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Title: Manufacturing techniques along with physical and mechanical properties of wood plastic composite (WPC) board from Jial Bhadi, Jiga (*Lannea coromandelica*), (HOUTT) MERR

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MANUFACTURING TECHNIQUES ALONG WITH PHYSICAL AND MECHANICAL PROPERTIES OF WOOD PLASTIC COMPOSITE (WPC) BOARD FROM JIAL BHADI, JIGA (*Lannea coromandelica*), (HOUTT) MERR.

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This dissertation has been prepared for the partial fulfillment of the requirements of Four (4) years professional B. Sc. (Hons.) degree in Forestry from Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh.

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PROJECT THESIS
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DECLARATION

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

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Signature

15.12.13

H. M. Mamunur Rashid

Dedicated
To My
Beloved Parents &
Loving Sister Meem

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The Author

H. M. Mamunur Rashid

ABSTRACT

The present study was conducted to evaluate the physical and mechanical properties of wood plastic composite board from Jial Bhadi, Jiga (*Lannea coromandelica*). In this study Jial Bhadi, Jiga (*Lannea coromandelica*) is a multipurpose usable tree of Anacardiaceae family was used as wood particle in wood plastic composite (WPC) board manufacturing and polypropylene was used as binder. The study was conducted based on three different ratios A (60:40), B (65:35) and C (70:30) of wood particle and polypropylene for manufacturing Wood Plastic Composite (WPC) board from Jial Bhadi, Jiga (*Lannea coromandelica*). It has been found that the density of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board were 1029.2 kg/m3, 929.05 kg/m3 and 840.70 kg/m3 respectively. The moisture content of three different ratios A (60:40), B (65:35) and C (70:30) were 5.15%, 6.46% and 7.09% respectively. Water absorption of three different ratios in (WPC) boards were 30.91%, 35.29% and 40.47% respectively after 24 hours immersion in water. The thickness swelling of three ratios 24.94%, 29.84% and 35.43% respectively after 24 hours immersion in water. The linear expansion of three ratios found 0.92%, 1.21% and 1.38% respectively after 24 hours immersion in water. The modulus of rupture (MOR) of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) were found 24.59 N/mm², 17.69 N/mm² and 15.13 N/mm² respectively and modulus of elasticity (MOE) of the three ratios were 2937.13 N/mm², 2452.26 N/mm² and 2165.86 N/mm², respectively. Although some properties of these boards have followed some international standards like, ANSI, IS, AS/NZS, BS and German standards.

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ABBREVIATION

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
g/cm^3 or gm/cm^3	Gram per cubic centimeter
Ha	Hectare
kg/m^3	Kilogram per cubic meter
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
PVC	Poly vinyl chloride
PP	Polypropylene
PVAC	Poly-vinyl acetate
rpm	Rotor per minute
SD	Standard deviation
UTM	Universal Testing Machine
WP	Wood particle

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND JUSTIFICATION OF THE STUDY

Wood is one of the lingo cellulosic materials and valuable forest resources on the earth and it conforms to the most varied requirements (Anon, 1982). Wood is one of the most valuable resources on the earth and it conforms to the most varied requirements. About 70% demand for timber and 90% for fuel wood of the country is met from the trees grown in village groves of Bangladesh Wood from times immemorial has been the most useful of all the readily available materials to mankind (Anon, 1982). But due to heavy and illegal extraction of timber forest resource has becomes too much meager in Bangladesh and occurring of scarcity of timber. In this case wood composites represent one of the most challenging product groups in the world from a marketing point of view because of their number, versatility, end-use variation, dissimilarities of the producer base and resource richness.

Wood plastic composite (WPC) is a product which could be obtained from plastic and wood. WPC is a composite with a rapid growing usage consisting of a mixture of wood waste and polymeric material (*Soury et al. 2009*). Wood plastic composites (WPC) are a new generation of the composites experiencing considerable growth in production and demand in many countries. A wide range of polymers; such as polypropylene, polyethylene, polyesters, etc as well as lignocelluloses; such as wood flour, wood fibers, etc are used for their production (*Jiang et al. 2003*).

The term WPCs refers to any composites that contain plant (including wood and non-wood) fibers and thermoplastics. Thermosets are plastics that, once cured, cannot be melted by repeating. Thermoplastics are plastics that can be repeatedly melted. Polypropylene (PP), polyethylene (PE) and polyvinyl chloride (PVC) are the widely used thermoplastics for WPCs and currently they are very common in building, construction, furniture and automotive products (*Panthapulakkal et al. 2006*).

WPC has become currently an important address of research that gained popularity over the last decade especially with its properties and advantages that attracted researchers such as: high durability, Low maintenance, acceptable relative strength and stiffness, fewer prices relative to other competing materials, and the fact that it is a natural resource (*Bengtsson and Oksman 2006*) & (*Winandy et al. 2004*). Wood plastic composites have found commercial success in exterior applications. Scientific investigations of these materials have concentrated, mainly, on improving mechanical properties. While wood plastic composites may have good rot resistance, few scientific studies on the biodegradation of these materials have been carried out.

