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UTILIZATION OF BHANT (*Clerodendrum infortunatum* L.) STALK AS A RAW MATERIAL FOR PARTICLE BOARD MANUFACTURING

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DECLARATION

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

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Name of the candidate: Md. Safiqul Islam

DEDICATED

TO

MY BELOVED LATE MOTHER

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ABSTRACT

The present study was investigated the potential use of Bhant (*Clerodendrum infortunatum*) stalk for the production of particleboards. In this study, woody stalk of Bhant was used as wood particle (WP) and urea formaldehyde (UF) was used as binder in Particleboard manufacturing. The aim of this study was to produce single layer particleboard from the Bhant stalk and evaluation of their physical and mechanical properties. Three types of single layer particleboard i.e., coarse particle (CP) – fine particle (FP) mixed particleboard were manufactured with 6% urea formaldehyde (UF) resin. Three types of broads were prepared with three different ratios A (100:0), B (70:30), C (50:50) of particleboard manufactured from Bhant. Water absorption and thickness swelling tests were carried out to determine dimensional stability of the boards while modulus of rupture and modulus of elasticity tests were carried out to assess the mechanical strength of the boards. Particleboards produced using Bhant stalk ratio of coarse and fine particle (50:50) gave the best results in terms of the lowest mean values of water absorption (68.67 %) and thickness swelling (32.38 %), as well as the highest values of modulus of rupture (27.857 N/mm^2) and modulus of elasticity (3520.11 N/mm^2). So, woody stalk from Bhant contributed as a good source of particleboard manufacturing.

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ABBREVIATIONS

Anon	Anonymous
ANOVA	Analysis of Variance
LSD	Least Significant Difference
APCC	Asian and Pacific Coconut Community
ASTM	American Society for Testing and Materials
AWPA	Australian Wood Panels Association
BBS	Bangladesh Bureau of Statistics
FAO	Food and Agricultural Organization of United Nations
gm/cm^3	Gram per cubic centimeter
Ha	Hectare
kN	Kilo Newton
lb/ft^3	Pound per cubic feet
cm	Centimeter
m	Meter
mm	Millimeter
µm	Micro meter
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MPa	Mega Pascal
N/mm^2	Newton per square millimeter
CP	Coarse particle

FP	Fine particle
rpm	Rotor per minute
SD	Standard deviation
UTM	Universal Testing Machine

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND OF THE STUDY

In the last 40 years successful development of wood based panels with the economic advantage of low cost wood and other lignocellulosic materials is the proficient alternative of solid wood. The demand of composite wood products such as particleboard, plywood, hardboard, oriented standard board, medium density fiberboard and veneer board has hiked significantly throughout the world. Among them, the demand of particleboard has been increasing significantly because of house construction, interior decoration, manufacturing of furniture, flooring, home constructions, stair treads, cabinets, tabletops, sliding doors, lock blocks, displays, table tennis, pool tables, kitchen work tops, and work surfaces in offices, educational establishments, laboratories and other industrial products. This huge demand of particleboard accelerates the declining rate of natural forest resources. Thus, the demand of alternative sources of raw materials is increasing ever more. Alternate lignocellulosic materials like agricultural residues and non-woody plant fibers may play a major role in minimizing the demand of manufacturing the composite panels (Anon, 2006).

Bhant is botanically known as *Clerodendrum infortunatum* (Fam: Lamiaceae). *Clerodendrum* has about five hundred and eighty species reported from various parts of the world; among them *C. infortunatum* is a native Indian species. Bhant is commonly known as Hill Glory Bower. Bhant is a gregarious perennial shrub. It attains a height of about 1-2m at the fully flowered stage. These bhant stalks are mostly used as fuel (Youngquist, 1999).

Although many studies have been conducted on bhant leaves as medicinal uses, but none of them explores the utilization of bhant stalk for particleboard production. Therefore, the aim of this study is to produce single layer particleboard with UF resin from the bhant stalk and evaluation of their properties.

1.2. OBJECTIVES OF THE STUDY

- To assess the physical and mechanical properties of particleboard using Bhant species.

CHAPTER TWO: REVIEW OF LITERATURE

2.1 GENERAL INFORMATION ABOUT PARTICLEBOARD

2.1.1 DEFINITION OF PARTICLEBOARD

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. (Srivastava, 1969). 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, generally a synthetic resin, to which other chemicals (e.g., fire retardant, fungicide, water retardant etc.) may be added to improve certain properties (Salehuddin, 1992).

2.1.2 BRIEF HISTORY AND DEVELOPMENT OF PARTICLEBOARD

Particleboards are not more than a few decades old production. 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. But before that scarcity in raw materials of plywood, first efforts were made in the early 1920's for manufacturing of particleboard. But it was unsuccessful as for the lack of suitable adhesives. Then new techniques introduced in the 1930's in resin applications with 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. Today's particleboard manufacturer provides high-quality products that consumers require due to up gradation of manufacturing techniques (Anon, 2007 and Moslemi, 1985).

2.1.3 TYPES OF PARTICLEBOARD

There are different types of particleboards depending on –

2.1.3.1 TYPES OF PARTICLES USED

- **Flake board:** A particleboard in which the wood is largely in the form of flakes, giving the surface a characteristic appearance (Srivastava, 1969).
- **Chip board:** A particleboard made from chips. It is made in varying thickness and may be surfaced with paper, veneers, plastic materials, etc. (Anon, 1970 and Srivastava, 1969).
- **Shavings board:** A particleboard in which wood shavings are the chief constituents. (Anon, 1970 and Srivastava, 1969).
- **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 (Anon, 2008[a] and Salehuddin, 1992).
- **Oriented strand board:** Oriented strand board, or OSB, or Sterling board (UK) or Smart Ply (UK & Ireland) is an engineered wood product formed by layering strands (flakes) of wood in specific orientations (Anon, 2008[b] and Salehuddin, 1992).

2.1.3.2 PARTICLE SIZE DISTRIBUTION IN THE THICKNESS OF BOARD

- Single layer or homogeneous board,
- Three layer board, where course particles in the core layer are sandwiched between fine particles in the face layers, and
- Multi-layer or graduated board, with a graduation of particle ranging from the finest in the face layer to the coarsest in the core (Salehuddin, 1992).

2.1.3.3 DENSITY OF THE PARTICLEBOARD

- **Low density particleboard:** Density below 590 kg/m^3 or 37 lb/ft^3,
- **Medium density particleboard:** Density ranges from 590 to 800 kg/m^3 or 37 to 50 lb/ft^3 and
- **High density particleboard:** Density represents above 800 kg/m^3 or above 50 lb/ft^3 (Srivastava, 1969).

