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MANUFACTURING OF CITRIC ACID TREATED JUTE STICK BOARD

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Summia Rahman

Abstract: This study was concluded to manufacture cross bonded jute stick board with different concentration of citric acid solution. The boards were manufactured under the pressing condition of 200°C for 10 mins. The citric acid concentration was varied in the range of (20-60) wt% and the target density was 0.8 g/cm^3. The bending strength (MOR and MOE) for 40% citric acid treated board was 55.17 N/mm^2 and 9146.477 N/mm^2, respectively which was higher than 20% and 60% citric acid treated board. Furthermore, this value was higher than UF resin bonded board and satisfied the requirement of international standard. On the other hand, by adding 40% citric acid, the WA and TS value of the board was decreased, hence it was concluded that citric acid of 40% was effective in manufacturing cross bonded jute stick board.

Dedicated to

My Beloved Parents

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Chapter 1

General Introduction

1.1. Current status of forest and agricultural resources

At present the earth is occupied by 3.87 billion ha forest having biomass 421.27 billion tons. Of the total world biomass Asia shares 17.86% (Asian Development Bank, 2016). According to the United Nations Food and Agriculture Organization (FAO), an estimated 18 million acres (7.3 million hectares) of forest have lost each year. Bangladesh has merely 1.9 percent of its land area under forest cover.

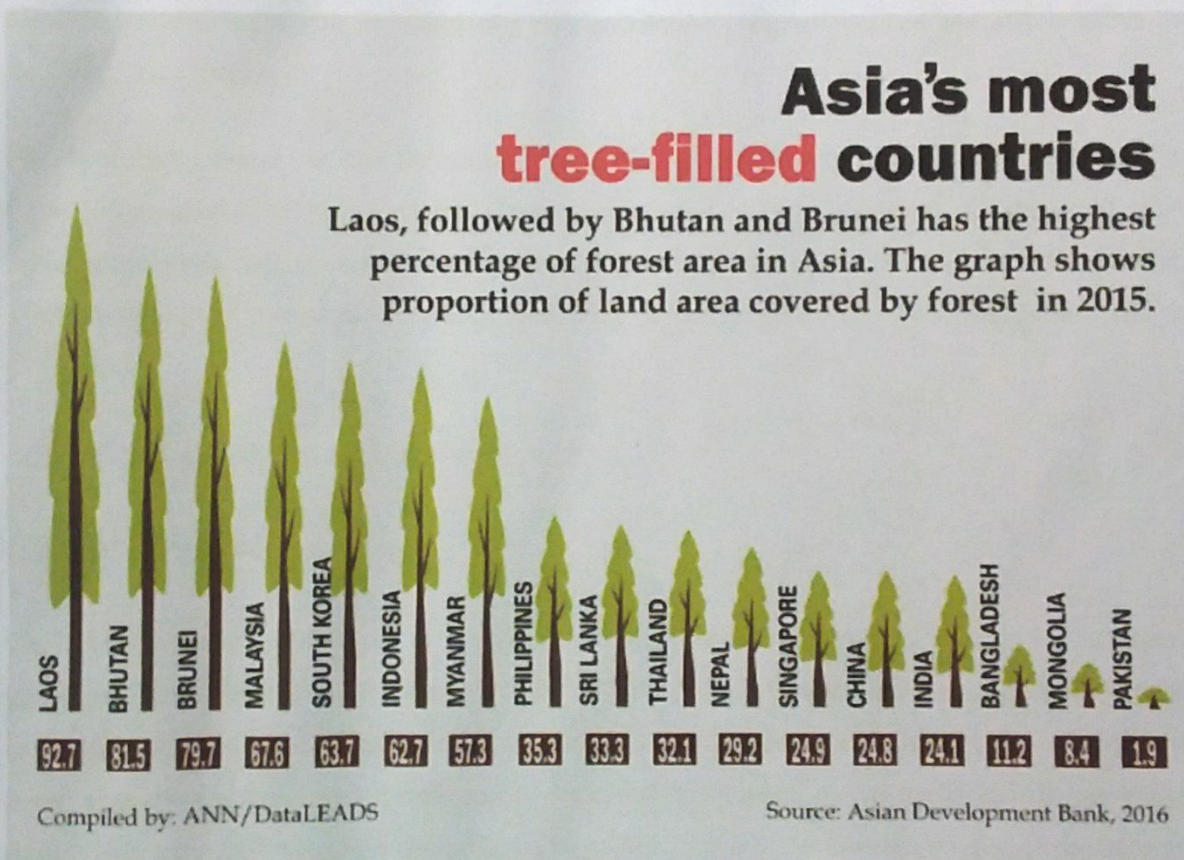


Fig 1.1: Asia's most tree filled countries (Source: Asian Development Bank,2016)

Bangladesh is among the countries with least forest in Asia, according to the data of Asian Development Bank, 2016.Bangladesh having 11.2 per cent of forest areas of the total area of our country.

Bangladesh is an agriculture based country where more than 65 per cent of the people live in rural areas. We have 9.12 million ha of cultivated land. Recent study shows that 70 per cent of total energy consumption comes from biomass. Typically, agricultural residues vastly meet the household energy demands in rural and semi-urban areas. This is practiced mainly because of the fact that around 65 per cent of our economic activities are based on agriculture. The rain fed ecosystem on the other hand produces huge amounts of biomass resources e.g. agriculture residues(crop/tree residue, rice husk,and jute stick). Wood is the main fuel for cooking and other domestic requirements. It is not surprising that population pressure has had an adverse effect on the indigenous forests.

The facts about wood use and deforestation are bleak, but one solution to the problem can be found in abundance across our country. Using agricultural residues, wheat, rice, barley and other cereal grain straw, jute stick and corn stalks as industrial feedstock for the construction material. The percentage of forest is drastically reducing as the demand for wood based product is increasing.

