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Title: Development of Natural Rubber Latex based Bioadhesive for manufacturing of particle board

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Programme: Bachelor of Science in Forestry

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**DEVELOPMENT OF NATURAL RUBBER LATEX BASED
BIOADHESIVE FOR MANUFACTURING OF PARTICLE
BOARD**



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**FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
Khulna University,
Khulna
2018**

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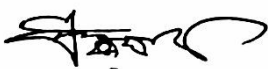
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COUSRE TITLE: PROJECT THESIS

COURSE NO.: FWT-4114

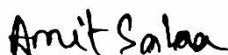
[This thesis paper has been prepared for the partial fulfillment of the requirements of Four years B. Sc. (Hons.) degree in Forestry from Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh]

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DECLARATION

I, Amit Kumar Saha, Student ID- 130516, hereby declare that this project thesis is based on my own research work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at other institutions.

Amit Saha

Amit Kumar Saha

**Dedicated
To
My Beloved Parents
And Sisters**

ACKNOWLEDGEMENT

First of all, I am very much grateful to the almighty God for giving me the opportunity to finish my research study successfully.

I would like to express my sincere gratitude and profound appreciation to my supervisor Professor Dr. Md. Nazrul Islam, Forestry and Wood Technology Discipline, Khulna University, Khulna for his continuous supervision, guidance, inspiration, valuable advice and thoughtful suggestions during the study period and providing useful books and papers in preparing and writing up this research paper.

I wish to express my special thanks to my two honorable senior Md. Nasim Rana, Khondoker Siddikur Rahaman, Teertha Jit Roy, Sourav Bachi Ratul and all my friends especially Shraboni Deb and Sabuj Majumder; administrative staffs and staffs of the laboratories of FWT discipline, Khulna University.

Finally, I would like to express my appreciation and gratitude to my beloved parents and other family members who always inspired me and sacrificed their happiness for my education and happiness.

Amit Kumar Saha

ABSTRACT

The purpose of this study was to utilize the natural rubber latex and starch as an adhesive in the particle board production. Natural rubber (NR) latex and starch was used as an adhesive for particle board production. Natural rubber and starch both are produced from the plant origin. This will be used as an alternative of UF resin. Because UF is not environmentally friendly but it will be totally environmentally friendly. Three combination of ratio, 3:1; 2:2 and 1:3 NR latex and starch, formic acid adhesive were used for the board manufacturing. In this study mainly 22.5 ml NR latex with 7.5ml starch and formic acid, 15 ml NR latex with 15ml starch and formic acid and 7.5 ml NR latex with 22.5ml starch and formic acid were used among the adhesive ratio of the particle. The particleboards were analyzed according to ANSI standards for its physical and mechanical properties. pH of natural rubber latex was 10 and the viscosity was 7.5 MPa.s. The board which contain 7.5 ml NR latex with 22.5ml starch and formic acid provide better physical result like density water absorption and provide better mechanical strength like MOE, MOR than 15 ml NR latex with 15ml starch and formic acid and 22.5 ml NR latex with 7.5 ml starch and formic acid. The results of this study indicated that NR latex can be used as a viable alternative binder by mixing with starch and formic acid.

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ABBREVIATION

ASTM	American Society for Testing and Material
NRL	Natural Rubber Latex
NR	Natural Rubber
MDF	Medium Density Fiber Board
UTM	Universal Testing Machine
ANSI	American National Standard for Basic Hardboard
MOE	Modulus of elasticity
MOR	Modulus of rupture
TS	Thickness swelling
WA	Water absorption
Kg	Kilogram
mm	Millimeter

Chapter One

Introduction

1.1 Background of the study

Forest area of Bangladesh is decreasing with increasing the population. For this reason, the availability of solid wood is decreasing. Now peoples of Bangladesh are very much interested about the composite products. Because, composite materials are very cheap and lighter than solid wood. Composite material is one which is combined of any kind of re-constitute materials such as dust, particles, and fibers that settle with glues by means of pressure, heat and chemicals. As an alternative of wood, Particle Board plays a significant role in our daily life (Zheng et al. 2007). Now many researchers are interested to develop and characterize new and low cost materials from renewable local resources. Bangladesh is an agricultural country. Every year huge amount of agricultural waste (jute stick, bagasse, kenaf etc.) is produced from agricultural field and which has no utilization. So agricultural waste like jute stick can be a good raw materials for composite industries.

For manufacturing of particle board resin or adhesive is used as a binder. Particle board industries are mainly familiar with synthetic resin like formaldehyde based, isocyanate based and vinyl acetate resins. Among them urea formaldehyde resin is the most popular resin. Urea formaldehyde is used as an adhesive in particle board manufacturing more than 100 years, as they have high reactivity and low cost (Roumeli et al. 2012). It is also a low water resistance materials and it is not environmentally friendly. It is emitted as this reason it is hazardous for our health (Osemeahon and Barminas2007). UF adhesive is a carcinogen material and is harmful to human, animal and environment (Naya and Nakanishi 2005). Industries are now thinking about the production of environmentally friendly composite materials. Industries today are under tremendous pressure to design ecologically and environmentally friendly viable materials for their products. This is because of growing environmental awareness and new rules and regulations that are binding on industries. As a result researchers are thinking about the manufacturing of natural composites. Now wood scientists are making binder less board, cement bonded board and natural adhesives bonded board, which may be the alternatives of UF resin bonded board. To address these problems, natural adhesive derived from renewable resources such as protein, tannin, lignin, and starch are being investigated (Trosa and Pizzi 1997). Many researchers have been reported ways of reducing the utilization of the synthetic adhesive such as development of natural adhesives (Xu J et. al., 2005).

Natural rubber latex is a natural adhesive which can be used as an alternative of UF resin. NR latex is one of the natural adhesive extracted from latex from one kind of tree i.e. *Hevea brasiliensis* (Yuhazri et al. 2011). NRL is a milky brown, slightly viscous latex suspension which exhibits good moisture and mold resistance with no toxicity. It is a locally available product. It can be used as an adhesive in particle board production. It has been widely explored and used for the synthesis of wood adhesives especially for non-polar adherents (Pizzi, 1994) with modification done to increase its performance on polar surfaces. NR latex is an environmentally friendly material which has no environmental hazards. In this study natural rubber latex can be used as an adhesive for manufacturing of particle board. For increasing the strength of the board some other materials like additives can be added in the board. For increasing the strength of the board starch and formic acid can be used in the manufacturing the board.

Starch is a biopolymer which is renewable, widely available and biodegradable. It has been actively used as binders, glues and pastes even during ancient years (Kennedy Harry, 1989). However, starch has its main limitation of not having strong bonding capacity to glue wood based materials (Imam et al., 2001; Imam, Mao, Chen and Greene, 1999). For increasing the strength of natural rubber latex and starch, formic acid is used in the manufacturing of particle board. NR latex and starch can increase the physical and mechanical properties of the particle board. When formic acid mixed with them it increase the strength of the board because of formic acid make hydrogen bond with the particles. The board strength may be comparable to the UF resin bonded board and it is a pure bio product and environmentally friendly (Akbari et. al. 2014). In this study, the main thing is the application of natural rubber latex as an adhesive in the manufacturing of particle board from jute stick.

1.2 Research objective

The objective of this research is to investigate the feasibility of NR latex based bio-resin for particleboard fabrication that reinforced with jute stick particles. Latex is a milky brown material which is extracted from rubber tree. Every years Bangladesh produced huge amount latex from the rubber tree. It is mainly used for making shoes, car tiers etc. But it can be used in composite industries as an adhesive. So, the

Specific research objectives

1. To fabricate the jute stick particleboards by using different mixing ratios of NR latex and starch as binder.
2. To study the effect of different mixing ratios of NR latex and starch on the properties of jute stick particleboards.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 General information about particleboard

2.1.1 Definition of particleboard

A structural material made of wood fragments, such as chips or shavings that are mechanically pressed into sheet form and bonded together with resin. Particleboard is defined as a panel product manufactured from lingo-cellulosic materials, primarily in the form of discrete particles, combined with a synthetic resin or other suitable binder and bonded together under heat and pressure (Miller *et. al.* 1977).