In this study Jial Bhadi, Jiga (*Lannea coromandelica*) is a multifarious usable tree of Anacardiaceae family was used as wood particle in wood plastic composite (WPC) board manufacturing. It is a neglected but a novel source of renewable ligno-cellulosic raw material. But due to little knowledge about the technical feasibility of making particleboard from these novel sources of ligno-cellulosic raw material, these are now being underutilized and using as fuel wood. The stem and branch has the ligno-cellulosic constitution which can potentially be used as the raw material for particleboard production (*Satyavati GV et al., 1987*). Therefore the study has carried out to determine the physical and mechanical properties after manufacturing wood plastic composite board from Jial Bhadi, Jiga (*Lannea coromandelica*). If these are studied for finding out the technical feasibility to convert them into particleboard, a new avenue can be opened to the particleboard manufacturing industries at the present situation of raw material crisis as well as the economic values of these materials will be increased.

1.2 OBJECTIVES OF THE STUDY

- To assess physical and mechanical properties of wood plastic composite board using Jial Bhadi, Jiga (*Lannea coromandelica)* as raw materials.
- To compare the quality and properties of board using different ratio of wood flour and Polypropylene

CHAPTER 2

LITERATURE REVIEW

2.1 WOOD

2.1.1 PHYSICAL COMPOSITION

Wood (xylem) is composed of elongated cells; they are oriented in the longitudinal direction of the stem (Figure 2.1). The ends are connected through openings, and these openings are called pits. These cells vary in function and differ in shape. They perform in the transport of liquid and act as food reserves. They also provide necessary mechanical support to the tree (Eero Sojstrom, 1993).

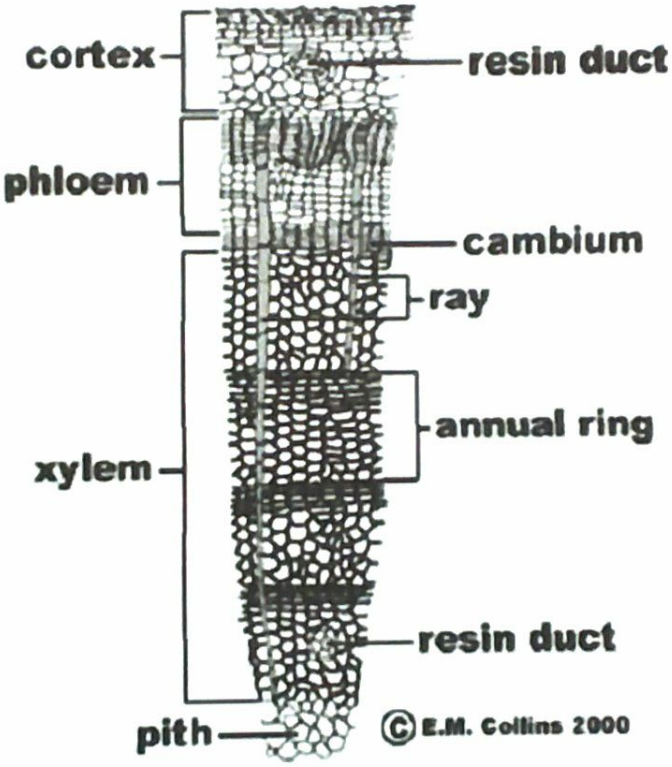

Figure 2.1 Diagram showing a section of a dicot stem

2.1.2 XYLEM ULTRA STRUCTURE

The xylem cells consist mainly of cellulose, hemicellulose, and lignin. Cellulose is comprised of a crystalline structure, while hemicellulose has a semi-crystalline structure and lignin is an amorphous polymer. The cell wall is built up by several layers, namely the middle lamella (ML), primary wall (P), outer layer of the secondary wall (S_1), middle layer of secondary wall (S_2), inner layer of the secondary wall (S_3) and warty layer (W) (Figure 2.2). These layers differ from each other based on their chemical composition and their structure. The ML is located between the cells and serves the function of binding wood cells together. Though it contains pectin in the initial stages it becomes lignified in later stage of life (Fengel and Wegener, 1983).

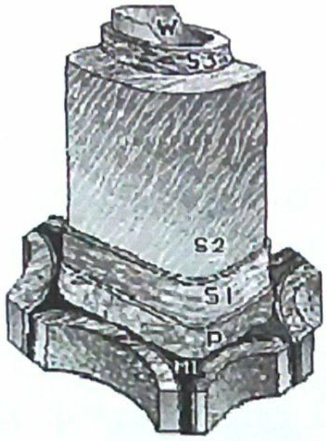

Figure 2.2 Structure of wood cell, showing the middle lamella (ML), primary wall (P), outer (S_1), middle (S_2) and inner (S_3) layers of secondary cell wall and the warty layer (W).