1.2. Status and characteristic of jute

1.2.1 Current Status of Jute

The contribution of jute sector to economy of Bangladesh is enormous. This sector has been generating employment to a large segment of total population of the country, directly and indirectly over the years. Bangladesh produces 5.5-6.0 million (55-60 lakh) bales of raw jute every year of which some 3.2 million (32 lakh) bales are used in the existing 148 jute mills. Bangladesh exports 2.4 million (24 lakh) bales of jute. Some 1, 60,000 employees of the country are directly employed in the jute mills. The total demand for jute goods in the international market is 0.75 million (7.50 lakh) tons. Bangladesh exports 0.46 million (4.60 lakh) tons of jute goods. Dhaka controls 62 per cent share of the total jute goods market of the world and earn Taka 20.125 billion (2012.5 corer) by exporting jute goods. Bangladesh is the lone exporter of raw jute. In recent year the country exported 2.4 million (24 lakh) bales of raw jute valued at Taka 9.77 million (977 corer). In total Bangladesh fetched Taka 29.395 billion (2939.5 corer) by exporting raw jute and jute goods. (Yusuf, 2007)

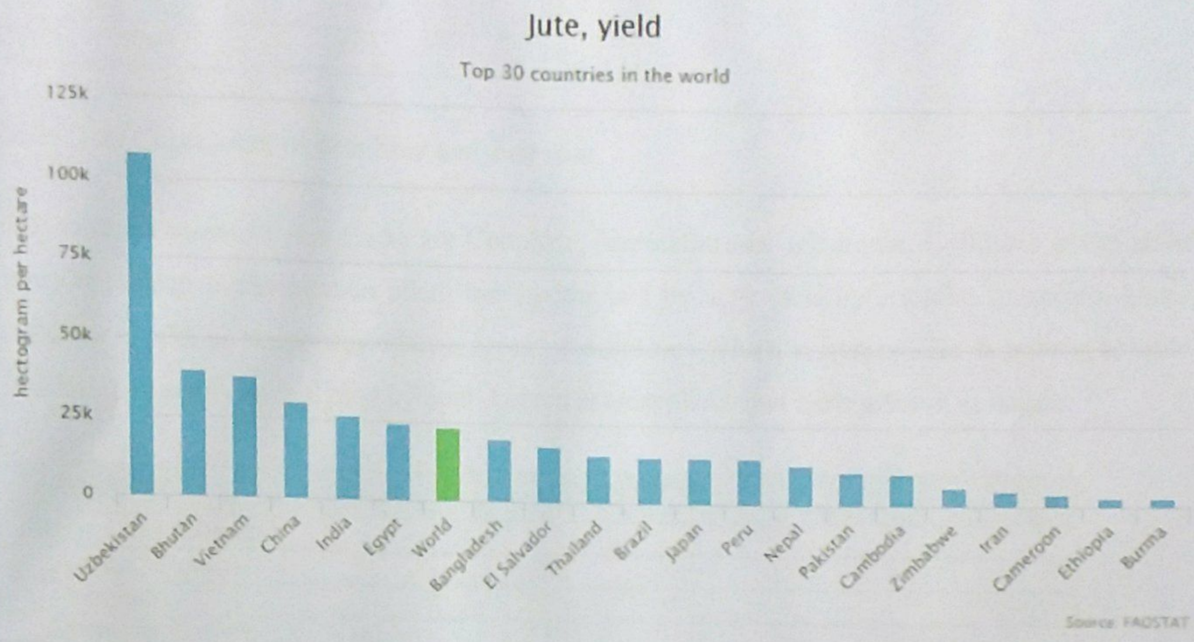


Fig 1.2: Jute yield of top 30 countries in the world. (Source:FAOSTAT)

Bangladesh hold 7th place among all the countries in the world in jute production. Which indicates we have ample amount of residues (jute stick) as well. In any sustainable development, there must be a long-term guaranteed supply of resources. To insure a continuous supply, management of agricultural land should be proactively designed for both sustainable agriculture and the promotion of healthy ecosystems. (Sukma, 2017).

1.2.2 Characteristics of Jute Stick

Jute stick contain a higher amount of hemicelluloses and lignin comparison to jute fiber, which makes jute stick more preferable to wood industry.

Constituent	Jute Fiber (%)	Jute Stick (%)
Alpha Cellulose	61	40.8
Lignin	11.5	23.5
Hemicellulose	24	32.9
Ash	1.6	0.8
Others	1	1.0

Table 1.1: Constituent of Jute fiber and Jute stick

The main elements of jute sticks are Cellulose, hemicelluloses and lignin. Cellulose is the main element, which is resistant to alkali but hydrolyzed by acid. It is hydrophilic in nature. Hemi cellulose works as supporting matrix agent of cellulose. Which is hydrophilic in nature, soluble in alkali and easily hydrolyzed by acid. Lignin is amorphous and hydrophobic in nature.

Constituents	Quantity (% Wt.)
Major Constituents	
Alpha-Cellulose	40.8
Pentosan	22.1
Uronic anhydride	7.5
Acetyl content	4.5
Lignin	23.5
Minor Constituents	
Fat & Wax	1.9
Nitrogenous Matter	1.1
Ash	0.8
Monosaccharide Constituents	
Glucose	43.2
Xylose	18.7
Mannose	1.6
Galactose	1
Arabinose	0.6
Rhammose	0.4

Table 1.2:Major constituents, minor constituents and monosaccharide constituents of Jute Stick

1.2.3 Utilization of Jute Stick:

Jute stick is a byproduct of Jute. However nearly 30 lakh tones of jute sticks are produced every year which can be easily utilized in wood industry based on agricultural resource. Jute sticks are traditionally used mainly as cooking fuel and fencing in rural areas. Jute Stick is very popularly use for charcoal production. Bangladesh exported jute stick carbon to China and earned Tk 140 million during the fiscal year 2015-16, according to industry insiders. From the table -1, The jute plants have average 956.38 thousand tone leaf and 423.4 thousand tone root per year which are rotten and mix with the soil. This increases the fertility of land by giving Urea, TSP, MP, Zips am, Dolomite, Ferrous Sulfate, Magnesium Sulfate, Zink sulfate to the soil (IJSG, 2003).