2.1.3.4 EXPOSURE OR SERVICE CONDITION

- **Particleboards for indoor use:** Where exposure to water or high humidity does not occur and
- **Particleboards for exterior use:** Where exposure to environmental conditions occur. Exterior particleboards may be further classified into-
    - Structural and
    - Non-structural boards (Salehuddin, 1992).

2.1.4 RAW MATERIALS FOR PARTICLEBOARD MANUFACTURING

2.1.4.1 LIGNO-CELLULOSIC MATERIALS

2.1.4.1.1 WOODY MATERIALS

- Planer savings,
- Sawmill residues, such as slabs, edging, trimmings, etc.
- Residues from timber cutting in furniture and cabinet manufacturing plants,
- Residues from match factories,
- Veneer and plywood plant residues,
- Saw dusts, and
- Bark (Salehuddin, 1992).

2.1.4.1.2 NON-WOODY MATERIALS

- Jute sticks,
- Bagasse,
- Bamboo,
- Flax shaves,
- Cotton stalks,
- Almost any agricultural residue (such as husks, coconut coir etc.) after suitable treatment (Youngquist, 1999).

2.1.4.2 CHEMICALS

2.1.4.2.1 BINDER OR ADHESIVE

Adhesives or binders are the materials used in the fabrication of timber structures and components offers a neat and efficient method of bonding together the separate pieces of wood, or of board products such as plywood, chipboard, or fibreboard, which comprise the finished product. ASTM (1997) defines an adhesive as a substance capable of holding materials together by surface attachment. The bond attained must meet the strength requirements for the structure as a whole and this bond must remain unaffected by the condition to which it will be exposed throughout its life (Youngquist, 1999).

2.1.4.2.1.1 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.

- **Natural adhesive:** Adhesives of natural origin- such as animal, casein, soybean, starch and blood glues are still being used to bond wood in some plants and shops, but are being replaced more and more by synthetics (Vick, 1999).
- **Synthetic adhesive or Synthetic resin adhesive:** Synthetic adhesives are man-made polymers which resemble natural resins in physical characteristics but which can be tailored to meet specific woodworking requirements. Synthetic adhesives can be categorized into two groups, namely thermosetting adhesives and thermoplastic adhesives (*Natasa et al. 2011*).

2.1.5 VARIABLES AFFECTING THE QUALITY OF PARTICLEBOARD

- **Particle geometry and slenderness ratio (s):** The main aspect of particle geometry is the slenderness ratio range of 120 to 200 seems best (Salehuddin, 1992).
- **Raw materials and compression ratio:** Particleboard must be compressed during hot pressing from 5 percent to 50 percent. Lower-density raw materials have greater compression ratio. So higher modulus of rupture, modulus of elasticity, internal bond and tensile strength properties are achieved (Salehuddin, 1992).
- **Binder mixing proportion and mixing:** Generally adhesives mixing proportion for particleboard is different for different types of adhesives. Based on ratio of wood flour and binder WPC board property will vary (Anon, 2006).
- Pressing time, temperature, pressure etc. are also affecting the quality of particleboard.

2.2 USES OF PARTICLEBOARD

Particleboards are used as:

- Shelves
- Table tops
- Cabinets
- Wall cases
- Benches
- Book cases
- Kitchen cabinets
- Piano and organ parts
- Flush-door cores
- Mobile homes
- Floor underlayment, etc.

2.3 ADVANTAGES OF PARTICLEBOARD

- Particleboards overcame 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 can tailor products for particular end-use.
- The characteristics 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.
- The variation in strength stiffness due to anisotropy in wood is largely overcome as also the differential changes in dimension due to absorption and desorption of moisture along or across the grain of wood.
- During the manufacture of particleboard, various treatments, such as heating, incorporation of chemical additives, etc. may be carried out to improve many physical and mechanical properties including the dimensional stability.
- 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 panelling, for exterior sideboards, for load bearing flooring purposes and so on.
- Perhaps the most important advantages of particleboard is that it can be made in large dimension (Salehuddin, 1992).

2.4 CONSIDERATIONS FOR THE QUALITY OF PARTICLEBOARD

i. Geometry of the particles i.e. length, width, thickness, diameter, etc.

ii. Species from which the raw materials are collected.

iii. Slenderness ratio (s), i.e. the ratio of length (l) over thickness (t) of particles with square of rectangular of cross section, s = l/t, or the ratio of length over diameter (d) for round particles, s = l/d, is a highly important parameter. For the majority of properties, long thin chips, with slenderness ratio of 120 to 200 seem best. However, surface quality and internal bond strength are higher with small particles, i.e. with lower slenderness ratio (Salehuddin, 1992).

2.5 GENERAL INFORMATION ABOUT BHANT (Clerodendrum infortunatum L.)

2.5.1 GENERAL INFORMATION

English Name: Hill glory bower

Botanical name: *Clerodendrum infortunatum* (L.) (Anon, 2006)

Synonyms

Synonym *Clerodendrum viscosum Vent.,*

Synonym *Ovieda infortunata (L.) Baill.*

2.5.2 DESCRIPTION

Clerodendrum species are trees, erect or rambling shrubs, rarely herbs. Branches terete, quadrangular, glabrous or pubescent. Leaves simple, decussate-opposite or whorled in 3's or 4's, petiolate or sessile, exstipulate. Inflorescence axillary cyme, terminal thyrse or rarely corymb. Flowers bisexual, calyx campanulate rarely tubular 5 lobed, rarely 2-4 lobed. Shrubs; bark grey and corky; young shoots tawny villous. Leaves 8-17 x 6-12 cm, ovate or orbicular, apex acuminate, villous beneath and tomentose above; basally 5-7 nerved; petiole to 8 cm long. Corolla white, tubular; tube 1-1.5 cm long, villous without; lobes 6-10 mm long, oblong, hairy without. Stamens 4; filaments slender, purplish, 2-2.5 cm long; anthers oblong. Ovary globose; style slender; exserted, 2-2.5 cm long. Drupe 6-8 mm across, globose, bluish-black on ripening; fruiting calyx enlarged, pink. Seeds 2-4, globose, 2-3 mm across (Youngquist, 1999).

2.5.3 GENERAL HABITAT

Moist evergreen forests, along river banks and near Villages at an altitude of about 1500-5000 ft. Degraded forest areas and also in the plains (Youngquist, 1999).