A particleboard is a board (or sheet) constituted from fragments of wood and/or other lingo-cellulosic materials (chips, shavings, flakes, splinters, sawdust, etc.), bonded with organic binders with the help of one or more agents like heat, pressure, humidity, catalyst, etc. (Shrivastava, 1997). Particleboard is used widely in the manufacture of furniture, cabinets and floor. It may be classified as a panel product manufactured under pressure and heat from particles of wood or other lingo-cellulosic materials bonded entirely with a binder and other chemical are added for increasing the products properties. Panels are made in a variety of sizes and density, thus providing great opportunity to design the ultimate product with the specific particleboard needed. (Salehuddin, 1992).

2.1.2 History and development of particle Board

Particleboards are not more than a few decades old production. It is invented in the 19th century. In 1902, Earnest Hubbard published a paper, "Utilization of wood waste". This was the first publication about making particle board (Eastman *et. al.* 1997). Before particleboard, modern plywood, as an alternative to natural wood, was invented in the 19th century, but by the end of the 1940s there was not enough lumber around to manufacture plywood affordably. By that time particleboard was intended to be a replacement (Sheng, 2004). For making ply wood more raw materials is needed and it has some negative effect on forest. As this reason, first efforts were made in the early 1920's for manufacturing of particleboard. But it was unsuccessful as for the lack of suitable adhesives. After an unsuccessful application of manufacturing of particle board a new technique was applied in the early 1930's. Resin is applied for the growing demand paved the way for the industrial production of particleboard in the early 1940's (Moslemi, 1985). The first commercial piece was produced during World War II at a factory in Bremen, Germany. It used waste material such as planer shavings, off-cuts or sawdust, hammer-milled into chips, and bound together with a phenolic resin. It was thought up by

German Luftwaffe fighter pilot and inventor Max Himmelheber, in first made in a factory in Bremen, Germany during the Second World War. When particle board first came onto the market, it was only made available to the wealthy because the price was higher than some real timbers. Over time, the manufacturing process matured, the supply became steadier, and the material became cheaper. Today's particleboard manufacturer provides high-quality products that consumers require due to up gradation of manufacturing techniques (Moslemi, 1985; Sheng, 2004).

2.1.3 Types of particle board

There are different types of particleboards depending on:

2.1.3.1 Types of particles used

Flakeboard: A particleboard in which the wood is largely in the form of flakes, giving the surface a characteristic appearance (Shrivastava, 1997). A small wood particle of predetermined dimensions specifically produced as a primary function of specialized equipment of various types, with the cutting action across the direction of the grain (either radially, tangentially, or at an angle between), the action being such as to produce a particle of uniform thickness, essentially flat, and having the fiber direction essentially in the plane of the flakes, in overall character resembling a small piece of veneer (Shrivastava, 1997).

Chipboard: A particleboard made from chips. It is made in varying thickness and may be surfaced with paper, veneers, plastic materials, etc. (Shrivastava, 1997). Gluing together wood particles with an adhesive, under heat and pressure makes chipboard. This creates a rigid board with a relatively smooth surface. Chipboard is available in a number of densities: -normal, medium and high-density. (Salehuddin, 1992).

Shavings board: Wood shavings are the chief constituents of shaving board. (Shrivastava, 1997). Shavings are produced from various kinds and sizes of trees being converted to lumber of different dimensions. Shavings ordinarily come from air-dried or kiln-dried wood. Shaving produced from machining dry wood of a single species afford their producer the best prospects for marketing waste material. Uniform particle sizes (achieved by screening) are needed for some uses. Shavings, when exposed to the weather, deteriorate very rapidly and lose much of their value (Salehuddin, 1992).

Wafer board: It is a structural material made from rectangular wood flakes of controlled length and thickness bonded together with waterproof phenolic resin under extreme heat and

pressure (Salehuddin, 1992). Waferboard is a widely used, versatile structural wood panel. Waferboard's combination of wood and adhesives creates a strong, dimensionally stable panel that resists deflection, delamination, and warping; likewise, panels resist racking and shape distortion when subjected to demanding wind and seismic conditions. Relative to their strength, waferboard panels are light in weight and easy to handle and install (Shrivastava, 1997).

Oriented strand board: Oriented strand board, or OSB, or Sterling board (UK) or Smart Ply (UK and Ireland) is an engineered wood product formed by layering strands (flakes) of wood in specific orientations (Salehuddin, 1992). Oriented strand board is manufactured in wide mats from cross-oriented layers of thin, rectangular wooden strips compressed and bonded together with wax and synthetic resin adhesives. The resin types typically used include phenol formaldehyde (PF), melamine fortified urea-formaldehyde (MUF) or isocyanate, all of which are moisture resistant binders. In Europe, it is common to use a combination of binders, typically PMDI would be used in the core and MUF in the face layers and this has the advantage of reducing press cycles whilst imparting a bright appearance to the surface of the panel (Shrivastava, 1997).

2.1.3.2 Density of the particle board

Low density: Particle board which density is below 590 kg/m^3 is called low density particle board.

Medium density: Particle board which density range is $590\text{-}800 \text{ kg/m}^3$ is called medium density particle board.

High density: Particle board which density is above 800 kg/m^3 is called high density particle board.

2.1.3.3 Particle size distribution in the thickness of board

Single layer or homogeneous board: Single-layer particleboards are made from pressing together wood particles of similar sizes to form a flat, dense board. This type of particleboard is suitable as a base for plastic lamination and veneering, but not for painting. Single-layer particleboards are used commonly for interior applications. They have some water-resistance capabilities, but are not fully waterproof (Shrivastava, 1997).

Three layer board: A three-layer particleboard is made from sandwiching a layer of larger wood particles between two layers of high-density, finer wood particles. The outer layers have

a higher amount of resin adhesive than the inner layer. Three-layer particleboards have smooth outer layers that are suitable for painting. These boards are not as dense as single-layer boards and tend to split easily (Shrivastava, 1997).

Graded-density boards: Graded-density particleboards are similar to three-layer particleboards. They have an inner core of coarse wood particles sandwiched between two outer layers of finer particles. However, unlike a three-layer particleboard, the transition between the coarse surfaces to the finer ones is gradual. Graded-density particleboards are used in cabinet construction and for furniture components (Salehuddin, 1992).

2.1.4 Raw materials for particleboard manufacturing

2.1.4.1 Ligno-cellulosic materials

- ❖ Woody materials
- ❖ Saw dusts
- ❖ Logging residues
- ❖ Sawmill residues, such as slabs, edging, trimmings, etc.
- ❖ Logging residues, such as short logs, broken logs, crooked logs, small tree tops and branches, forest thinning, etc.
- ❖ Planer savings
- ❖ Veneer and plywood plant residues

2.1.4.2 Non-woody materials

- ❖ Jute sticks
- ❖ Kenaf
- ❖ Bagasse
- ❖ Bamboo
- ❖ Flax shaves
- ❖ Cotton stalks
- ❖ Cereal straw
- ❖ Almost any agricultural residue after suitable treatment (Youngquist, 1999)

2.1.5 Advantages of particle board

- ❖ Particle board ensure the wise use and optimum utilization of wood waste or wood of inferior quality (Low density wood).
- ❖ Particle board is fairly inexpensive to manufacture, which translates into lower cost for the consumer.
- ❖ Particle board is readily available and can be easily decorated in different styles with laminated overlays.
- ❖ Particle board is lighter than solid wood and for this reason it is easy to move.
- ❖ Particleboards overcome some inherent weakness of solid wood and make useful products out of wastes, small pieces of wood and inferior species thus ensuring complete utilization of raw materials, make products with unique properties and can tailor products for particular end-use.
- ❖ The characteristic defects of wood such as knots, spiral grain, etc., may either be eliminated or scattered throughout the particleboard during manufacturing. Thus ensure not occurring defects during service condition.
- ❖ In manufacturing of particle board agricultural wastage can be used as raw materials and for this reason it reduced the pressure on forest.
- ❖ By using different species and adhesives, or particles of different size and geometry, particleboard may be manufactured suitable for exposure to weather, for interior use, for interior paneling, for exterior sideboards, for load bearing flooring purposes and so on.
- ❖ Particle board looks more even & uniform than conventional wood.
- ❖ The variation in strength and stiffness due to anisotropy in wood is largely overcome as also the differential change in dimension due to absorption and desorption of moisture along or across the grain of wood.
- ❖ Perhaps the most important advantage of particleboard is that it can be made in large dimensions (Salehuddin, 1992).