Type of product nutrients	Dry fibre (%)	Dry sticks (%)	Dry leaves (%)
N	0.43	0.21	3
P2O5	0.19	0.09	.37
K2O	1.65	0.75	2.2

Table 1.3: Estimated amounts of N, P, and K in fiber, sticks and Leaves as % of total dry weight of products. (Source: IJSG, 2003 and Dempsey, 1975.)

From table-1 we can conclude that Jute Stick only contribute a little in the production of nutrients in comparison with dry fiber and dry leaves. Therefore, utilization of jute stick as a raw material for wood industry is an effective way to reuse this material.

Contribution of Jute	Amount(Tone/hectare)
Fibre Production	1.98
Jute Stick	4.94
Leaf	1.92
Rotten Water	1.07
Root	0.85
Carbon-Oxide Absorbed	14.66
Oxygen Emission	10.66

Source: Islam, M. Mahbubul Islam(2011).Importance of Jute in Bangladesh. Krishi Khota. Dhaka. Ministry of Agriculture.

Table 1.4: Contribution of jute on environment.

Average production of jute stick is 2480.62 thousand tons per year and the trend of jute stick production is steady over the years(Islam, M. Mahbubul Islam, 2011). The huge amount of jute sticks are used for wood based industries, pulp and paper industries and household fuel which reduce the cutting down of trees that preserve the nature.

Recently, the investigation of wood-based composites produced using agricultural waste and natural adhesives has become very important due to the decreased wood resources and fossil resource reserves.

1.3. Status and characteristic of citric acid and its utilization

1.3.1 Current Status of Citric Acid:

Global sale of citric acid was valued at US$ 2,756.5 Mn in 2015, and is projected to be valued at US$ 4,494.8 Mn by 2026. The global market for citric acid stood at USD 2.6 Billion in 2014, at USD 3.6 Billion by 2020 and is projected to grow at a CAGR of 5.5% from 2015 to 2020. In developed regions, it has struggled with rising prices of molasses, a key raw material in citric acid production. Despite this, the global market is impacted by large-scale production and export of inexpensive citric acid products from the Asia-Pacific market, especially from China.

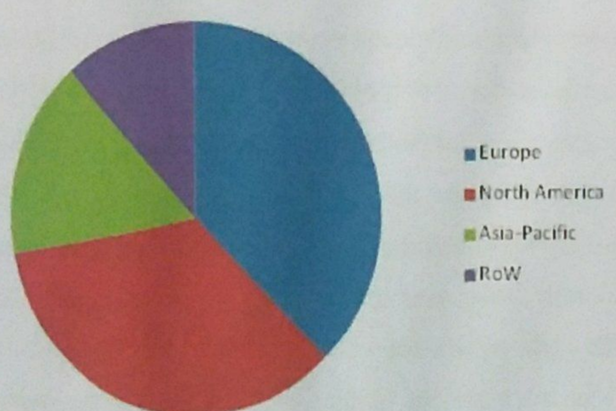


Fig 1.3: Citric acid market size (value), by region, 2014 (Source: Markets and Markets, 2017)

1.3.2 Characteristics of citric acid:

Citric acid (2-hydroxypropane- 1, 2,3-tricarboxyl) is a natural constituent of many plants, animal tissues and physiological fluids. In trace amounts it appears in a variety of fruits and vegetables, but macroscopic quantities are present in citrus fruits notably lemons and limes. Fruits having above 1 % (on the dry weight basis) are: lemons 4.0–8.0 %, black currents1.5–3.0 %, grapefruits 1.2–2.1 %, oranges, tangerines, red currents, raspberries and strawberries contain citric acid in the 0.6–1.3 % range.

Citric acid monohydrate crystallizes from cold solutions and the crystals lose their hydration water if gently heated at 70–75 °C and melt in the range of 135–152 °C. Fast heating leads to dehydration at about 100 °C, melting at 153 °C and decomposition above 175 °C.

1.3.3 Utilization of citric acid:

Citric acid is a commercially important specialty chemical with several applications (Vandenberghe et al. 2004). Some applications of citric acid include utilization as a preservative, flavor enhancer, a chelating agent, pH regulator, antioxidant and stabilizer (Soccol et al. 2006).

Many studies have focused on finding new adhesives based on renewable materials, such as citric acid (Umemura et al. 2012; Widyoriniet al.2006).Citric acid has been researched as a cross-linking agent to improve the physical and mechanical properties of wood, paper (Caulfield, 1994), cotton (Morris et al., 1994, 1995),and cellulosic material (Katovic et al., 2000).Citric acid, which is natural organic polycarboxylic acid containing three carboxyl groups, could act as a binding agent for boards made from wood (Umemura et al. 2012). The results show that citric acid bonded board's exhibit high mechanical properties and good dimensional stability. In case of the manufacturing of particleboard from wood, citric acid was used with sucrose as the adhesive (Umemura*et al.*, 2013; 2014). Furthermore, they discovered that the physical properties was improved using the citric acid to sucrose ratio of 25/75 wt%. This mean that, sucrose as a disaccharide contributed in improving bond ability of the particleboard. However, conventional natural adhesives contain harmful chemical substances, i.e., various organic solvents and aldehyde compounds that cause environmental pollution and damage health(Shebe, 2013). Considering these problems, research should be focused on obtaining an excellent bonding performance using natural adhesive without the addition of harmful chemical sub-stances. Based on the chemical composition of Jute stick as mentioned above, jute stick contained higher cellulose percentage among all the chemicals it has. In cellulose there are hydroxyl groups.

In citric acid there are 3 carboxyl groups that have a chance to ester linkage with hydroxyl groups found in sample, which will reduce hygroscopicity and shrinkage, swelling properties and improve the performance.

1.4. Objectives of the Study:

The objectives of this research were:

- To manufacture cross bonded jute stick board with citric acid.
- To evaluate physical and mechanical properties of these kind of boards.