2.5.4 DISTRIBUTION

Found along river banks and wet areas from plains to 1500m. Common. India, Sri Lanka, Myanmar, Indo-China and Malaysia (Youngquist, 1999).

2.5.5 REPRODUCTION

Clerodendrum species flowers are complete, bisexual, i.e., with functional male (androecium) and female (gynoecium), including stamens, carpels and ovary. Pollination is entomophilous i.e., by insects. Flowering/Fruiting: Almost throughout the year (Youngquist, 1999).

2.5.6 DISPERSAL

Seeds dispersed by anemochory i.e., wind dispersal, zoochory i.e., dispersal by birds and animals, anthropochory i.e., dispersal by humans (Youngquist, 1999).

2.5.7 USES

- Used in Ayurveda and Siddha medicine for rheumatism, fever, diarrhea and skin complaints.
- Has good antibacterial activity.
- Fresh leaf juice is said to be vermifuge.
- Medicinal.

CHAPTER THREE: MATERIALS AND METHODS

3.1 MATERIALS AND EQUIPMENT

3.1.1 CHIPPER

A locally made small lab scale chipper was used to chip the raw materials. The rpm of the chippers' motor was 1420.

3.1.2 HOT PRESS

A digital hydraulic hot press was used to press the mat into particleboard. It has multi-layer plate. The both platen were movable up and down. Maximum temperature range within 400℃ and pressure up to 5MPa commonly occur.

3.1.3 HYDRAULIC UNIVERSAL TESTING MACHINE (UTM)

An analogue hydraulic Universal Testing Machine (UTM), model: WE-100, made by Time group Inc. was used to determine the mechanical properties of the particleboards. There were two units of this machine, one was control unit and another was working unit. A meter was attached with the control unit for measuring the load (kN). And a scale (mm) was attached with the working unit to measure the deflection. The length of the span, on which the samples were laid, was 248 mm. Another part of the working unit was used to determine the tensile strength, which works vertically.

3.1.4 OVEN

A lab scale ventilated oven (Name: Gallennkamp, Size 1, made in UK) was used to determine the moisture content (%) of raw materials as well as the particleboards. A digital indicator outside the oven indicated the inside temperature.

3.1.5 MOISTURE METER

An analogue moisture meter (Model: RC-1E, made by Delmhorst Instrument Co., USA) was used to measure the moisture content of particles.

3.1.6 ELECTRIC BALANCE

An air tight digital balance (Model: AB 204, made in Switzerland) was used to measure the weight of the raw materials as well as particleboards and also used to measure the weight of different ingredients of the adhesive.

3.2 METHODS AND PROCEDURES

3.2.1 COLLECTION OF RAW MATERIALS

The raw material Bhant (*Clerodendrum infortunatum*) was collected from beside the highway road at Zero point under Khulna District as raw material for the manufacturing of Particleboard. For the purpose of preparing samples the defect free bole is selected and then it chipped by chopper machine. After chipping, the wood chips are run into grinder machine, by which the wood turned into Wood particle. In this study the size of particle ranges < 1mm is used.

3.2.2 SELECTING VARIABLES

There are two types of variables, i.e. dependent and independent. In this study, temperature and pressure are the dependent variable. Temperature is fixed at 160°c and pressure is 5 MPa. According to *Nadir et al., (2011)*, temperature has little effect on mechanical properties of Particleboard. Different study shows that 5 MPa pressures are better for producing good quality Particleboard. On the other hand, melting temperature of Urea formaldehyde is ranges 130-160°C. So that fixing temperature at 160°C is very reasonable for this study.

Beside this, wood particle ratio is the independent variables. Within this fixed variables three different ratio A (100:0), B (70:30) and C (50:50) was taken for manufacturing Particle Board (PB) from Bhant (*Clerodendrum infortunatum*).

3.2.3 MANUFACTURING PLACE

The Particleboard was manufactured at wood lab that is controlled under by Forestry and wood technology discipline, Khulna University, Khulna. All tests for its quality were also done there.

3.2.4 MANUFACTURING PROCEDURE

3.2.4.1 PREPARATION OF RAW MATERIAL

The stalk was cut into narrow sticks after which the narrow sticks were cut into small pieces by circular saw to feed into the chipper. Then the pieces of stalk kept under open sun for 30 days for drying (Salehuddin, 1992; AWPA, 2001 and Youngquist, 1999).

3.2.4.2 PARTICLE PREPARATION

To produce particles of the stalk chipping was done with chipper machine. The small pieces of stalk were inserted separately into the chipper machine. The holes in the perforated mesh that was used in the chipper machine were approximately 8 mm in diameter. From the chipper machine the particles were collected manually (Salehuddin, 1992; AWPA, 2001).

3.2.4.3 DRYING OF SCREENED PARTICLES

After screening the particles of each type were inserted in to the oven for drying. In the oven the temperature was 103^0 C and after drying the moisture content was 5.8%. For use with binder, the particles must be reduced to about 2% to 7% moisture content (Anon, 2006).

3.2.4.4 MIXING OF BINDER

The addition of adhesive that means was Urea formaldehyde (UF) mixed with Wood particle (WF) by handshaking process then formed into a product (Hwang and Hsiung, 2000). It is a critical step for both product quality and production efficiency (Youngquist, 1999). In this study A (100:0), B (70:30) and C (50:50) ratio of Wood particle (WP) and Urea formaldehyde (UF) mixed Particleboard was manufactured from Bhant (*Clerodendrum infortunatum*). In case of Particleboard the raw materials are first mixed together, and the composite blend is then formed into a product.

The combination of these steps is called in-line processing, and the result is a single processing step that converts raw materials to end products. (Harper and Wolcott, 2004; Herrera and Valadez, 2004; Lu et al. 2000).

3.2.4.5 MAT FORMING

After mixing with adhesive, the particles of each type of ratio were formed into mat separately on the separate steel sheet. The mats of each type were formed manually. Mat is formed into 3-4 times and even 20 times thicker than the target board thickness, depending on the particle geometry and density of the raw material (Salehuddin, 1992 and Youngquist, 1999).

3.2.4.6 HOT PRESSING

After mat formation, a steel sheet was placed on to the mat (for each type) and then inserted manually into the hot press (each type separately) for pressing. After inserting the mat into the hot press, the pressure was raised manually by digital hydraulic hot press up to 5 MPa. There the total press time was 8 minutes, temperature was 160°C. After pressing the average thickness of the boards was 9 mm.