2.1.3 CHEMICAL COMPOSITION

Wood is a lignocellulosic material and is composed of approximately 50-65% cellulose, 20-25% lignin and 1-10% extractives and traces of ash. The ratio of constituents differs based on species. The absorption of water by cellulose depends on the number of hydroxyl groups that are not linked with other hydroxyl groups. Usually, the crystalline structure of cellulose will not take part in chemical reaction because of it unavailable hydroxyl groups but only the amorphous region (Fengel and Wegener, 1983).

2.2 GENERAL INFORMATION ABOUT PARTICLEBOARD

2.2.1 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).

2.2.2 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).

2.2.3 TYPES OF PARTICLEBOARD

There are different types of particleboards depending on –

2.2.3.1 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).

2.2.3.2 PRESSING METHODS

- Particleboard manufactured by **flat-press process**, where pressure is applied perpendicular to board surface, particles generally falling flat along the plane of the board surface,
- Particleboard manufactured by **extrusion process**, where resin-bonded particles are forced between parallel hot plates or dies for consolidation and cure, particles lying largely at right angles to the board surface and
- Particleboard manufactured by **moulding process**, where products are moulded into the desired shape with heat and pressure by using specially constructed mould or dies (Salehuddin, 1992).

2.2.3.3 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).

2.2.3.4 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).

2.2.3.5 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).

2.2.3.6 TYPES ACCORDING TO AUSTRALIAN STANDARDS

- **Standard particleboard:** Particleboard suitable for general purpose and dry interior use. It is not suitable for exterior use or interior areas where wetting or prolonged high humidity conditions are likely.
- **Moisture resistant (MR) particleboard:** Particleboard suitable for areas of occasional wetting and high humidity. Not suitable where submerging, hosing or continual wetting is likely to occur.
- **High performance (HP) particleboard:** Particleboard suitable for use in certain structural applications.
- **Particleboard for flooring:** Particleboard manufactured specifically for use as domestic or industrial flooring (AWPA, 2008).

2.2.4 RAW MATERIALS FOR PARTICLEBOARD MANUFACTURING

2.2.4.1 LIGNO-CELLULOSIC MATERIALS

2.2.4.1.1 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,
- ✓ Logging residues, such as short logs, broken logs, crooked logs, small tree tops and branches, forest thinning , etc, and
- ✓ Bark (Salehuddin, 1992)

2.2.4.1.2 NON-WOODY MATERIALS

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

2.2.4.2 CHEMICALS

2.2.4.2.1 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).

2.2.4.2.1.1 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).

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- **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*).

a) **Thermosetting adhesives:** These types of adhesives are usually based on formaldehyde (UF), Phenol formaldehyde (PF), Resorcinol formaldehyde (RF), Phenol resorcinol formaldehyde (PRF), Melamine formaldehyde (MF), Melamine urea formaldehyde (MUF), isocyanate etc; resigns. Thermosetting polymers make excellent structural adhesives because they undergo irreversible chemical change, and on reheating, they do not soften and flow again (*Natasa et al. 2011*).

b) **Thermoplastic adhesives:** These are based on poly-vinyl acetate (PVAC). Thermoplastics are long-chain polymers that soften and flow on heating, and then harden again by cooling. They generally have less resistance to heat, moisture, and long-term static loading than do thermosetting polymers. Common wood adhesives that are based on thermoplastic polymers include polyvinyl acetate emulsions, elastomerics, contacts, hot-melts etc. (Vick, 1999).

- **Cement as binder for particleboard:** Although, above two types of adhesives are mainly used in the particleboard industries, but now-a-days cement (Portland) is also used as a binder for particleboard (Kavanagh, 2009).

2.2.4.2.2 OTHER ADDITIVES

Additives are mainly used to improve the certain properties of particleboard such as moisture repellency, fire retardancy etc. Following additives are mainly used –

- **Paraffin wax or wax emulsion:** This additive is generally used in small amount (1% or less) for imparting liquid-water repellence to the board.
- **Fire retardants:** Fire retardants are used to improve the fire resistance capacity of the board. Ammonium borate, phosphate and sulphate, di ammonium phosphate and orthophosphate, zinc chloride and borate, boric acid and borax etc. are used, singly or in combinations, as fire retardants.
- **Preservatives:** Fungicides and/or insecticides may be added to the board for protection against bio-deterioration especially when the board is to be used in the severe exposure conditions.
- **Curing agents:** These are usually called hardeners, accelerators or catalysts added for accelerated curing or polymerization of thermosetting adhesives. Ammonium salts of strong acids, such as chlorides, sulphates etc. are commonly used as hardeners.
- **Buffers:** Buffers are added for increased storage life of adhesive (Salehuddin, 1992).

2.3.5 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.