Chapter 2

2. Materials and methods

2.1.Materials:

Raw material:

Bales of Jute sticks were collected from Gopalganj district.

Adhesive:

Citric acid anhydride was purchased from local market. Citric acid was dissolved in distilled water to prepare 20%, 40% and 60% concentration of the solution.

Preparation of raw material:

Raw material was air dried for seven days. Fibers on the sticks were separated manually.

Then sticks were cut into desirable size by using conventional hand tool. Sticks were cut into 31 cm in size and 21 cm in size.

2.2.Method:

Pre drying:

After stacking the sticks in several layers, sticks were dried in oven at 103^0C for 24 hours. To reduce the moisture content of the sticks pre drying is necessary. To make sure all the sticks were dried properly, sticks were stacked.

Fig 2.1: Staking stick before putting it in oven

Preparation of solution:

Solution were prepared for 20%, 40% and 60% citric acid concentration. 1000ml solution have been prepared for each citric acid concentration. For preparing 20% citric acid solution 200g citric acid is added with 800 ml water. For preparing 40% citric acid solution 400g citric acid is added with 600 ml water. For preparing 60% concentration of citric acid solution, 600g citric acid is added with 400 ml water. After adding citric acid with distils water, the solution was placed in hot water at a temperature of 80^0C.The solution is stared continuously with a glass rod,until the citric acid mixed completely in water and give an appearance like transparent water. After that the solution was left for at least 3 hours at room temperature.

Fig 2.2: Measured Citric acid and water

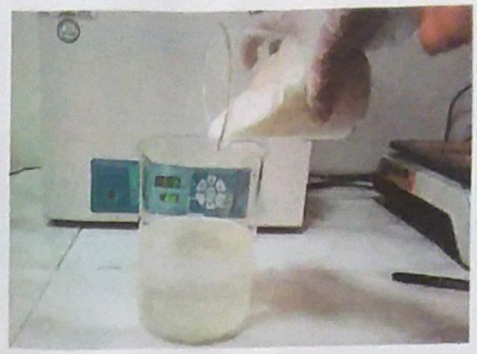


Fig 2.3: Citric acid is adding in water

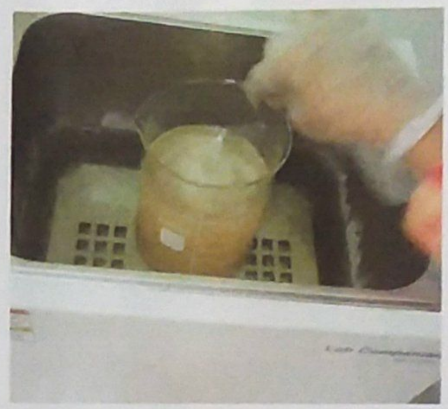


Fig 2.5: Beaker is placed in hot water bath at 800C with continuous stiring.

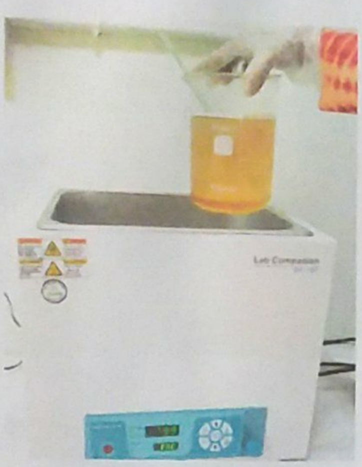


Fig 2.4: Citric acid completely dissolved in water

Fig 2.6: Prepared solution after 3 hours

Citric acid impregnation process:

A stainless steel tray is needed for this purpose. Citric acid can not react with stainless steel at room temperature. The solution of citric acid was poured into the tray. Then the oven dried Jute sticks were immersed fully in the solution for 3 minutes. To make sure all the sticks stay immersed for 3 minutes, some weights on those stricks had been given by placing beakers with equal amounts of water in it.

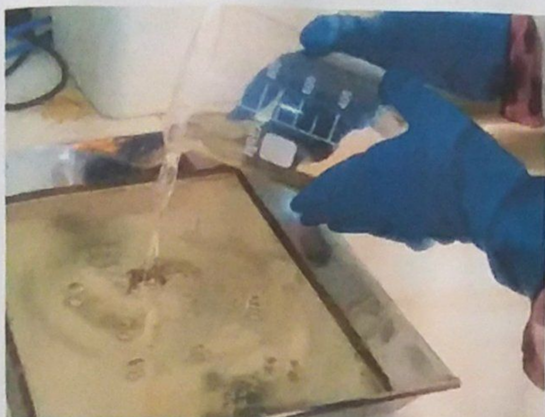


Fig 2.7: Pouring Citric acid solution

Fig 2.8: Immersed Jute sticks

After three minutes those sticks were shaken gently just to avoid extra amount of citric acid solution on it. After that those sticks were stacked with space in between to dry properly and placed it in oven at 80^0C for 48 hours.

Assembling of Sticks:

Assembling of sticks played a vital role to manufacture this board. To make a 5 layer board the number of long jute stick is around 80 and the number of short jute stick is also the same. Long sticks were cut into 31 cm in size and short sticks were cut into 21 cm in size. At first the long sticks were assembled vertically with no space in between. This is the first layer. Then the short sticks were assembled horizontally with no space in between along the length. This is the second layer. Similarly three more layers were assembled one after another. The sticks were assembled into a rectangular of iron mould on a stainless steel plate lined with a superior quality teflonsheet to prevent the consolidated mat from sticking to the platen during pressing. Teflon sheet also made a good impression on the appearance of the board.

Hot Pressing:

Aftter assembling the assembled sticks were hot pressed at 200^0C temperature at air dried condition at 7.5 Mpa pressure for 10 mintes. Density of the boards was controlled at 0.8 gm/cm^3. Then press was switched off but prssure was not released at that time.Then the board was allowed to cool for 15 minutes. Then pressure was released slowly and broght the board out.

Fig 2.9 : Hot Press

After the boards of each type were produced separately, these were trimmed at edges with the fixed type circular saw. The dimentions of each type of boards were 30x 20x 0.7 cm.