After pre-pressing, the mats are hot-pressed into panels. Hot-press temperatures for thermoplastic materials (e.g. Urea formaldehyde) usually range from 165°C to 190°C. Pressure depends on a number of factors, but it is usually in the range of 1.37 to 3.43 MPa and >3.35 MPa for medium-density and high density boards. Upon entering the hot press, mats usually have a moisture content of 8% to 12%, but this is reduced to about 5% to 9% during pressing. This process of particleboard manufacturing is called flat-press process (AWPA, 2001 and Youngquist, 1999).

3.2.4.7 CONDITIONING AND FINISHING

After stopping temperature the board was remained fixed for cooling or conditioning. The hot boards are removed from the press (or sawn across on continuous presses) and further conditioned to equilibrate board moisture content and to stabilize and fully cure the adhesives (AWPA, 2001). After the boards of each type were produced separately, these were trimmed at edges with the fixed type circular saw. The dimensions of each type of boards were then 30 cm×20 cm. The board is trimmed to obtain the desired length and width and to square the edges. Trim losses usually amount to 0.5% to 8%, depending on the size of the board, the process employed, and the control exercised (Youngquist, 1999).

3.2.5 SPECIFICATIONS OF MANUFACTURED PARTICLEBOARDS

Table 3. 1 Specifications of manufacturing Particleboard from Bhant (*Clerodendrum infortunatum*)

Dimensions (mm)	150 x 150
Thickness (mm)	9 (Average)
Layer	Single
Board Types	3 [A (100:0), B (70:30), C (50:50)]
Replications	3 (for each type)
Total board manufactured	9
Binder	Urea formaldehyde

3.2.6 LABORATORY TESTS

The laboratory tests for characterization of physical properties and mechanical properties for each type of particleboards were carried out respectively in the Wood Technology Laboratory of Forestry and Wood Technology Discipline of Khulna University and in the Laboratory of Civil Engineering Department of Khulna University of Engineering and Technology, Khulna. The properties were tested according to the procedures defined in the American standard for particleboards (ANSI A208.1–1993) (NPA, 1993) (Anon, 1985).

3.2.6.1 PREPARATION OF SAMPLES FOR TESTING

Three replications of each type of boards were manufactured as stated earlier. For testing physical properties, three samples were collected from each board of each type. So the total number of sample was nine (9) for each type of particleboard for testing of physical properties. The Density and Moisture Content were determined on the same nine (9) samples and the Water Absorption and Thickness Swelling were determined on the other nine (9) samples. For testing mechanical properties, three samples were collected from each board of each type. So the total number of sample was nine (9) for each type of particleboard for testing of mechanical properties. The MOR and MOE were determined on the separate samples.

The dimension of samples for testing the physical properties was approximately (150 mm x 35 mm) and for testing the mechanical properties was approximately (180 mm x 35 mm).

3.2.7 DETERMINATION OF PHYSICAL PROPERTIES

All the samples are cut into (50 mm x 35 mm) dimension for testing physical properties. The laboratory test for characterization of physical properties is carried out in the laboratory of Forestry and Wood Technology Discipline, Khulna University, Bangladesh. At first all the specimens are weighted and green dimension are taken at room temperature. Then all the samples are kept into oven for 24 hours. After drying oven dry weight and dry dimension are also measured. Next, the samples are soaked into water for 24 hour. Finally, the wet dimension are taken and all the physical properties are calculated.

3.2.8 DETERMINATION OF MECHANICAL PROPERTIES

All the samples are cut into required dimension for testing mechanical properties. The laboratory test for characterization of mechanical properties is carried out in the laboratory of Civil Engineering Department of Khulna University of Engineering and Technology, Khulna, Bangladesh.

3.2.9 ANALYSIS OF DATA

All the data, produced during the laboratory tests for characterization of physical and mechanical properties of each type of particleboards, were analyzed by using Microsoft Office Excel 2007 and SAS (Statistical Analysis System) software. ANOVA (Analysis of Variance) and LSD (Least Significant Difference) were done to analyze the data.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 RESULTS

The results of different physical and mechanical properties that were found during different laboratory tests are delineated (with standard error bar) here. The abbreviations used in this chapter are CP, FP, A (100:0), B (70:30) and C (50:50) which are stands for Coarse particle, Fine particle, 100% Coarse particle with 0% Fine particle, 70% Coarse particle with 30% Fine particle and 50% Coarse particle with 50% Fine particle respectively.

4.1.1 PHYSICAL PROPERTIES

4.1.1.1 DENSITY

Density is quantity that is used to describe the mass of a material per unit volume (Irle and Barbu, 2010). It has been found that the density of three different ratio A (100:0), B (70:30) and C (50:50) of Particleboard manufactured from Bhant (*Clerodendrum infortunatum*) are 0.689 gm/cm^3, 0.70 gm/ cm^3 and 0.777 gm/cm^3 respectively (Fig-4.1). The variation in density among the different types of Particleboards may be due to the variation in ratio of the different types wood particles itself. From the following (Fig-4.1), we have seen that wood particles ratio has impact on density. Density is gradually increased with the increases fine particles in particleboard ratio. So we can say the same amount but different ratio of wood particle may causes of different density in Particleboard. From the analysis of variance (Table A-1), it has been observed that there was significant difference ($P < 0.05$) in density among the different types of Particleboards. According to American National Standard (ANSI) A208.1-1993 (NPA, 1993), all types of boards manufactured are fall into the range of medium density particleboard (.64-.80 gm/cm^3).