2.3 WOOD PLASTIC COMPOSITES

2.3.1 DEFINITION

The acronym 'WPC' covers an extremely wide range of composite materials that use plastics ranging from PP to PVC and binders/fillers ranging from wood flour to natural fibers (e.g. flax) (*Rails et al. 2001*). WPCs are true composite materials and have properties of both wood and plastic. WPCs exhibit stiffness and strength properties between those for plastic and wood, but the density is generally higher than the individual components. The properties of WPCs come directly from their structure; they are an intimate mix of wood particles and plastic. The plastic coats the wood particle as a thin layer. The properties of WPCs can be tailored to meet the product requirements by varying the species and geometry of wood or plastic. For example, PE based products are cheaper and have a higher heat distortion temperature than the PVC based products but the PVC products are easier to paint and post treat (Anon, 2003). Pigments, UV stabilizers and fire retardants can all be added to the WPC raw material before extrusion to improve specific properties. WPCs have good stiffness and impact resistance properties, dimensional stability, and resistance to rot, excellent thermal properties and low moisture absorption (Maldas and Kokta, 1993).

2.3.2 APPLICATIONS OF THE WPC PRODUCTS

Advantages, desired properties, environmental regulations, and awareness have led to the substitution of using conventional woods with the WPC. Its production is growing over time due to its several applications (*Adhikary et al. 2008*). Main motives include-

- It can be moulded in any particular mold with a variety of shapes and angles, so it can give any desired design (*Takatani et al. 2007*).
- It can be treated in the same manner as the conventional wood using the same cutting and sawing equipment (*Winandy et al. 2004*).

Therefore, it is easy to use any conventional wood workshop with WPC products which have proven to give the same functionality as conventional wood in many areas (Wechsler and Hiziroglu, 2007). Various WPC products are available in the US market substituting some of the conventional wood products such as outdoor deck floors (*Winandy et al. 2004*). It is also used for railings, fences, landscaping timbers, siding, park benches, molding and trim, window and door frames, panels and indoor furniture (*Winandy et al. 2004*). In addition, Wood plastic composites can also substitute neat plastics in applications where the need for an increase in stiffness is an addition; where the wood fiber elasticity is almost 40 times higher than that of polyethylene and the overall strength is approximately 20 times greater (Bengtsson and Oksman, 2006). It has also higher thermal and creep performance compared to plastics and thus could be used in many structural building applications (Wechsler and Hiziroglu, 2007).

2.3.3 MATERIAL UTILIZED IN WPC PRODUCTS

Wood and plastics (virgin or recycled) with various types, grades, sizes, and conditions are the main materials utilized in WPC production. WPC is composed mainly from a plastic matrix reinforced with wood and other additives sometimes are added using the appropriate processing procedures. Mentioned that WPC is a composite composed from a natural fiber/filler (such as kenaf fiber, wood flour, hemp, sisal etc.) which is mixed with a thermoplastic (*Najafi et al. 2007*). They added that virgin thermoplastic materials (e.g. high and low density polyethylene (LDPE and HDPE), polypropylene (PP), polyvinyl chloride (PVC)) are commonly utilized. In addition, any recycled plastic which can melt and be processed in a temperature less than the degradation temperature of the wood filler (200℃) could be used to produce WPC (*Najafi et al. 2007*). Huge majority of WPC utilizes polyethylene and they classified the types of plastic used in WPC as follow: polyethylene (83%), polyvinyl chloride (9%), polypropylene (7%), others (1%), (Morton and Rossi, 2003).

In this study I have used polypropylene as binder and Jial Bhadi, Jiga (*Lannea coromandelica*) as wood chips.

2.2.4 ADVANTAGE OF WPC OVER OTHER MATERIALS

The fact that WPC ingredients are mainly composed from wood and plastic has led to the rapid worldwide growth of its production due to the high availability of non-utilized plastic and wood wastes. Dividing the subject into two main sub-subjects, the plastic waste has the highest contribution regarding its huge available quantities which gives a strong advantage to WPC. The market potential regarding the usage of plastic waste into other utilizations is huge due to the high amounts of its disposition which constitutes the largest share of the global municipal and industrial solid waste. Plastic waste constitutes more than 60% of the total municipal and industrial solid waste (MSW), 22% was recovered and 78% disposed (*Kikuchi et al. 2008*). In India, Plastic in municipal solid waste makes up to 9–12% by weight of the total in addition to other wastes which may contain much higher proportions of plastics (*Panda et al. 2010*).

WPCs aim to increase the efficiency of wood usage by up to 40% compared to traditional wood processing. WPCs also provide other environmental benefits, such as:

- They use residual wood (eg. sawdust) and recycled plastic.
- WPCs contain no formaldehyde or volatile organic compounds.
- WPCs are potentially recyclable since it can be reground and processed.
- WPCs are considered nonhazardous waste and can be disposed of by standard methods. The basic material structure of WPCs shows that leaching from WPCs is minimal to non-existent (Anon, 2003).