Trimming:

After the boards of each type were produced separately, these were trimmed at edges with the fixed type circular saw. The dimentions of each type of boards were 30x 20x 0.7 cm.

2.3.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).

2.4. Determination of Mechanical Properties

All the samples are cut into required dimension for testing mechanical properties. The laboratory test for characterization of mechanical properties was carried out in Akij Particle Board industry.

2.5.Determination of Physical Properties

All the samples are cut into (5cm × 5cm) dimension for testing physical properties. The laboratory test for characterization of physical properties was carried out in the laboratory of Forestry and Wood Technology Discipline, Khulna University, Bangladesh. At first all the specimens were weighted and green dimension are taken at room temperature. 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-

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

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-

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

Where,

Gt=Thickness swelling (%)

t_1= Thickness of the sample before immersion in water (gm.)

t_2= Thickness of the sample after (24 hrs) immersion in water (gm.)

For measuring moisture content and weight percentage gain 4 random jute sticks for each kind of board is selected namely, s1,s2,s3 and s4. Moisture content and weight percentage gain were calculated for each of the stick individually and done an average of those values.

Moisture content

Moisture content was calculated by the following formula-

$$MC = \frac{W2 - W_3}{W3} \times 100 \text{ (ASTM, 1997)}$$

Where,

MC= Moisture content (%)

W_2= Weight of the oven dried samples after immersion in citric acid for 3 minutes (gm).

W3= Weight of the citric acid immersed sample after drying it in oven for 48 hours(gm).

Weight Percentage Gain

Weight gain was calculated by the following formula-

$$WPG = \frac{W3 - W1}{W1} \times 100 \text{ (ASTM, 1997)}$$

Where,

WPG= Weight Percentage Gain (%)

W_3= Weight of the citric acid immersed sample after drying it in oven for 48 hours(gm).

W1= Oven dried weight of sample for 24 hours (gm).

2.6. Evaluation of the physical properties

After conditioning for 1 week at a room temperature of 20 °C, the boards were tested according to the Japanese Industrial Standards for particleboards (JIS A 5908, 2003). The bending properties of the boards, i.e., the modulus of rupture (MOR) and the modulus of elasticity (MOE), 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 internal bonding (IB) strength was investigated using a 50 x 50 x 9 mm specimen of each board. The thickness swelling (TS) and water absorption (WA) values of each board after water immersion at room temperature for 24 hours.

Chapter 3

3. Result and Discussion:

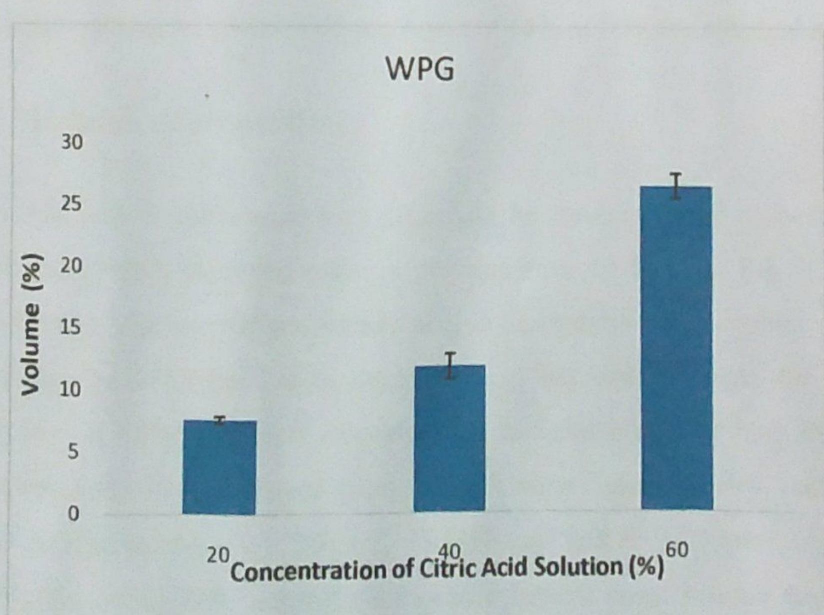


Fig 3.1:Effects of citric acid concentration on weight gain.

The percentage of weight gain gradually increased with increasing citric acid content. In case of 20% citric acid concentrationthe weight gain of the sample was lowest. For 40% citric acid treated sample, the weight gain of the sample was higher than 20% citric acidtreated sample. In case of 60% citric acid concentration, the weight gain of the sample was higher than 20% and 40% citric acid treated sample.

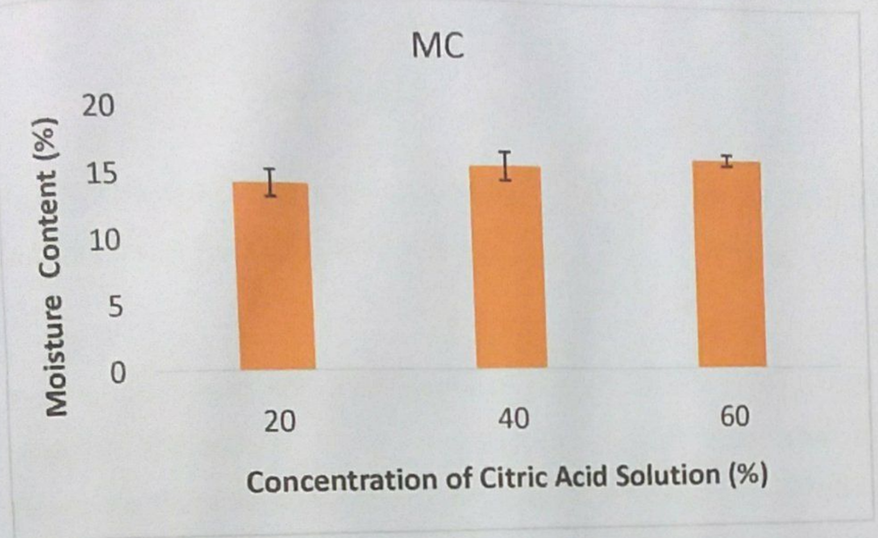
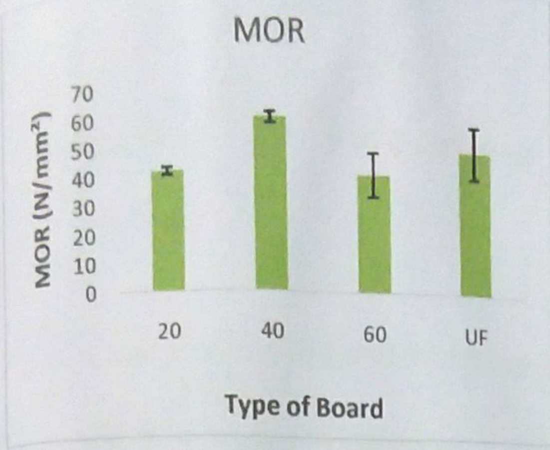