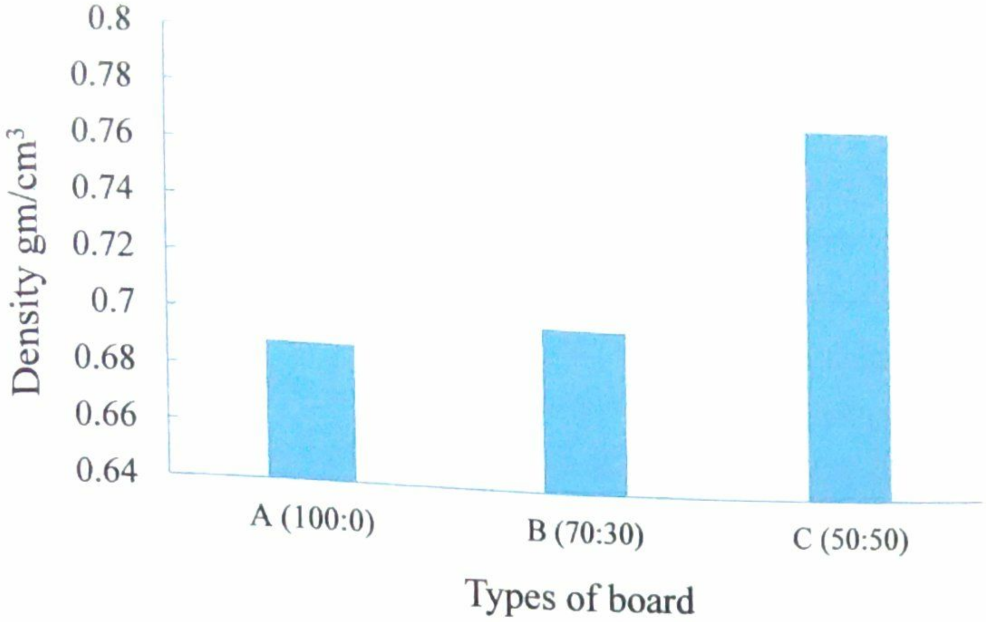

Figure 4. 1 Density of Particleboard with different ratio of CP and FP

4.1.1.2 MOISTURE CONTENT

Espert et al. (*2003)* stated that wood consists mostly of vessels in which moisture is absorbed. Following (Fig. 4.2) demonstrated that with the increasing of fine particles ratio percentage, the MC content straightly increases.

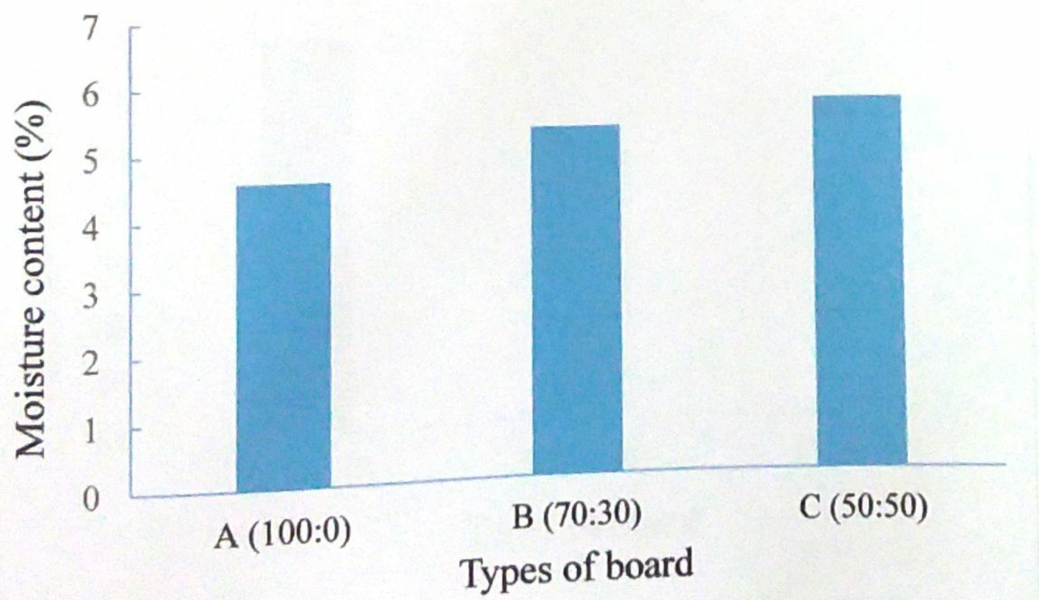

Figure 4. 2 Moisture content (%) of Particleboard with different ratio of CP and FP

The moisture content of three different ratios A (100:0), B (70:30) and C (50:50) of Particleboard manufactured from Bhant (*Clerodendrum infortunatum*) are 4.583%, 5.34% and 5.763 % respectively (Fig. 4.2). The variation in moisture content in different types of boards may be due to the variation in ratio among different wood particles itself. The moisture content ratio of wood particle C (50:50) was higher (5.763%) than that of other types of particles. From the analysis of variance (Table A-3), it has been observed that there was significant difference ($P < 0.05$) in moisture content among the different types of Particleboards. The maximum moisture content in the standard particleboard was not found as per ANSI A208.1–1993 (NPA, 1993).

4.1.1.3 WATER ABSORPTION

It was found that the absorption of water of three different ratios A (100:0), B (70:30) and C (50:50) of Particleboard manufactured from Bhant (*Clerodendrum infortunatum*) are 78%, 74.33% and 68.67% respectively after 24 hours immersion in water. For all formulations, the higher compaction ratio always absorbed a lower amount of water than the lower compaction ratio. Water entry into the higher density boards occurred at a slower rate due to the decreased porosity and the increased wood material. If density increases porosity will decrease. So here high density board has absorbed less water than the other two types of board (Fig.4.1).

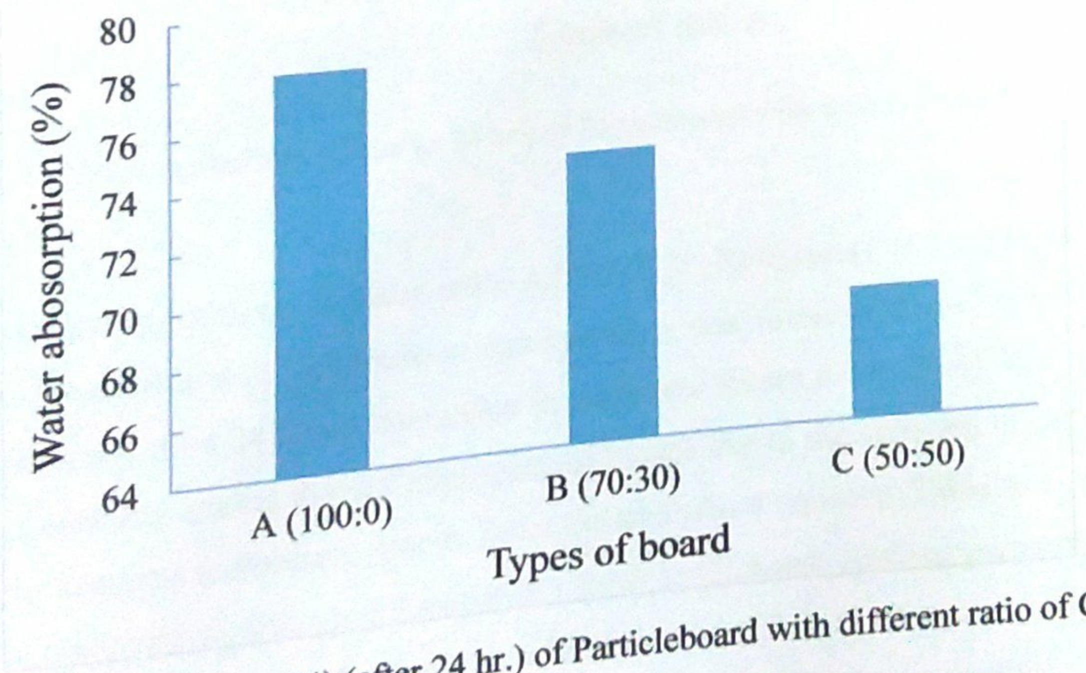

Figure 4. 3 Water absorption (%) (after 24 hr.) of Particleboard with different ratio of CP and FP

From the analysis of variance (Table A-5), it has been observed that there was significant difference ($P < 0.05$) in water absorption percentages among the different types of Particleboards. The water absorption percentage by standard particleboard was not found as per ANSI A208.1–1993 (NPA, 1993).