2.1.6 Considerations for the quality of particleboard

Quality of particleboard largely depends on the following factors:

- ❖ Density
- ❖ Layering
- ❖ Types of adhesive
- ❖ Geometry of the particles i.e. length, width, thickness, diameter, etc.
- ❖ Species from which the raw materials are collected.
- ❖ Slenderness ratio. Surface quality and internal bond strength are higher with small particles, i.e. with lower slenderness ratio (Salehuddin, 1992).

2.1.7 Manufacturing process of particle board

Following are the process of particle board manufacturing:

1. Particle preparation:
 - Debarking is done.
 - Chippers, hammer mills, ring flakers, ring mills etc. are used.
2. Particle classification/screening and conveying:
 - The particles are fed over a vibrating flat screen or a series of screens.
3. Particle drying:
 - 2% to 7% moisture content is required
 - The main methods used to dry particles are rotary, disk and suspension drying
4. Blending:
 - Addition of adhesive and other chemicals such as wax, hardeners etc. to the dry particle furnish is called blending.
 - It is a critical step for both product quality and production efficiency.
 - Basically three systems are used- a) the contact and friction system, i.e., simple mixing, b) the spreader roll system and c) spray nozzle system.
5. Mat formation and conveying:
 - Mat is formed into 3-4 times and even 20 times thicker than the target board thickness.
 - Batch mode or by continuous formation (moving belt).
6. Pressing:
 - Single and multi-opening presses.

- Hot-press temperatures for thermo-setting resins usually range from 140°C to 180°C
- Cold pressing is done at room temperature for thermoplastic resin.

7. Conditioning and Finishing:

- The hot boards conditioned to equilibrate moisture content and to stabilize and fully cure the resin. This conditioning usually follows cooling in star coolers for broads with urea formaldehyde resins. Phenolic bonded particle board is usually hot stacked for some days to ensure final cure of the resin.
- The board is trimmed to obtain the desire length and width. Trim losses usually amount to 0.5% to 8%
- The boards are sanded or planed prior to packing and shipping.

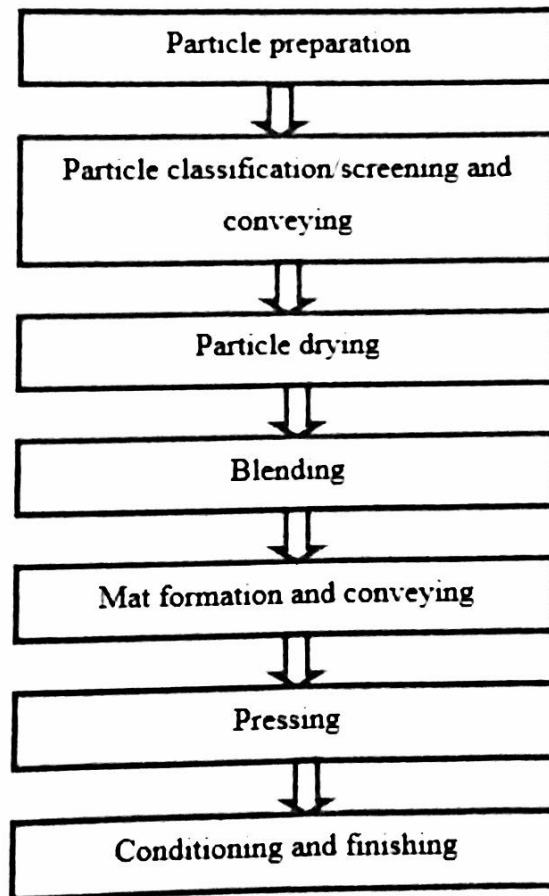


Fig: 2.1 Flow diagram of particle board manufacturing

2.1.8 Uses of particle board

Following are the uses of particle board:

- ❖ Store Fixtures
- ❖ Kitchen Cabinets
- ❖ Office and Residential Furniture
- ❖ Manufactured Home Decking
- ❖ Furniture
- ❖ Ceiling
- ❖ Shelving
- ❖ Dore core etc.

2.1.9 Binder or Adhesive

Adhesives are substances capable of holding materials together in a useful manner by surface attachment. The principle attribute of adhesives is their ability to form strong bonds with surfaces of a wide range of materials and to retain bond strength under expected use conditions (Lehman, R. L., 2004). ASTM (1997) defines an adhesive as a substance capable of holding materials together by surface attachment.

2.1.10. Types of adhesive/ binder

There are mainly two types of adhesive. One originated from natural sources known as natural adhesive and another is synthetic adhesive.

Synthetic adhesive or synthetic resin adhesive

Adhesives of synthetic origin are called synthetic adhesives. These are man made polymers which resemble natural resins in physical characteristics but which can be tailored to meet specific wood working requirements. Synthetic adhesive are two types:

1) Thermosetting adhesives

These types of adhesives are usually based on formaldehyde. Thermosetting adhesives undergo a chemical change during application and curing. The bonds formed by thermosetting adhesives are generally moisture resistant and support loads under normal use. Phenol formaldehyde, Urea formaldehyde are the example of thermosetting adhesives.

2) Thermoplastic adhesives

Thermoplastic adhesives are especially useful because they can be used in a dry form and are already fully polymerized as received. The bonding process basically involves softening or melting the polymer while in contact with their adherents, and allowing the joint structure to

cool. The structure can be easily disassembled or repositioned by reheating while applying force.

Natural adhesive

These kind of adhesive are produced from natural sources. These adhesives were made from animal blood, hide, casein, starch, soybean, dextrin and cellulose. While natural adhesives are still being used in some non-structural products, they do not provide the necessary strength and durability required for engineered wood products.

2.2. Natural rubber latex as a natural adhesive

2.2.1 General information about natural rubber latex

NR latex is one of the natural adhesive extracted from latex from one kind of tree i.e. *Hevea brasiliensis* (Yuhazri et al. 2011). NRL is a milky brown, slightly viscous latex suspension which exhibits good moisture and mold resistance with no toxicity. It has been widely explored and used for the synthesis of wood adhesives especially for non-polar adherents (Pizzi, 1989) with modification done to increase its performance on polar surfaces. Chemically NR latex is *cis* 1,4-polyisoprene. A linear, long chain polymer with repeating isoprenic units (C_5H_8), it has a density of 0.93 at 20° C (Maya Jacob John, 2012). Latex is harvested by a process known as tapping, which consists of regularly incising the trunk bark to cut through the laticifer network. This allows latex to flow out through the wound to be collected and later processed into natural rubber. Tapping is repeated regularly, so an important limiting factor of natural rubber yield is latex regeneration. Regeneration relies on both complex rubber biosynthesis pathways in laticifers, and on water and various organic sources such as sucrose and nitrogen supplied to these cells by the surrounding parenchyma (Tungngoen et al. 2009).

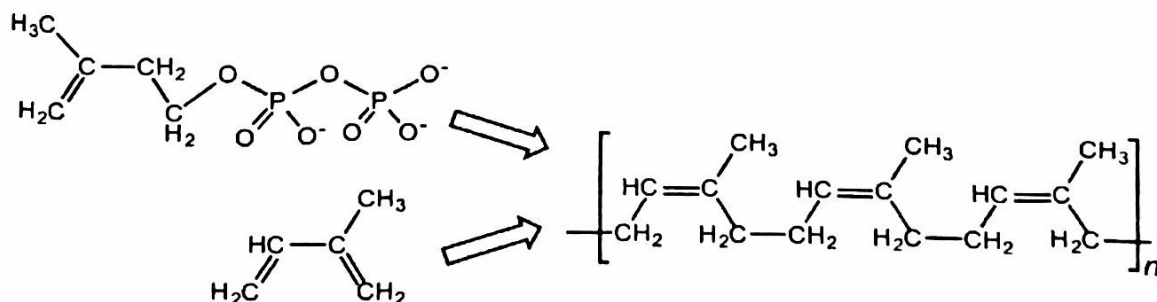


Fig: 2.2 Structure of natural rubber latex (Tungngoen et al. 2009)

2.2.2. Component of natural rubber latex

Natural rubber latex is the mixture of some materials. Following are the component of natural rubber latex (Ani, N. C. 2014):

Table: 2.1 Component of natural rubber latex

Component	% Composition
Rubber hydrocarbon	93.3
Acetone extract	2.9
Protein	2.8
Moisture	0.6
Ash	0.5-1.0

(Ani, 2014)

2.3. Starch as an additives

2.3.1. General information of starch

Starch is an abundant, inexpensive, renewable and biodegradable polymer. It is the second most abundant natural polymer after cellulose and can be obtained mainly from the roots, stalks and seed of staple crops such as rice, corn, wheat, tapioca and potato. Starch is a natural polymer which possesses many unique properties (Abilash and Sivapragash 2013). By combining the individual advantage of starch and synthetic polymers, starch based biodegradable polymers found to be potential due to the wide variety of available manufacturing process. Starch is a relatively inexpensive and renewable product from abundant plants and use as binders, sizing materials, glues and paste but the strength of the bonding capacity is not good for glue wood (Zhenjiong Wang, 2011). It is a white, granular, odourless, and tasteless powder that is insoluble in cold water, alcohol, or other solvents (Mark C. Swanson, 2002). Starch is widely use in commodity applications in food, paper making, fine chemicals and packing materials because of low impact. These promising technologies may provide an environmentally friendly alternative to the present of UF adhesive in wood composites industries (Magdy M. Senna, 2012).