Fig3.2: Moisture content at different citric acid concentration

Moisture content was controlled in a range of 14% to 15% for different citric acid concentration.

3.1 Mechanical properties

The influence of concentration of citric acid on the mechanical properties of cross bonded jute stick board were observed under a pressing time of 10 min. Fig 3.3and Fig 3.4 shows the relationship between different citric acid concentration and variation of bending properties of cross bonded jute stick board. Irrespective of the type of board, the MOR and MOE values increased at 40% citric acid concentration and decreased for both 20% and 60% citric acid concentration. The maximum average MOR value for 20%, 40% and 60% citric acid treated cross bonded board is 41.7N/mm², 55.17N/mm² and 43.38N/mm², respectively and the MOE values for 20%, 40% and 60% citric acid treated cross bonded board is 7915.003 N/mm², 9146.477 N/mm² and 7529.093 N/mm²respectively.



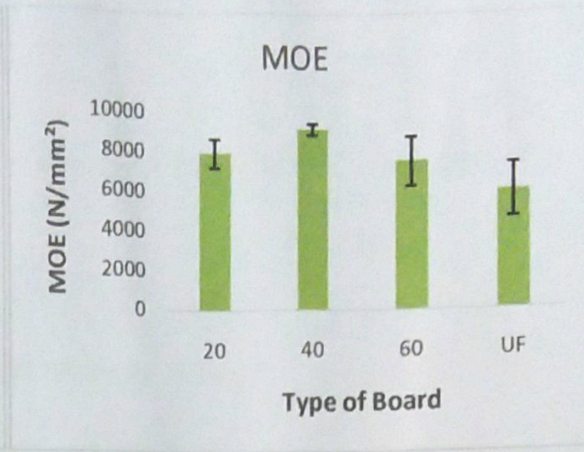


Fig3.3: Effects of citric acid concentration on Modulus of Elasticity of Boards (MOE)

Fig 3.4: Effects of citric acid concentration on Modulus of Rupture of Boards (MOR)

In 20% citric acid concentration, the solution was very thin, water like. Which was hard to penetrate. Because of lower concentration of citric acid, internal bonding was not so good. Hence, mechanical properties decreased. In 40% citric acid concentration, the solution was a little bit thicker than 20% citric acid concentration. The viscosity of the solution was good to penetrate which results strong internal bonding and mechanical properties increased. In 60% citric acid concentration, the solution was much thicker, oil like which was hard to penetrate. This large amount of citric acid made the raw material brittle and lower the internal bonding. Hence, mechanical properties decreased.

The MOR and MOE of UF bonded board results lower than cross bonded jute stick board treated with 40% citric acid concentration. UF was brushed only on the surface of the sticks but it was not penetrated into the cell wall of the sticks so may be UF Bonded the sticks at outer binding line and no inner bonding line was created (Ceman, 2015). This could be a probable reason for decreasing MOR and MOE value of UF board.

Citric acid had good bond performance for wood-based molding, and its main bonding mechanism was ester linkages between the carboxyl groups of citric acid and hydroxyl groups of wood components (Umemura et al. 1991).

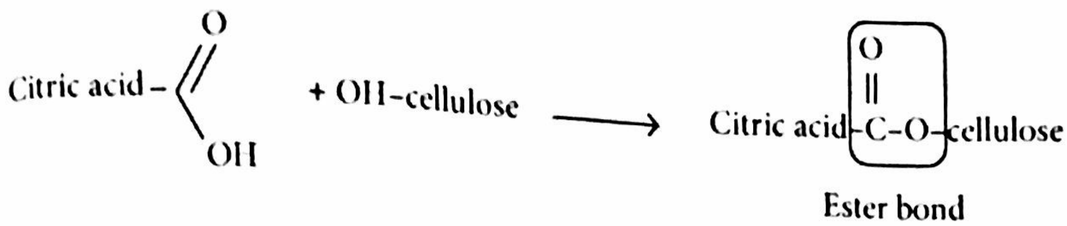


Fig 3.5: Citric acid react with hydroxyl group and form ester linkage.

Citric acid is a cross linking agent, it reacts with the hydroxyl groups and reduces the hygroscopicity of wood as well as the tendency of wood to swell or shrink (Rowell 1991). Ummemura et al (2012) pointed out that ester linkage can be detected by Fourier transform infrared spectroscopy (FTIR), which indicated that the carboxyl groups from wood, improving the performance of boards. In jute stick there are a major percentage of cellulose and hemicelluloses, containing hydroxyl groups which react with carboxyl groups of citric acid and form ester linkage C=O. Consequently, the formation of ester linkages would result in good adhesive-ness and impart excellent physical properties and dimensional stabilities to the boards (Sukma, et al. 2016).

According to Wing (1996) when citric acid is heated, it loses water molecule, which thereby creates an anhydride; with more heat, the acid loses another water molecule. When the acid reacts with the hydroxyl groups of cellulose, monoesters can be formed.