2.2.5 MARKET POTENTIAL

The awaiting market for WPC is huge due to the high production of plastics and wood which constitutes a significant amount of solid waste which is mostly disposed not recovered (*Adhikary et al. 2008*). WPC presents a promising raw material source for new value added products due to the large amount of daily waste generation and low cost (*Najafi et al. 2007*). WPC commercial products are increasingly replacing many products in many applications especially the construction related ones (*Yeh et al. 2009*). WPCs have gained an ever larger share; especially for decks and other outdoor structures (*Youngquist et al. 1992*). Other production lines of fencing, roofing, and siding have started to get a noticeable market share (*Winandy et al. 2004*). Approximately one-half of all industrial materials used in the United States are wood-based; thus, the finding that the WPC market is increasing is not a surprise. The growth of WPC decking in the U.S. has started from less than 1 % in mid-90's to over 10% today with growth projected by several studies to reach 20% before the end of 2010 (*Winandy et al. 2004*). It was calculated at $US 2.6 billion in 2002 and was expected to grow approximately 5% per year and therefore a great potential of WPC domination was expected (*Winandy et al. 2004*).

2.2.6 CURRENT STATUS OF WPC PRODUCTION

Although the WPC industry is still only a fraction of a percent of the total wood products industry, it has made significant inroads in certain markets. According to estimates, the WPC market was 320,000 MT in 2001 and the volume is expected to more than double by 2005 (Morton and Rossi, 2003).

2.4 DETAIL ABOUT JIGA (*Lannea coromandelica*)

2.4.1 GENERAL INFORMATION

English Name: Odina

Vernacular Name: Jiga, Jiyal bhadi, Jiyal, Lohar bhadi, Odina, Urisa.

Scientific classification

Kingdom: Plantae

Phylum: Magnoliophyta

Class: Angiospermae

Order: Sapindales

Family: Anacardiaceae

Genus: Lannea

Species: *Lannea coromandelica*

Botanical name: *Lannea coromandelica* (Houtt) Merr. (Anon, 2006)

2.4.2 DESCRIPTION

Jial Bhadi, Jiga (*Lannea coromandelica*) is a large tree with spreading crown. It is a medium-sized deciduous tree. Bark light grey, exfoliating in thin irregular plates in older trees. Leaves alternate, pinnate, with 5-11 shortly stalked ovate or lanceolate leaflets 6-15 cm by 2.5-8 cm. Flowers pale yellow, 4-5 mm in diameter, in long slender inflorescences crowded towards the ends of the leafless branches. Fruit is oblong, fleshy, and red when ripe (Anon, 1970).

2.4.3 DISTRIBUTION

Jial Bhadi, Jiga (*Lannea coromandelica*) occurs mostly in tropical moist and dry deciduous forests where annual rainfall is below 150 cm and at comparatively low elevations. This plant is commonly cultivated on road sides, borderline of houses and grounds and also man-made forests. These forests are characterized by seasonal leaf shedding and profuse flowering of the trees. Leafless branches during flowering season in the month of March. Mainly distributed in Himalaya (Swat to Bhutan), Assam, Burma, China, Malaysia, Bangladesh (Das, 1990).

2.4.4 PLANT MORPHOLOGY

Jial Bhadi, Jiga (*Lannea coromandelica*) is a deciduous tree with rather thick, smooth, grey or whitish bark, which flakes off in small pieces, and with a straggling habit of growth. In Bangladesh the tree is usually only of small dimensions, but it is said to grow to a large size in more suitable climate (Anon, 2006).

2.4.5 LEAVES & LEAFLETS

The leaves fall during the cold weather, and the tree remains bare and ugly, until in March or April the small yellowish-green flowers, tinged with pink, appear in numerous spikes or sprays, which radiates from the tips of the rather thick soft twigs. The leaves are clustered at the end of the branches; each leaf is divided into several narrow leaflets with smooth edges and long tapering points, the leaflets being arranged in opposite pairs on either side of mid rib with a terminal leaflet at the tip (Anon, 2006).

2.4.6 FLOWERS

The flowers are unisexual; the two sexes being often borne on different trees, and if on the same tree, usually on separate branches. Most of the female flowers grow on short unbranched stalks, and most of the male flowers on longer, branching stalks. The handsome foliage appears after the flowers, and often not till May or June, when the last of the flowers have fallen. Like the leaves, the flowers are clustered at the end of the branches; each leaf is divided into several narrow leaflets with smooth edges and long tapering points, the leaflets being arranged in opposite pairs on either side of midrib with a terminal leaflet at the tip. Racemes are terminal, pendulous, to 25 cm. Flowers are polygamous. Calyxes are lobes in 4, imbricate. Petals in 4, lanceolate, imbricate, reflexed (Das, 1990).

2.4.7 FRUITS

The small, rather flat berries are usually borne in large numbers from the female trees, or female branches; and persist for a long time; they are red or brownish white ripe, and each contains a hard stone (Anon, 2006).

2.4.8 NURSERY TECHNIQUE

The plantations can be raised by direct sowing of seed, polypot seedlings and stump plantings. Fresh seeds are sown in bags in June, covered by a layer of hay. Shade is necessary. Germination is seen after 10 to 12 days. One year old seedlings are planted. Stump planting (stumps of 25 cm long) can also be done (Anon, 1970).