2.3.2. Starch structure

Starch is a polysaccharide, basically polymers of the six-carbon sugar D-glucose, often referred to as the “building block” of starch. The structure of the monosaccharide D-glucose can be depicted in either an open-chain or a ring. Starch consisting of D-glucose units, referred to as homoglucan or glucopy ranose, and two major bio-macromolecules-amylose and amylopectin.

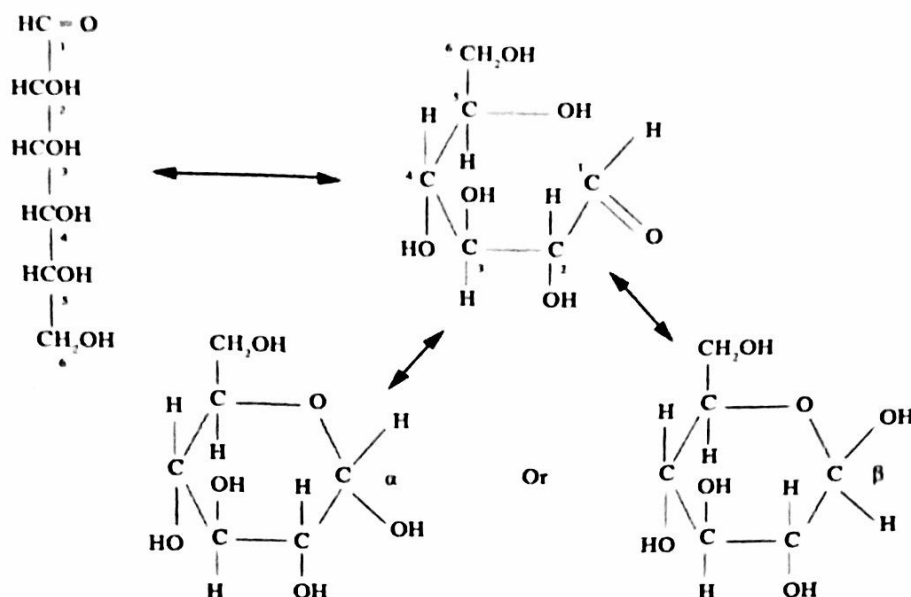
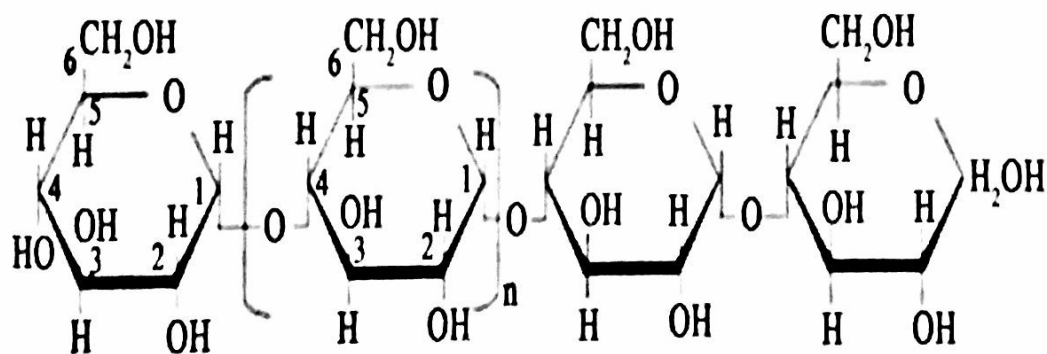


Fig: 2.3 Open-chain and pyranose ring structures of the hexose sugar D-glucose (Hood, L.F. 1982)

Amylose: Amylose is a relatively long, linear polymer composed almost entirely of α -1,4-linked D glucopyranose. Amylase has a molecular weight of approximately $1 \times 10^5 - 1 \times 10^6$ and a degree of polymerization (DP) by number (DP_n) of 324 - 4920, with around 9 - 20 branch points equivalent to 3 - 11 chains per molecules (Ball, S. *et. al.* 1998).



Amylose: α -(1 \rightarrow 4)-glucan: average $n = \text{ca. } 1000$. The linear molecule may carry a few occasional moderately long chains linked α -(1 \rightarrow 6)

Fig: 2.4 Structure of Amylose (Tester & Karkalas, 2002)

Amylopectin: Amylopectin, the predominant molecule in most normal starches, is a branched polymer that is much larger than amylose. Amylopectin is composed of α -1,4-linked glucose segments connected by α -1,6-linked branch points (Hanashiro, I. *et. al.* 2003). The small chains

have an average degree of polymerization (DP) of about 15, whereas that of the larger chains is about 45.

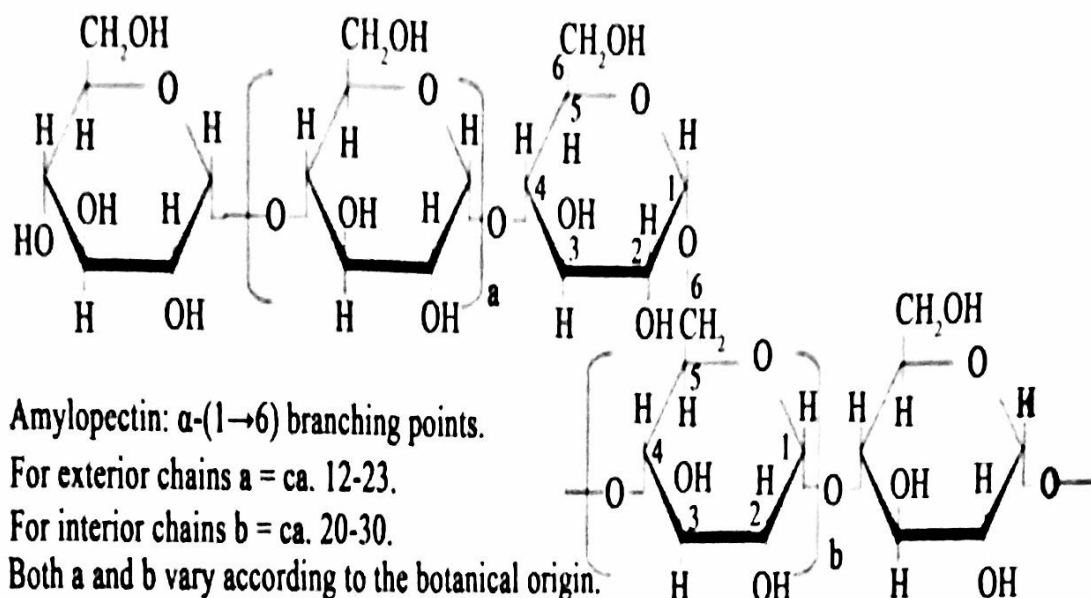


Fig: 2.5 Structure of Amylopectin(Tester & Karkalas,2002)

2.4. Formic acid

Formic acid, systemically named methanoic acid, is the simplest carboxylic acid. The chemical formula is HCOOH or HCO_2H . It occurs naturally. In nature, it is found in the stings and bites of many insects of the order Hymenoptera, particularly ants. Formic acid is also prepared in the form of its esters by treatment of carbon monoxide with an alcohol such as methanol (methyl alcohol) in the presence of a catalyst. The word "formic" comes from the Latin word for ant, *formica*, referring to its early isolation by the distillation of ant bodies, and the trivial name in some languages means "ant-acid". Formic acid is a colorless liquid having a pungent, penetrating odor at room temperature. It is miscible with water and most polar organic solvents, and is somewhat soluble in hydrocarbons. In hydrocarbons and in the vapor phase, it consists of hydrogen-bonded dimers rather than individual molecules.