4.1.1.4 THICKNESS SWELLING

The high moisture absorption of plant fibers leads to swelling and presence of voids at the interface (porous products), which results in poor mechanical properties and reduces dimensional instability of composites.

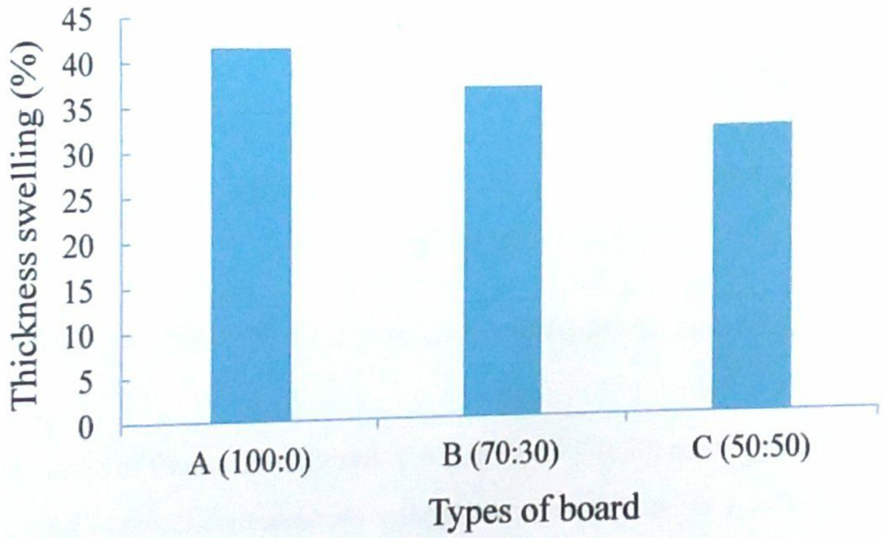

Figure 4. 4 Thickness swelling (%) (after 24 hr.) of Particleboard with different ratio of CP and FP

The thickness swelling of three different ratios A (100:0), B (70:30) and C (50:50) of Particleboard manufactured from Bhant (*Clerodendrum infortunatum*) was found to 41.667%, 37.333% and 32.38% respectively after 24 hours immersion in water and shown in Fig. (4.4). The variation in the thickness swelling among the different types of boards due to the variation in the amount of wood particles contents in different boards. From the analysis of variance (Table A-7), it has been observed that there was significant difference ($P < 0.05$) in thickness swelling percentages among the different types of particleboards. From the LSD (Least Significant Difference) analysis (Table A-8), it has been observed that there was significant difference in thickness swelling percentages among three types of board. The thickness swelling percentage after 24 hours immersion in water by standard particleboard was not found as per ANSI A208.1–1993 (NPA, 1993).

4.1.1.5 LINEAR EXPANSION

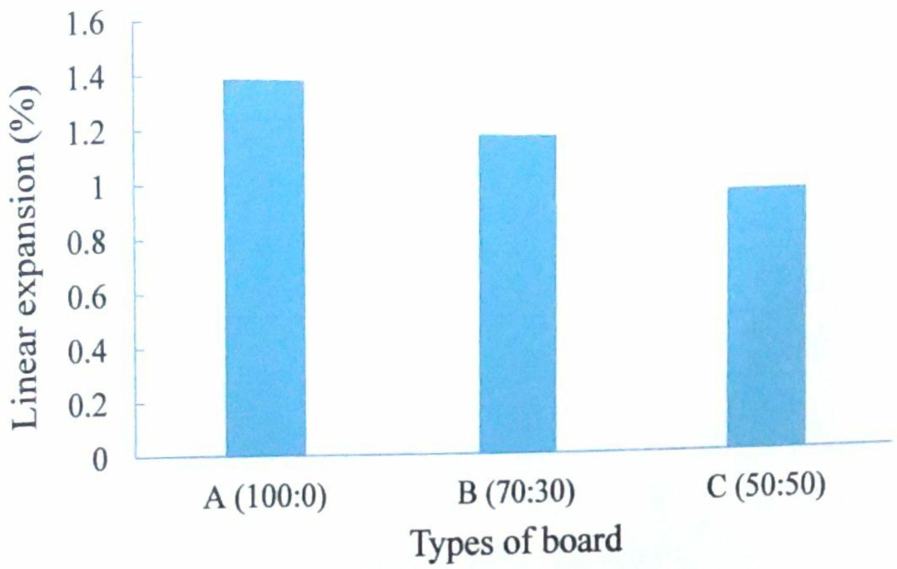

Figure 4. 5 Linear expansion (%) (after 24 hr.) of Particleboard with different ratio of CP and FP

The Linear expansion of three different ratios A (100:0), B (70:30) and C (50:50) of Particleboard manufactured from Bhant (*Clerodendrum infortunatum*) was found to 1.39%, 1.20% and 0.99% respectively after 24 hours immersion in water and shown in Fig. (4.5). The density and water absorption capacity have more effect on linear expansion of particleboard. Higher density board absorbs less water than a lower density board, so the linear expansion percentage of higher density board is lower than other two particleboards. From the analysis of variance (Table A-9), it has been observed that there was significant difference ($P < 0.05$) in linear expansion percentages among the different types of Particleboards. According to ANSI A208.1–1993 (NPA, 1993), the maximum average linear expansion of standard particleboard is 0.35 %, but the specified time was not found.