2.4.9 TRADITIONAL USE OF INVESTIGATED SPECIES

This plant is used as fuel wood, charcoal and timber. The soft branches of this tree contain large quantity of starch, and it is, therefore easy to propagate the tree by making cuttings and simply planting them in damp soil. For this reason it is common in and about villages, and is often used to make hedges and to mark boundaries (Das, 1990)

A gum which exudes from the bark is used in calico-printing, as a size for handmade papers, and as an addition to lime for white-washing. The bark yields a dye which is employed to colour silk a brown or golden colour, and is also used in tanning. The leaves make good fodder for cattle, elephants and in some places the tree is pollarded for this purpose (Das 1990).

The bark is astringent and used to cure ulcers, sprains, bruises, skin diseases, and dysentery. The gum, beaten up with cocoanut-milk, is applied to bruises and sprains. The Juice of the green brunches mixed with tamarinds, is given as an emetic in case of narcotic poisoning. A decoction of the bark is considered a cure for toothache, and powdered bark is used as toothpowder. The leaves are applied to elephantiasis of the leg and after being boiled are regarded as a remedy for all kinds of pains and swellings (Anon, 1979).

CHAPTER 3

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 4MPa 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 Jial Bhadi, Jiga (*Lannea coromandelica*) was collected from Islampur in front of Khan Jahan Ali Hall, Khulna University under Khulna District as raw material for the manufacturing of Wood Plastic Composite board. Age of the tree is 7 years; height is 10 m. 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 wood particle ranges < 1mm is used. The PP granules are then processed by grinder to pass through a mesh screen.

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 180°c and pressure is 4 MPa. According to *Nadir A. et al., 2011*, temperature has little effect on mechanical properties of WPC board. Different study shows that 4 MPa pressures are better for producing good quality WPC board. On the other hand, melting temperature of polypropylene is ranges 130-160°C. So that fixing temperature at 180°C is very reasonable for this study.

Beside this, wood-plastic ratio is the independent variables. Wood and plastic are quite difference in their nature, i.e. wood is hydrophilic and plastic is hydrophobic. A lot of study proved that wood-plastic ratio combination has a great effect on WPC board (*Nadir A. et al., 2011*). In such case with considering fixed variable temperature 180℃, Pressure 4 MPa and pressing time 25 min for each type of board was provided. Within this fixed variables three different ratio A (60:40), B (65:35) and C (70:30) was taken for manufacturing Wood Plastic Composite (WPC) from Jial Bhadi, Jiga (*Lannea coromandelica*).

3.2.3 MANUFACTURING PLACE

The WPC board 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 MATERIALS

The bark of the Jial Bhadi, Jiga (*Lannea coromandelica*) was removed by saw. Then the stem and branch 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 stem 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 stem chipping was done with chipper machine. The small pieces of stem and branch 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 SCREENING OF PARTICLES

Then all types of particle were screened manually by sieve no. 16. The fines under the sieve were rejected and the retaining particles on the sieve were collected separately. Oversized particles are again fed into the chippers (Youngquist, 1999).

3.2.4.4 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).

3.2.4.5 MIXING OF BINDER

The addition of adhesive the plastic material that means Polypropylene (PP) was 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 (60:40), B (65:35) and C (70:30) ratio of Wood particle (WP) and Polypropylene (PP) mixed Wood Plastic Composite (WPC) board was manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*). In case of WPC board 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. Some research about the effect of different ratio between wood particle and plastic on wood-plastic composites have also been done (Harper and Wolcott, 2004; Herrera and Valadez, 2004; *Lu et al. 2000*)

3.2.4.6 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. And the average mat thickness was about 5 times of the targeted board thickness (8 mm) for each type because PP has melting property. 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).

3.2.4.7 HOT PRESSING

After mat formation, a steel sheet was placed onto 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 4 MPa. There the total press time was 25 minutes, temperature was 180℃. After pressing the average thickness of the boards was 18.68 mm.

After pre-pressing, the mats are hot-pressed into panels. Hot-press temperatures for thermoplastic materials (e.g. high and low density polyethylene (LDPE and HDPE), polypropylene (PP), polyvinyl chloride (PVC)) 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).

3.2.4.8 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 WPC board from Jiga (*Lannea coromandelica*)

Dimensions (mm)	300 x 200
Thickness (mm)	9 (Average)
Layer	Single
Board Types	3
Replications	3 (for each type)
Total board manufactured	9
Binder	Polypropylene

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) as well as the Indian standard for particleboards (IS: 3087-1985) (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, Thickness Swelling and Linear Expansion 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 (50 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 by using following formula-

3.2.7.1 DENSITY

Density of each sample was measured in the Wood Technology Laboratory of FWT Discipline of Khulna University, Khulna. Density was calculated with the following formula-

$$\rho = \frac{m}{v}$$ (Desch and Dinwoodie, 1996)

Where, ρ = Density in gm/cm^3; m = Mass of the sample in gm and v = Volume in cm^3.