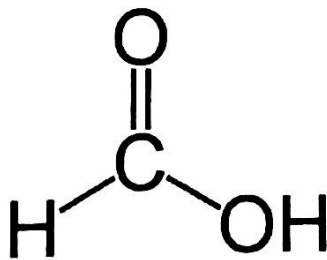


Fig: 2.6 Formic acid

CHAPTER THREE

MATERIALS AND METHODS

3.1. Materials

Main raw material for manufacturing of natural rubber latex bonded particle board is jute stick which is collected from the local market of Khulna. Another important material for manufacturing this particle board is natural rubber latex as an adhesive which is produced from the *Hevea Brasiliensis* tree. Natural rubber latex is collected from the Kaptai, Chittagong. NH_4 was added to the NR latex, to preserve it for many days. Starch is also used as an additives for manufacturing this particle board which is collected from the local market of Khulna. Formic acid is also used as a material for manufacturing this particle board which is used for increasing the strength of the particle board. Also water is used for making solution of the formic acid.



Fig: 3.1 Natural rubber latex

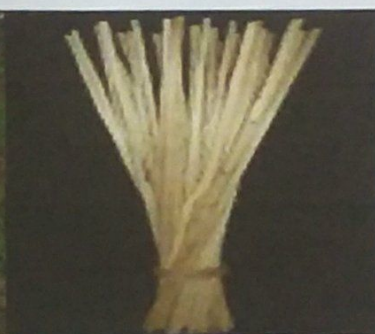


Fig: 3.2 Jute stick

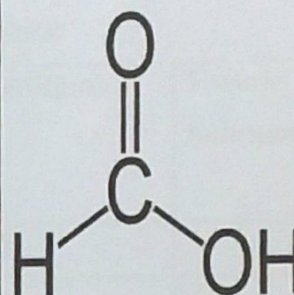


Fig: 3.3 Formic acid

3.2. Methods and procedures

Preparation of raw materials

After collection of raw materials it was air dried for 7 days. Then the jute stick was cut into small size chips by using conventional hand tool for using in the grinder.

Grinding of jute stick chips

Jute stick chips is inserted into the laboratory grinding machine manually. After grinding small sized jute stick is converted into jute stick particle. The particle sized is below 2mm, which was our required particles for this research.

Drying of jute stick particles:

Jute stick particles were dried in the laboratory oven at 103 degree for 24 hours. After drying the moisture content of the particles was 5-7%.

Making of formic acid solution

The concentration of formic acid was 30%. 70% water is mixed with 30% formic acid.

Weighting of natural rubber latex and starch

NRL and starch was weighted by the laboratory scale machine. The P^H value of the NR latex was 10 which was used in the board manufacturing and the viscosity was 7.5 MPa.s in the fourth rotter of the viscosity meter.

Mixing of the raw materials

Firstly starch was mixed with the jute stick particles. Then the NR latex was mixed with the jute particle and starch uniformly and shack it for many times. After mixing of NRL the solution of formic acid was mixed uniformly with the jute stick particle, NRL and starch and shack it for many times. The weight of jute stick particles was 300gm. and the weight of total adhesive was 10% of the jute stick particles. The adhesive was mixed with in the three ratio those are given in the table 3.1:

Table: 3.1 Composition of the adhesive treatment and particle

Treatment	Jute stick Particle(gm)	NR latex (wt %) (ml)	Starch(gm)	Formic Acid Solution(ml)
A	300	22.5	3.75	3.75
B	300	15	7.5	7.5
C	300	7.5	11.25	11.25

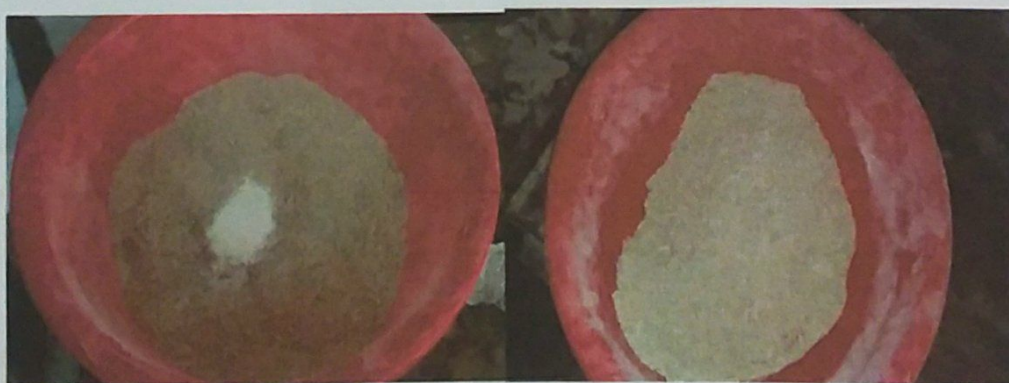


Fig: 3.4 Mixing of the raw materials

Mat forming

Each mixture was hand formed into a rectangular of iron mold on a stainless steel plate lined with a superior quality foil sheet to prevent the consolidated mat from sticking to the platen during pressing. The dimension was the mat was 12 inch \times 8 inch \times 3 cm.



Fig: 3.5 Formation of mat

Hot pressing

Hand formed mat was hot pressed at 180° c and 5 Mpa pressure. It was kept for 5 minutes.



Fig: 3.6 Hot press

Conditioning

After removing the board from the hot press the board was conditioned to equilibrate board moisture content and to stabilize and fully cure the adhesives.

Trimming

The boards were trimmed at edges with the fixed type circular saw. The dimension of each type boards were 11 inch \times 7 inch \times 0.6 cm.

3.3. Evaluation of particle board properties

3.3.1. Preparation of samples for testing

Three replications of each type of boards for testing mechanical test and three samples were collected from each type of board for physical test. The dimension of boards for mechanical test was 11 inch × 7 inch × 0.6 cm. And the dimension of samples for physical test was 5 cm × 5 cm.

3.3.2 Determination of physical properties

All the samples were cut into 5 cm × 5 cm. for testing physical properties. The laboratory test for characterization of physical properties was carried out in the laboratory, Forestry and Wood Technology Discipline, Khulna University. At first the samples were weighted and green dimension were taken at room temperature. Then all samples were kept into oven for 24 hours. After drying oven dry weight and dry dimension were also measured. Then the samples were submerged into water for 2 hours. Then the wet weight and dimension was taken and all the properties were calculated by using formula. Then the samples were again submerged into water for 24 hours. Then finally, wet weight and dimension was taken and all the properties were calculated by using formula.

Density

Density (D) of each board was calculated after measuring weight and volume using the following equation-

$$D = \frac{m}{v}$$

Where m is the mass and v is the volume of each sample.

(Desch and Dinwoodie, 1996)

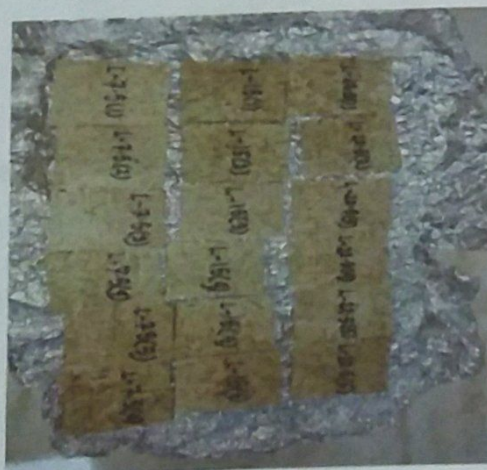


Fig: 3.7 Sample for density test

Moisture content

After measuring the initial mass and oven-dry mass moisture content (MC) was determined by following equation-

$$mc (\%) = \frac{m_{int} - m_{od}}{m_{od}} \times 100$$

Where m_{int} is the initial mass and m_{od} is oven-dry mass of the sample.

(Desch and Dinwoodie, 1996)

Water absorption

The water absorption (A_w) and thickness swelling (G_t) were determined by soaked in water for 24 hours. The water absorption and thickness swelling rate were increased with the time passed. After 2 hours and 24 hours the water absorption and thickness swelling were calculated by an electric balance and a digital slide caliper as a percentage.

Water absorption was calculated by the following formula-

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

Where m_1 is the weight of the sample before immersion and m_2 is the weight of the sample after immersion in water.