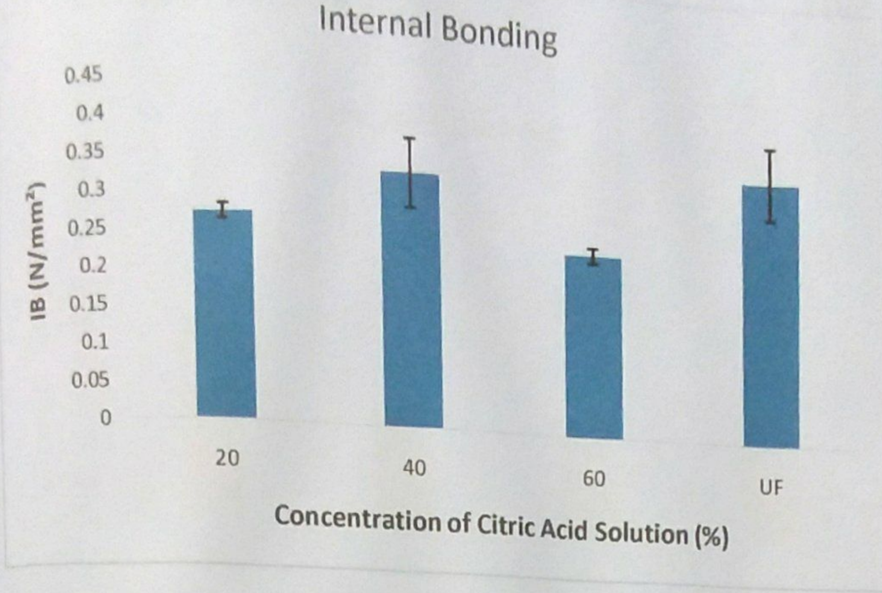


Figure 3.6: The figure shows the relationship between the citric acid content and the IB strength of UF board and jute stick cross bonded board with 20%, 40% and 60% citric acid concentration.

The IB strength of cross bonded jute stick boards treated with 20%, 40% and 60% citric acid was approximately 0.27 N/mm2, 0.32 N/mm2, and 0.24 N/mm2, respectively. The IB strength of cross bonded jute stick boards treated with 40% citric acid was slightly higher than that of boards bonded with 20% and 60% citric acid. In addition, the IB strength cross bonded jute stick boards treated with 30% citric acid were almost similar to UF boards. Generally, hemicellulose was decomposed easily by acid and heat, and then produced oligosaccharide that have rich hydroxyl group (Sukma, 2017). Therefore, we are expecting that under heating condition, the concentration of 40% citric acid decomposed hemicellulose effectively and produced oligosaccharide that have rich hydroxyl group. So there is more chances of the formation of ester linkage. Formation of ester linkage can provide good bond ability (Sukma, et al. 2016). That could be a good reason of increasing IB value for 40% citric acid treated cross bonded board. It is thought that lignin also contribute to the formation of bonding mechanism. The role of lignin in the bonding mechanism of the natural adhesives with citric acid is still unknown (Ragil et al., 2016).

3.2. Dimensional stability

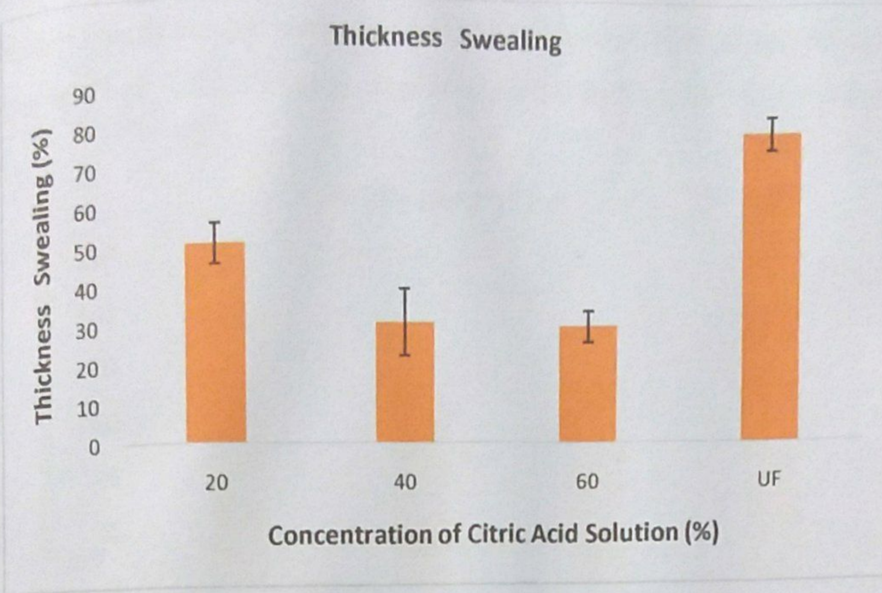


Fig 3.7: shows the effect of the citric acid content on the TS and WA values of 20%, 40% and 60% citric acid treated cross bonded board.

TS value decreased with increasing citric acid content. For 60% citric acid treated cross bonded board, TS value was the lowest (30.27%) and for 20% citric acid treated cross bonded board it was highest (52.2%). For 40% citric acid treated cross bonded board it was almost similar (31.15) to the board with 60% citric acid. Due to high cellulose and hemicellulose content of jute stick that contributed to the much amount of hydroxyl groups react with citric acid and generated cross-linking (Sukuma, 2017). Thus the hygroscopicity of the jute stick eliminated by existing of the cross-linking. As the citric acid concentration increased, the amount of carboxyl group also increased in the solution. So there is more possibility to form ester linkage, which will result less hygroscopicity of the material. This could be a probable reason for lowering TS value for 60% and 40% citric acid treated cross bonded board than 20% citric acid treated cross bonded board.

The TS values of the boards bonded with UF were approximately more than double (80%) than that of boards bonded with 40 wt% and 60 wt% citric acid. Because UF resin is less resistant to water and go through decomposition in the presence of amino methylene linkage resulting spring back of particleboard after immersion in water (Nemli, 2006). This result indicated that cross bonded boards bonded with citric acid had a good level of dimensional stability. The principal factors affecting the TS value of cross bonded boards are the concentration of citric acid used.