3.2.7.2 MOISTURE CONTENT

The moisture content was determined, from the differences in weights before and after the sample has been drying in the oven. Initial and final weight of the samples was measured by electric balance. It was calculated by the following formula-

$$MC\ (\%) = \frac{m_{int} - m_{od}}{m_{od}} \times 100 \qquad \text{(Desch and Dinwoodie, 1996)}$$

Where, MC = Moisture content (%), m_{int} = Initial mass of the sample (gm), m_{0d} = Oven-dry mass of the sample (gm).

3.2.7.3 WATER ABSORPTION

Water absorption is defined as the difference in weight before and after immersion in water and expressed in percentage. The water absorption was calculated by the following formula-

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

Where, A_w = Water absorption (%), m_2 = The weight of the sample after (24 hr.) immersion in water (gm), m_1 = The weight of the sample before immersion in water (gm).

3.2.7.4 THICKNESS SWELLING

Thickness swelling was calculated by the following formula-

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

Where,

G_t = Thickness swelling (%), t_2 = Thickness of sample after immersion (24 hr.) in water (mm), t_1 = Thickness of sample before immersion in water (mm).

3.2.7.5 LINEAR EXPANSION

The Linear Expansion was calculated by the following formula-

$$LX(\%) = \frac{L_A - L_B}{L_B} \times 100 \qquad \text{(ASTM, 1997)}$$

Where, L_A = Length of sample after immersion (24 hr.) in water (mm), L_B = Length of sample before immersion in water (mm).

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.

3.2.8.1 MODULUS OF RUPTURE (MOR)

Modulus of rupture (MOR) was measured with the Universal Testing Machine (UTM), model: WE-100, made by Time Group Inc. in the Laboratory of Civil Engineering Department of Khulna University of Engineering & Technology, Khulna.

The MOR was calculated from the following equation-

$$MOR = \frac{3PL}{2bd^2}$$ (Desch and Dinwoodie, 1996)

Where, *MOR* is the modulus of rupture in (N/mm^2), *P*= Load in N, *L*= Span length in (mm), *b*= width of test sample in (mm), *d*= Thickness of test sample in (mm).

3.2.8.2 MODULUS OF ELASTICITY (MOE)

The Modulus of elasticity (MOE) was also measured with the Universal Testing Machine (UTM) in the Laboratory of Civil Engineering Department of Khulna University of Engineering & Technology, Khulna. The modulus of elasticity (MOE) was calculated from the following equation-

$$MOE = \frac{P'L^3}{4\Delta bd^3}$$ (Desch and Dinwoodie, 1996)

Where, *MOE* is the modulus of elasticity in (N/mm^2), P' is the load in N at the limit of proportionality, *L* is the span length in (mm), Δ is the deflection in mm at the limit of proportionality, *b* is the width of sample in (mm), *d* is the thickness/depth of sample in (mm).

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 4

RESULTS AND DISCUSSION

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 WP, PP, A (60:40), B (65:35) and C (70:30) which are stands for wood particle, Polypropylene, 60% wood particle with 40% Polypropylene, 65% wood particle with 35% Polypropylene and 70% wood particle with 30% Polypropylene 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 (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 1029.2 kg/m3, 929.05 kg/m3 and 840.70 kg/m3 respectively (Fig-4.1). The variation in density among the different types of WPC boards may be due to the variation in ratio of the different raw materials itself. From the following (Fig-4.1), we have seen that wood plastic ratio has impact on density. Density is gradually increased with the increases plastic content in wood-plastic ratio.