Fig: 3.8 Water absorption test

Thickness swelling

Thickness Swelling was determined by using the following equation-

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

Where t_1 is the sample thickness before immersion and t_2 is the sample thickness after immersion into water.

3.3.3 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 wood laboratory of Khulna University.

Modulus of elasticity (MOE)

Modulus of elasticity (MOE) was measured by the Universal Testing Machine (UTM) (SHIMADJU, 50 KN, Japan). MOE was calculated by the following formula:

$$MOE = \frac{P / L^3}{4\Delta / bd^3}$$

(Desch and Dinwoodie, 1996)

Here,

P represents load in the limit of proportionality (N);

L is the length of the span (mm);

b is the width (mm);

d is the thickness (mm) and

Δ represents the deflection at the limit of proportionality (mm)

Modulus of rupture (MOR)

Modulus of Rupture (MOR) was measured by the Universal Testing Machine (UTM) (SHIMADJU, 50 KN, Japan). MOR was calculated by the following formula:

$$MOR = \frac{3PL}{2bd^2}$$

(Desch and Dinwoodie, 1996)

Tensile strength

Tensile was measured by the Universal Testing Machine (UTM) (SHIMADJU, 50 KN, Japan).

It is also a good parameter to test the strength and quality of the board.

3.3.4. Analysis of data

Board were produced in the laboratory and after prepared the board all the physical test were done in the laboratory. All the mechanical properties were tested by UTM. After getting all Physical and mechanical properties result of each type board were analyzed by using SPSS software and Microsoft office excels. ANOVA (Analysis of Variance) was done to see the variation among the prepared board.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Board properties on different NR latex content

The relationship between board physical and mechanical properties with different NR latex, starch and formic acid content was compared under a pressing temperature 180°C and 5 Mpa. Three types of particleboard were prepared on different NR latex, starch and formic acid content. Three types of NR latex ratio was used for producing boards. The board were named L-22.5(Here 22.5 ml NR latex was used among 30 ml adhesive), L-15(Here 15 ml NR latex was used among 30 ml adhesive), L-7.5 (Here 7.5 ml NR latex was used among 30 ml adhesive). Here total adhesive content was 10% of the particle. In this study total particle amount was 300 gm.



Fig: 4.1 Final board

4.1.1 Physical properties

4.1.1.1 Density

In this study the density of boards before oven dry were ranges from 877-895 Kg/m³. In case of density after oven dry density was changed. The density range after oven dry was 816-857 Kg/m³. Analysis of variance was also done for analysis of difference between densities. From the analysis of one way ANOVA it was found that there was no significant difference (One way ANOVA, df=2,15, F=2.571, p>0.05) among the densities of different types of board before oven dry. In case of density after oven dry there was no significant difference (One way ANOVA, df=2,15, F=2.819, p>0.05) among the densities of different types of board before oven dry.

Density is an important factor for particle board. The variation of density between particleboard was due to the variation of the raw materials itself. Density depends on the density of raw materials used, hot pressing conditions and other factors (Sekino, 1999). Pressing temperatures or press pressures have an important effect on board density (Arias 2008). Emphasized four factors which is mentioned that are significantly important for the density.

The variation of densities was due to mat thickness and pressing time variation. Density influence the bending properties of the boards. The MOR and MOE increased linearly with increasing densities. Physical properties also affected by density variation.

According to the ANSI standard the density of high density particle board is above 800 Kg/m^3 . But in this study the density is ranges from $816\text{-}895 \text{ Kg/m}^3$. So density is more or less perfect with the standard.

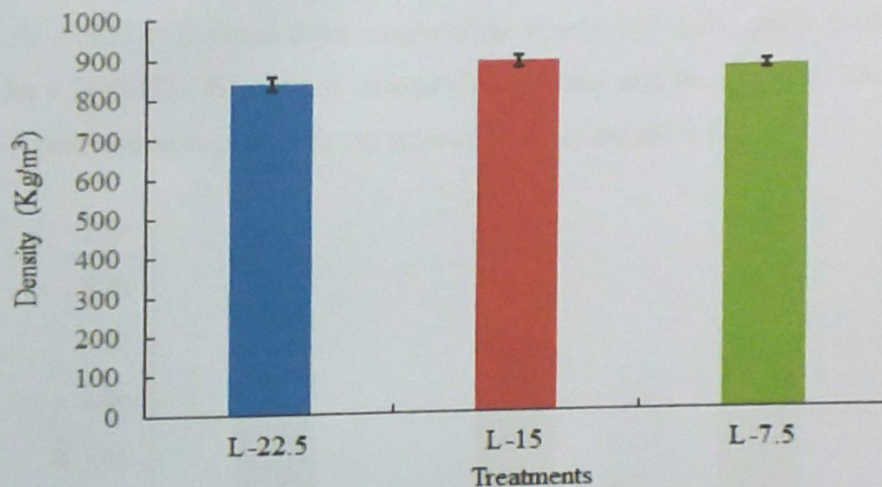


Fig: 4.2 Density of different types of board before oven dry

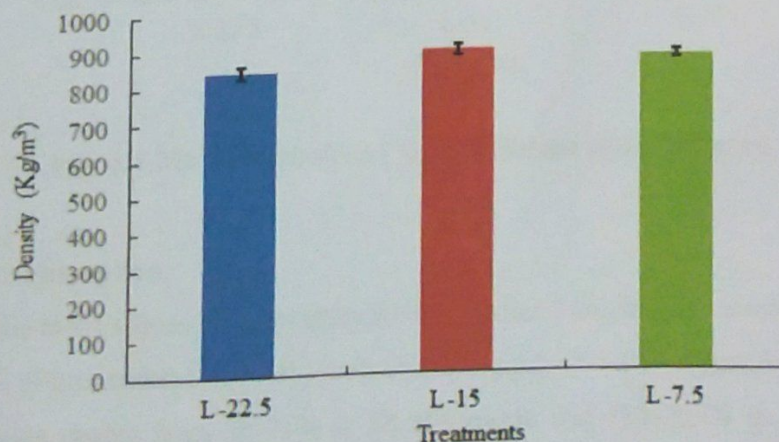


Fig: 4.3 Density of different types of board after oven dry

4.1.1.2 Moisture content

From the figure 4.4 it showed that moisture content ranges for this boards are 4.79-6.44%. Analysis of variance was also done for analysis of difference between different moisture content (%). From the analysis of one way ANOVA it was observed that there was a significant difference (One way ANOVA, $df=2,15$, $F=7.052$, $p<0.05$) among the different moisture content (%).

Moisture content is a vital physical property that causes change of other physical and mechanical properties of the boards. Moisture content of particle board is changed with the change of different parameters. Espert *et al.* (2003) stated that wood consists mostly of vessels in which moisture is absorbed. NR latex is also water soluble. Different percentage of NR latex and the different pH values may be the cause of variation in moisture content (%).

According to ANSI (1999) standard, the mean moisture content of particleboard shall not exceed 10% (based on the oven dried weight of the board). But in this study moisture content ranger from 4.79-6.44%. So moisture content (%) is perfect with the standard. Variation of the moisture content percentage of different types of board is shown in Fig: 4.4

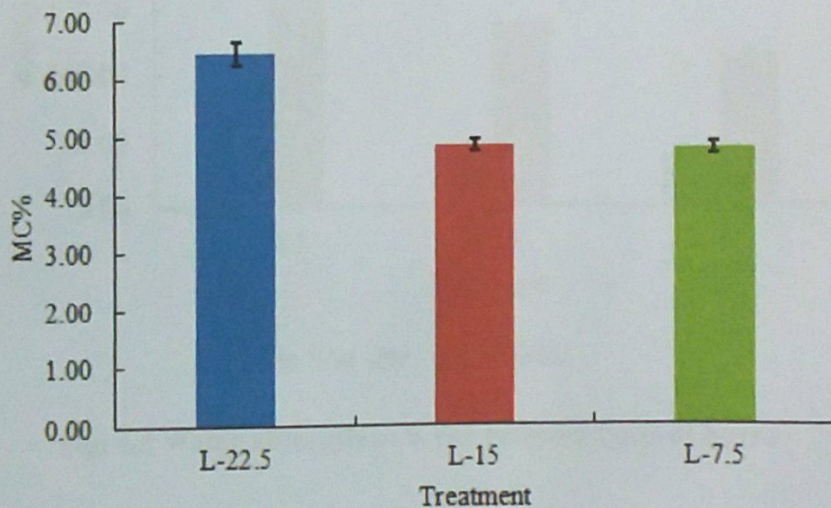


Fig: 4.4 Moisture content (%) of different types of board

4.1.1.3 Water absorption

Variation of the mean values of water absorption (%) after 2 hours of immersion (WA-2h) and after 24 hours of immersion (WA-24h) is shown in Fig.4.5. From the figure it showed that the water absorption ranges from 36-71% in 2h absorption and 115-205% in 24h absorption. Analysis of variance was also done for analysis of difference between different water

absorption (%). From the analysis of one way ANOVA it was observed that there was a significant difference (One way ANOVA, $df=2,9$, $F=13.551$, 44.148 , $p<0.05$,) among the different water absorption (%).