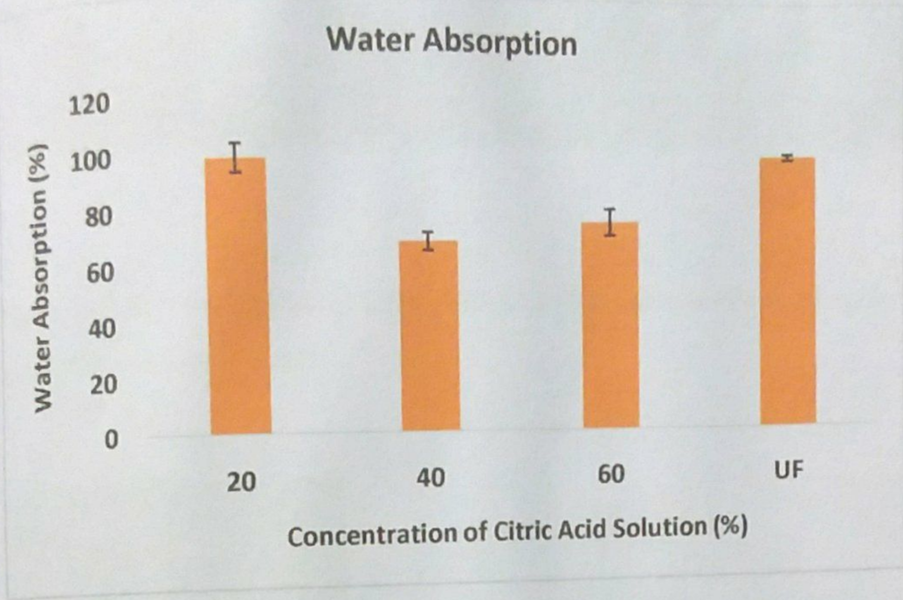


Fig 3.8:This figure shows the effect of the citric acid content on the water absorption values of 20%, 40% and 60% citric acid treated cross bonded board.

The WA value of the boards for 20%, 40% and 60% citric acid content decreased than those boards bonded with UF. This result indicates that citric acid inhibited water absorption by the boards during the water-immersion treatment. As a result, the water resistance of the boards has increased. However, the WA value for boards bonded with 40% citric acid was lower than boards with 20%and 60% citric acid content. Citric acid is a cross linking agent so it is possible to reduce shrinkage and swelling. In citric acid there are carboxyl group which react with hydroxyl group found in our sample at high temperature (200^{0}C) and pressure (7.5 MPa). That result ester linkage. The formation of ester linkages can result in good adhesiveness, bendability and provide good physical properties to the boards (Sukma, et al. 2016). As a result, the water resistance of the boards increased. Previously from the IB test result it is observed that boards with 40% citric acid concentration had the highest IB value(0.32 N/mm2). Because of good formation of ester linkage the TS and WA value reduced for boards with 40% citric acid content. Furthermore, UF boards have similar IB test value (0.35N/mm2) but UF resin is less resistant to water and go through decomposition in the presence of amino methylene linkage resulting spring back of particleboard after immersion in water (Nemli, 2006).

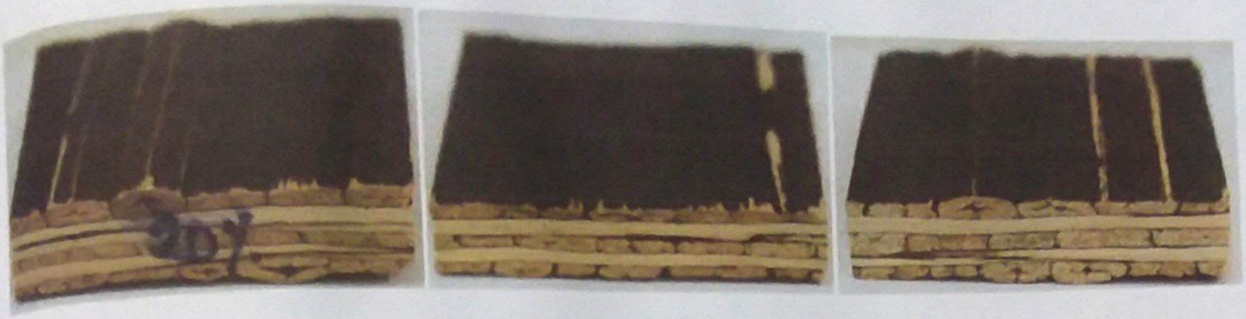


Fig: 3.9: Water absorption of 20%, 40% and 60% citric acid treated cross bonded board, after 24 hours submersion in water.

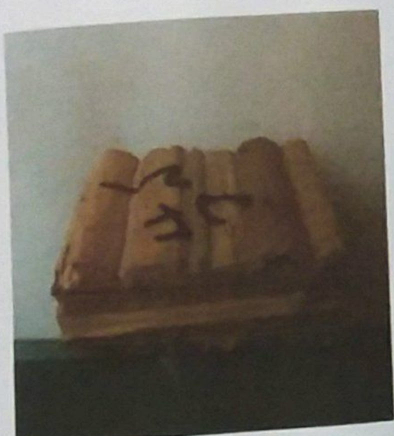


Fig 3.10:UF board after 24 hrs submersion in water, UF bonded cross board showed almost two times higher Water absorption than 40% citric acid treated cross bonded boards.

Chapter 4

Conclusion

- High performance citric acid treated environmentally friendly cross bonded jute stick board has been manufactured in the study.
- MOR and MOE value of 40% citric acid treated board was 55.17 N/mm^2 and 9146.477 N/mm^2 respectively.
- By adding 40% citric acid the dimensional stability can be improved.
- The mechanical and physical properties are better than Urea Formaldehyde bonded board.
- Further study is needed to elucidate the mechanism of citric acid treated board.

Chapter 5

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