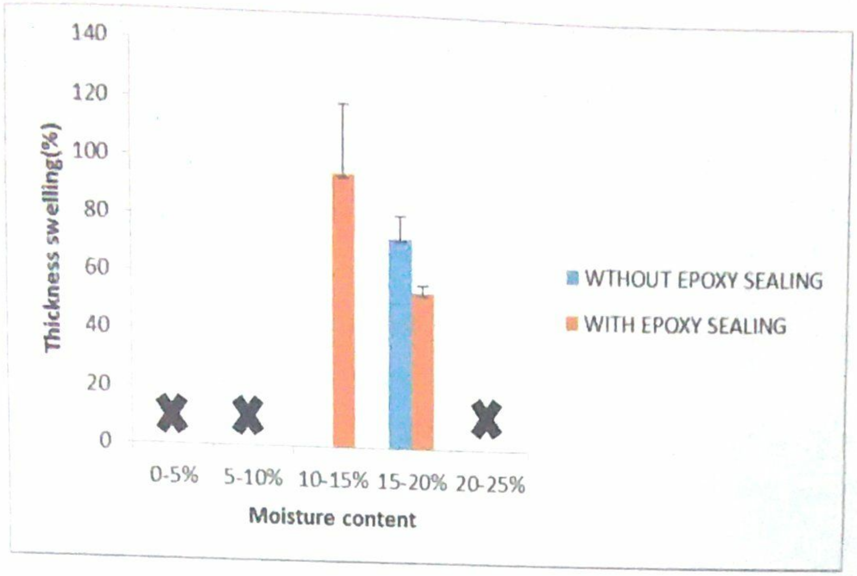

Fig. 4.2.5 Effects of moisture content on thickness swelling of binderless cross bonded board after 24 hours.

Chapter Five

CONCLUSION

- Jute stick can be used to manufacture high performance cross bonded binderless board without using any binding agent by controlling moisture content.
- When the moisture content is less than 5% delamination may occur during pressing. At 10-15% moisture content self bonding is not good. However board made at 15-20% moisture content exhibited high performance.
- Modulus of Elasticity and Modulus of Rupture at 15-20% moisture content were10359.4 N/mm2 and 76.4909 N/mm2 respectively. Thickness swelling and water absorption were 18.02% and 24.05%.
- Further study is underway to improve the dimensional stability of cross bonded binderless jute stick board.

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