L-7.5 showed better result and L-15 showed medium result and L-22.5 showed bad result. The main reason behind this, increasing of NR latex. NR latex contained huge amount of water as this reason when particle board produced from NR latex it has an affinity to water. As this reason water absorption is high in this board. Compared to low density particle board, high density particle board have lower porosity (Zheng *et al.*, 2007). But in this study NR latex was used as an adhesive as this reason the water absorption result was not good compare to other particle board.

According to ANSI (1999) standard, the water absorption of particleboard ranges from 6.4-45%. But in this study the water absorption result ranges from 36-71% in 2h absorption and 115-205% in 24h absorption and this is not good compare to the standard of ANSI (1999).

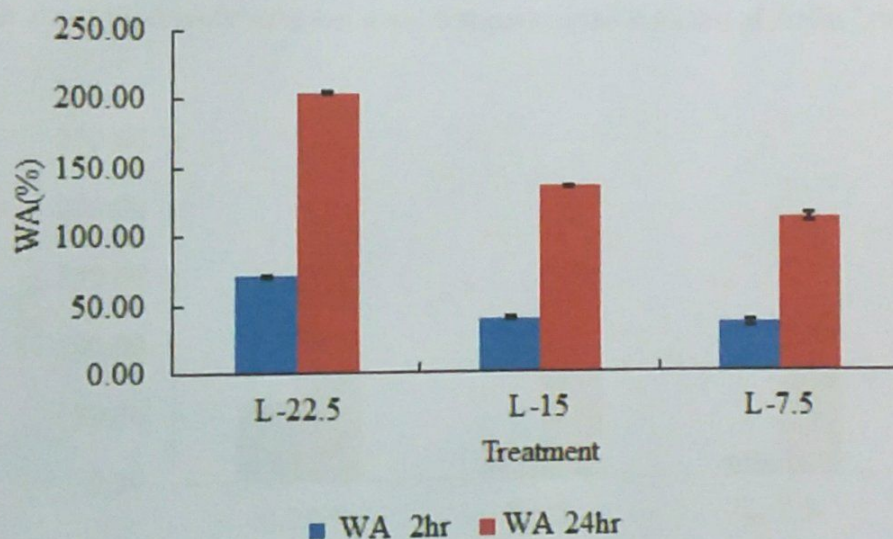


Fig: 4.5 Water absorption (%) of different types of board

4.1.1.4 Thickness swelling

Variation of the mean values of thickness swelling (%) after 2 hours of immersion (TS-2h) and after 24 hours of immersion (TS-24h) is shown in Fig.4.6. From the figure it showed that the thickness swelling can be categorized as poor for all the boards with adhesive formulations having higher NRL content with ranges from 15-58% in 2h absorption and 76-188% in 24h absorption. Analysis of variance was also done for analysis of difference between different thickness swelling (%). From the analysis of one way ANOVA it was observed that there was

a significant difference (One way ANOVA, $df = 2, 9$, $F=52.540$, 32.955 $p<0.05$) among the different thickness swelling (%).

Thickness swelling provide poor result in all types of board (Jayshree *et. al.*, 2016) The main reason behind this, increasing of NR latex. NR latex contained huge amount of water as this reason when particle board produced from NR latex it has an affinity to water. As this reason thickness swelling is high in this board. From the result it can be seen that thickness swelling was improved by adding the different composition of starch into natural rubber Latex. It can be concluded that the addition of starch in natural rubber latex reduced thickness swelling of particle board significantly. L-7.5 showed better result and L-15 showed medium result and L-22.5 showed bad result. This is because the pure starch is insoluble in cold water (Akbari *et. al.*, 2014).

According to ANSI (1999) standard, the thickness swelling of particleboard not exceed 35%. But in this study the thickness swelling result ranges from 15-58% in 2h absorption and 76-188% in 24h absorption and this is not good compare to the standard of ANSI (1999).

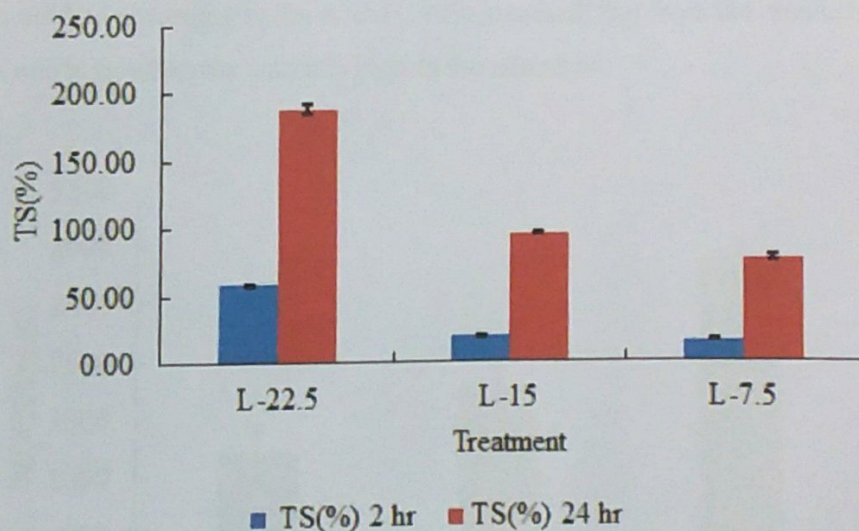


Fig: 4.6 Thickness swelling (%) of different types of board

4.1.2. Mechanical properties

4.1.2.1 Modulus of elasticity (MOE)

Variation of the mean values of MOE is shown in Fig: 4.6. From the figure it showed that MOE is ranges from 1190-2866 N/mm². Analysis of variance was also done for analysis of difference between different MOE values. From the analysis of one way ANOVA it was observed that there was a significant difference (One way ANOVA, $df=2, 6$, $F=29.586$, $p<0.05$) among the different modulus of elasticity.

From the result it observed that L-22.5 showed poor result and L-7.5 showed better result. L-15 showed average result. Considering the characteristics of the composites, it can be explained that NR latex contributed the elastic property to the composites. When it was added to the composites, it tended to reduce the brittle failure of the blend (Shey *et al.* 2006). But when the percentage of starch was increased in the concentration of adhesive it increased the elasticity of the board. NRL latex increase the elasticity but starch increase the strength of the boards.

According to ANSI (1999) standard, the modulus of rupture for particle board is ranges from 2000-6000 N/mm². But in this MOE is ranges from 1190-2866 N/mm². So the MOE value of this board is not bad according to the ANSI (1999) standard. But from the result it showed that MOE value was high when the starch is high in the adhesive.

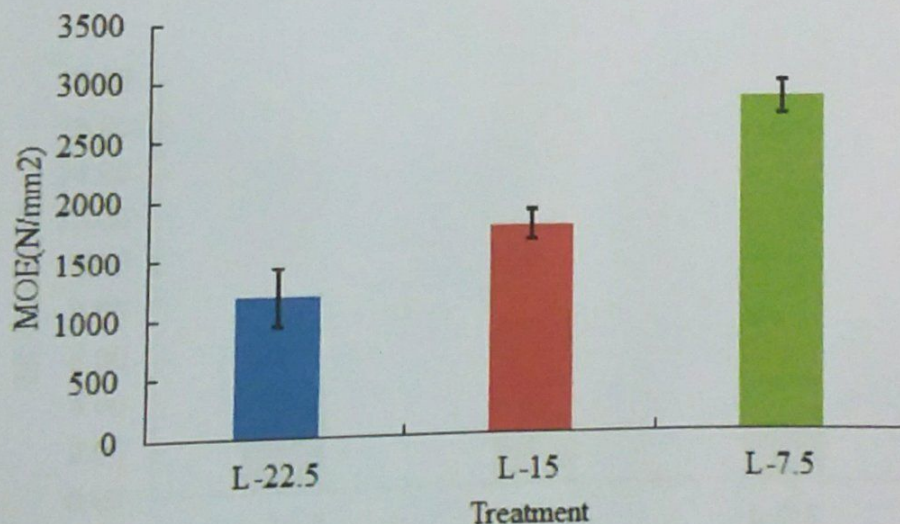


Fig: 4.7 Modulus of elasticity of different types of board

4.1.2.2 Modulus of rupture (MOR)

Variation of the mean values of MOR is shown in Fig: 4.6. From the figure it showed that MOR is ranges from 4.5-15.7 N/mm². Analysis of variance was also done for analysis of difference between different MOR values. From the analysis of one way ANOVA it was observed that there was a significant difference (One way ANOVA, $df = 2, 6$, $F=74.406$, $p<0.05$) among the different modulus of rupture.