4.1.2 MECHANICAL PROPERTIES

4.1.2.1 MODULUS OF RUPTURE (MOR)

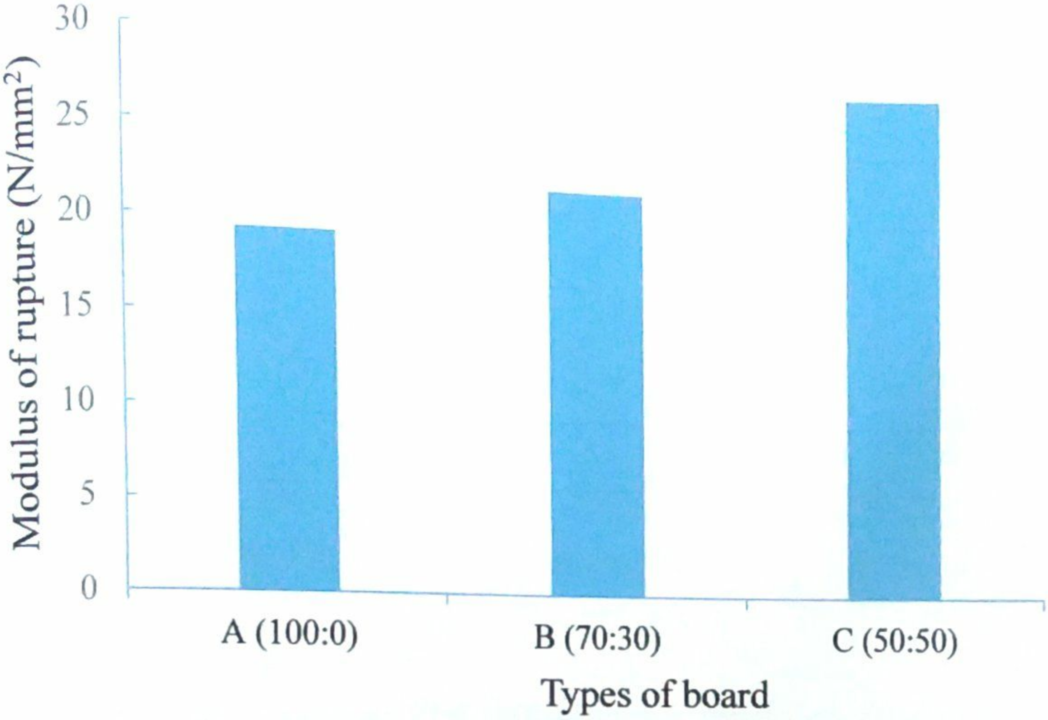

Figure 4. 6 Modulus of rupture (MOR) of Particleboard with different ratio of CP and FP

The modulus of rupture (MOR) of three different ratios A (100:0), B (70:30) and C (50:50) of Particleboard manufactured from Bhant (*Clerodendrum infortunatum*) was found to 19.363 N/mm^2, 22.227 N/mm^2 and 27.857 N/mm^2 respectively (Fig. 4.6). The MOR of ratios C (50:50) was found to higher than other types of Particleboards. The strength properties of the composite materials depend upon the compactness of the particles, species, adhesive etc. When species and adhesive are same, the strength properties depend upon mainly the compactness of the particles. The compactness of the particles is higher than that of particleboard due to extra pressure. It has been remarked from the Fig. (4.6) that the MOR of particleboard arrived at the highest value 27.857 N/mm^2 medium ratio of coarse particle and medium ratio of fine particle (*Shao-Yuan et al. 2011*). According to American National Standard (ANSI) A208.1–1993 (NPA, 1993), MOR of particleboards ranges from 16.5-23.5 N/mm^2 and two types of particleboards were in this range of this standard and one types exceeded in this range of the standard.

4.1.2.2 MODULUS OF ELASTICITY (MOE)

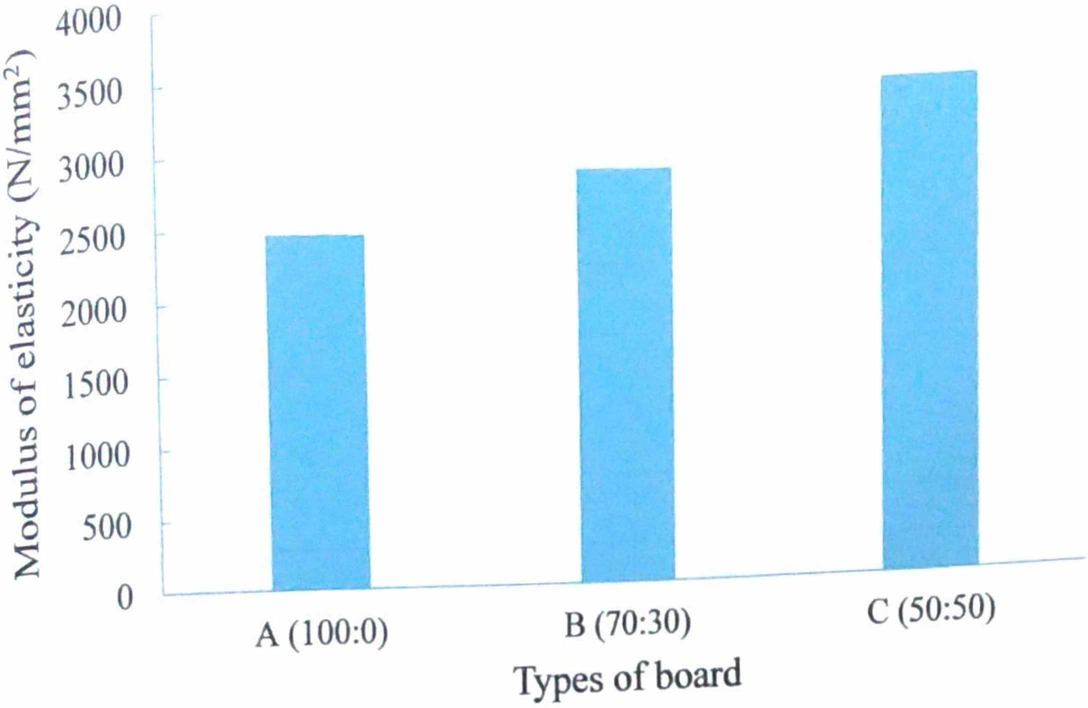

Figure 4. 7 Modulus of elasticity (MOE) of Particleboard with different ratio of CP and FP

The modulus of elasticity (MOE) of three different ratios A (100:0), B (70:30) and C (50:50) of Particleboard manufactured from Bhant (*Clerodendrum infortunatum*) was found to 2472.35 N/mm^2, 2935.95 N/mm^2 and 3520.11 N/mm^2, respectively (Fig. 4.7). Modulus of Elasticity affected similarly by density. Increasing board density increases modulus of elasticity; increasing surface density and surface particle alignment also increases modulus of elasticity. From the analysis of variance (Table A-13), it has been observed that there was significant difference ($P < 0.05$) in MOE among the different types of particleboards. According to American National Standard (ANSI) A208.1–1993 (NPA, 1993), the MOE of standard particleboard is 2,400- 2,750 N/mm^2 for high density grade, 1,725- 2,750 N/mm^2 for medium density grade and 550- 1,025 N/mm^2 for low density grade and only A (100:0) was in the range of high density grade and other two types exceeded the range of high density grade.