From the result it observed that L-22.5 showed poor result and L-7.5 showed better result. L-15 showed average result. Considering the characteristics of the composites, it can be explained that NR latex contributed the elastic property to the composites. When it was added to the composites, it tended to reduce the brittle failure of the blend (Shey *et al.* 2006). But when the percentage of starch was increased in the concentration of adhesive it increased the strength of the board. In case of MDF board starch reduce the strength of the MDF board, but in this starch increase the strength of the particle board (Jayshree *et. al.*, 2016). This was happened because of the variation in the raw materials.

According to ANSI (1999) standard, the modulus of rupture for particle board is ranges from 3-23.5 N/mm². But in this the MOR is ranges from 4.5-15.7 N/mm². So the MOR value of this board is not bad according to the ANSI (1999) standard. But from the result it showed that MOR value is high when the starch was high in the adhesive.

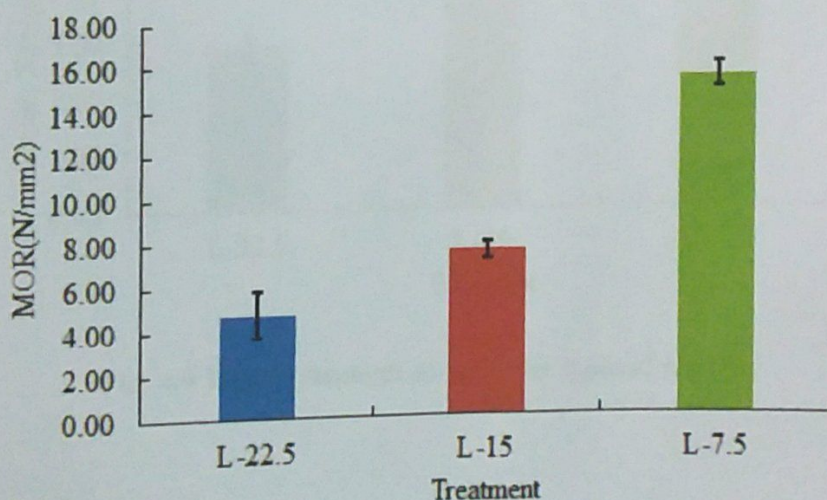


Fig: 4.8 Modulus of rupture of different types of board

4.1.2.3 Tensile strength

Variation of the mean values of tensile strength is shown in Fig: 4.7. From the figure it showed that tensile strength is ranges from 2.94-5.01 N/mm². Analysis of variance was also done for analysis of difference between different tensile strength values. From the analysis of one way ANOVA it was observed that there was no significant difference (One way ANOVA, df=2, 6, F=3.317, p>0.05,) among the different tensile strength.

From the result it observed that L-22.5 showed poor result and L-7.5 showed better result. L-15 showed average result. According to Akbari *et al* (2014) increasing of starch in the MDF board reduce the tensile strength of the MDF board but in case of particle board increasing of starch increase the tensile strength of the particle board. This happened because of the using of the particle in the board manufacturing in case of fiber.

According to ANSI (1999) standard, the tensile strength should more or less 20.7 N/mm². But in this study the tensile strength is ranges from 2.94-5.01 N/mm². From the result it showed that tensile strength is not good in the boards.

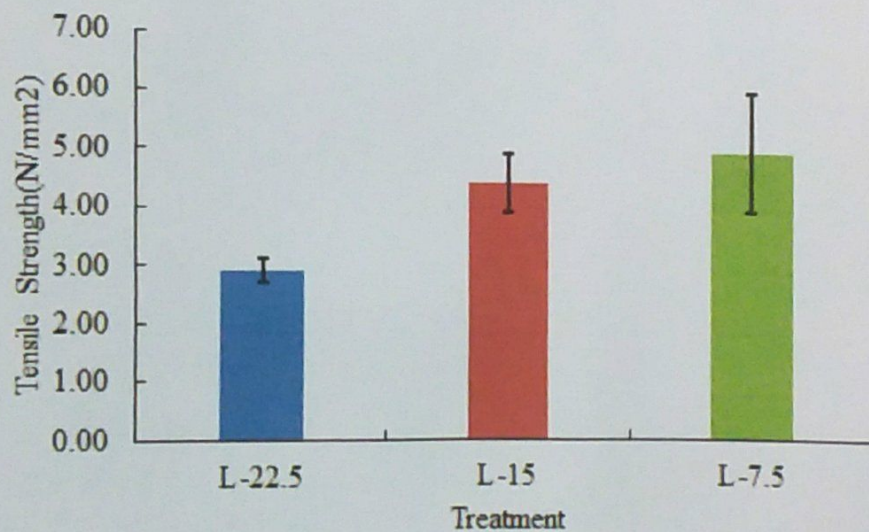


Fig: 4.9 Tensile strength of different types of board

CHAPTER FIVE

Conclusion

The purpose of this study was to utilize the natural rubber latex as an adhesive mixed with starch. Three types ratio of natural rubber latex, starch and formic acid adhesive was mixed with the jute stick particle, and hot press was used to produce the board. Among the three types ratio L-7.5 ml when mixed with the 22.5 ml starch and acid solution provided better result than other two type's adhesive ratio. The particle board which produced from the natural rubber latex and starch provided good density, moisture content (%) and mechanical properties (MOE, MOR). But in case of water absorption it does not provide good result. So further study is needed for this. Provably streaming of particle or heat treatment could be an effective way to reduce water absorption performance of the natural rubber latex based particle board.

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Appendix

1. Anova result for density before oven dry of the samples:

One way ANOVA

Density before oven dry

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9228.778	2	4614.389	2.571	.110
Within Groups	26925.500	15	1795.033		
Total	36154.278	17			

2. Anova result for density before oven dry of the samples:

One way ANOVA

Density after oven dry

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7567.444	2	3783.722	2.819	.091
Within Groups	20130.333	15	1342.022		
Total	27697.778	17			

3. Anova result for moisture content of the samples:

One way ANOVA

Moisture content

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	10.507	2	5.254	7.052	.007
Within Groups	11.175	15	.745		
Total	21.682	17			

4. Anova result for water absorption of the samples:

One way ANOVA

Water absorption

	Sum of Squares	df	Mean Square	F	Sig.
WA2 Between Groups	2861.376	2	1430.688	13.551	.002
Within Groups	950.234	9	105.582		
Total	3811.610	11			
WA24 Between Groups	17514.983	2	8757.491	44.148	.000
Within Groups	1785.296	9	198.366		
Total	19300.279	11			

5. Anova result for thickness swelling of the samples:

One way ANOVA

Thickness swelling

	Sum of Squares	df	Mean Square	F	Sig.
TS2 Between Groups	4533.357	2	2266.679	52.540	.000
Within Groups	388.279	9	43.142		
Total	4921.636	11			
TS24 Between Groups	28420.143	2	14210.072	32.955	.000
Within Groups	3880.822	9	431.202		
Total	32300.965	11			

6. Anova result for modulus of elasticity of the samples:

One way ANOVA

MOE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4343679.985	2	2171839.993	29.586	.001
Within Groups	440446.387	6	73407.731		
Total	4784126.372	8			

7. Anova result for modulus of rupture of the samples:

One way ANOVA

MOR

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	188.099	2	94.050	74.406	.000
Within Groups	7.584	6	1.264		
Total	195.683	8			

8. Anova result for tensile strength of the samples:

One way ANOVA

Tensile strength

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6.881	2	3.441	3.317	.107
Within Groups	6.224	6	1.037		
Total	13.105	8			