Table 4. 1 Result summary for Physical and Mechanical Properties

Board/ Standard Types	Physical Properties					Mechanical Properties	
	Density (gm/cm³)	MC (%)	WA (%) (24 hr.)	TS (%) (24 hr.)	LX (%) (24 hr.)	MOR (N/mm²)	MOE (N/mm²)
A(100:0)	0.689	4.583	78	41.667	1.39	19.363	2472.35
B(70:30)	0.70	5.34	74.33	37.333	1.20	22.227	2935.95
C(50:50)	0.777	5.763	68.67	32.38	0.99	27.857	3520.11
ANSI A208.1–1993	a	-	-	-	0.35[b]	3.0 - 23.5	550 - 2,750

High density = > 0.80 gm/cm³, [a]Medium density = 0.64 to 0.80 gm/cm³ and Low density = < 0.64 gm/cm³, [b]Immersion time not specified.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The study investigated the properties of single layer particleboards manufactured from Bhant stalks with UF resin. In this work, woody stalks from Bhant (*Clerodendrum infortunatum*) contributed as a good source of Particleboard manufacturing. The performance of Particleboard in terms of density, moisture content, MOR and MOE increases along with the increase of fine particle proportion. Water absorption, thickness swelling, linear expansion increases along with the decrease of fine particle proportion in particleboard and vice versa. Among the three different ratios of Particleboards from Bhant (*Clerodendrum infortunatum*), C (50:50) ratio has satisfied most in case of physical and mechanical properties. Particleboards that satisfy the ANSI/A208.1-1999 standard can be produced from bhant stalks using urea-formaldehyde as a binder. If Bhant (*Clerodendrum infortunatum*) is used commercially for manufacturing particleboard, it will be an appropriate alternate source of raw material for particleboard industries. In this situation, the government and particleboard industry owners may take initiatives for utilizing Bhant (*Clerodendrum infortunatum*) as an alternate source of raw material for manufacturing of particleboard in future.

5.2 RECOMMENDATIONS

From my study it has been found that the density of three different ratios A (100:0), B (70:30) and C (50:50) of Particleboard manufactured from Bhant (*Clerodendrum infortunatum*) has satisfied the physical and mechanical properties of the international standards. But further study can also be carried out with different adhesives like Phenol Formaldehyde (PF), Melamine Formaldehyde (MF), Poly vinyl chloride (PVC), Poly-vinyl acetate (PVCA) etc. for manufacturing Particleboard manufactured from Bhant (*Clerodendrum infortunatum*).

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APENDIX: ANALYSIS OF VARIENCE

TABLE A-1: ANOVA FOR DENSITY

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.013794	2	0.006897	50.71324	0.000174	5.143253
Within Groups	0.000816	6	0.000136			
Total	0.01461	8				

TABLE A-2: LSD FOR DENSITY

Board types	N	Mean	Grouping
C (50:50)	3	0.77700	A
B (70:30)	3	0.7000	B
A (100:0)	3	0.68900	B

TABLE A-3: ANOVA FOR MOISTURE CONTENT

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.144378	2	1.072189	7883.743	5.5E-11	5.143253
Within Groups	0.000816	6	0.000136			
Total	2.145194	8				

TABLE A-4: LSD FOR MOISTURE CONTENT

Board types	N	Mean	Grouping
C (50:50)	3	5.76300	A
B (70:30)	3	5.3400	B
A (100:0)	3	4.58300	C

TABLE A-5: ANOVA FOR WATER ABSORPTION AFTER 24 HOURS

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	132.5534	2	66.2767	49.69759	0.000184	5.143253
Within Groups	8.0016	6	1.3336			
Total	140.555	8				

TABLE A-6: LSD FOR WATER ABSORPTION AFTER 24 HOURS

Board types	N	Mean	Grouping
A (100:0)	3	78.00	A
B (70:30)	3	74.3300	B
C (50:50)	3	68.6700	C

TABLE A-7: ANOVA FOR THICKNESS SWELLING AFTER 24 HOURS

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	129.5641	2	64.78207	476338.7	2.5E-16	5.143253
Within Groups	0.000816	6	0.000136			
Total	129.565	8				

TABLE A-8: LSD FOR THICKNESS SWELLING AFTER 24 HOURS

Board types	N	Mean	Grouping
A (100:0)	3	41.6670	A
B (70:30)	3	37.3330	B
C (50:50)	3	32.3800	C

TABLE A-9: ANOVA FOR LINEAR EXPANSION AFTER 24 HOURS

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.2402	2	0.1201	300.25	9.68E-07	5.143253
Within Groups	0.0024	6	0.0004			
Total	0.2426	8				

TABLE A-10: LSD FOR LINEAR EXPANSION AFTER 24 HOURS

Board types	N	Mean	Grouping
A (100:0)	3	1.3900	A
B (70:30)	3	1.2000	B
C (50:50)	3	0.9900	C

TABLE A-11: ANOVA FOR MODULUS OF RUPTURE (MOR)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	112.0474	2	56.02372	14005929	9.83E-21	5.143253
Within Groups	2.4E-05	6	4E-06			
Total	112.0475	8				

TABLE A-12: LSD FOR MODULUS OF RUPTURE (MOR)

Board types	N	Mean	Grouping
C (50:50)	3	27.8570	A
B (70:30)	3	22.2270	B
A (100:0)	3	19.3630	C

TABLE A-13: ANOVA FOR MODULUS OF ELASTICITY (MOE)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1653969	2	826984.4	2.07E+09	3.06E-27	5.143253
Within Groups	0.0024	6	0.0004			
Total	1653969	8				

TABLE A-14: LSD FOR MODULUS OF ELASTICITY (MOE)

Board types	N	Mean	Grouping
C (50:50)	3	3520.11	A
B (70:30)	3	2935.95	B
A (100:0)	3	2472.35	C