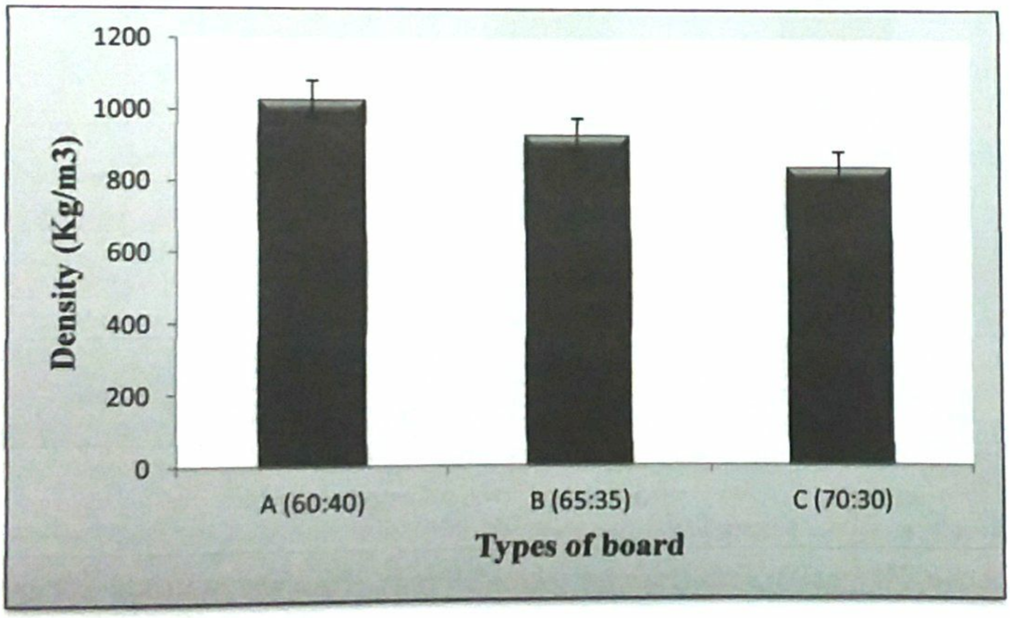

Fig. 4.1 Density of WPC board with different ratio of WP and PP

So we can say the same amount but different ratio of wood particle and polypropylene may causes of different density in WPC board. The higher ratio of polypropylene represents higher in density then the lower content of polypropylene.

From the analysis of variance (Table A-3.1), it has been observed that there was significant difference ($P < 0.01$) in density among the different types of WPC boards.

According to ANSI A208.1–1993 (NPA, 1993), all types of boards manufactured are fall into the low density (LD) grade (< 640 kg/m^3) and according to Indian Standard IS: 3087-1985 (Anon, 1985), the density of standard particleboard is 500 - 900 kg/m^3. But according to Australian and Newzeland Standard AS/NZS 1859.1: 2001.Int (The Laminex Group, 2003) and German Standard DIN 68 761 (Verkor and Leduge, 1975), the density of standard particleboard is 640 kg/m^3 and 600 – 750 kg/m^3, respectively. The density of the three types of board follows the both type of standard.

4.1.1.2 MOISTURE CONTENT

Espert et al. (*2003*) stated that wood consists mostly of vessels in which moisture is absorbed. But plastic that has hydrophobic nature and tends to impede the entry of water into plastic board. Following (Fig. 4.2) demonstrated that with the increasing of wood-plastic ratio percentage, the MC content straightly decreases.

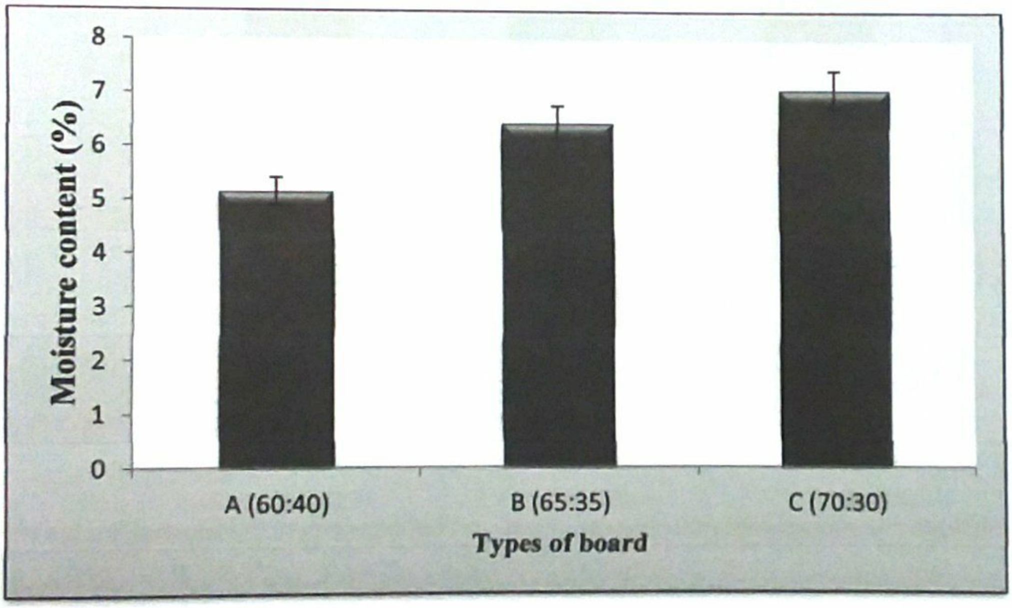

Fig. 4.2 Moisture content% of WPC board with different ratio of WP and PP

The moisture content of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 5.15%, 6.46% and 7.09% respectively (Fig. 4.2). The variation in moisture content in different types of boards may be due to the variation in ratio among different raw materials itself. The moisture content ratio of wood particle and polypropylene C (70:30) was higher (7.09%) than that of other types of particles.

From the analysis of variance (Table A-3.3), it has been observed that there was significant difference ($P < 0.01$) in moisture content among the different types of WPC boards. The maximum moisture content in the standard particleboard was not found as per ANSI A208.1–1993 (NPA, 1993) and IS: 3087-1985 (Anon, 1985) as well as British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975). But according to Australian and Newzeland Standard (AS/NZS 1859.1: 2001.Int), the moisture content of standard particleboard is 5-8% (for 18 mm thick board) (The Laminex Group, 2003). So the moisture content% of the three types of board below the level of standard of the both type of standard.

4.1.1.3 WATER ABSORPTION

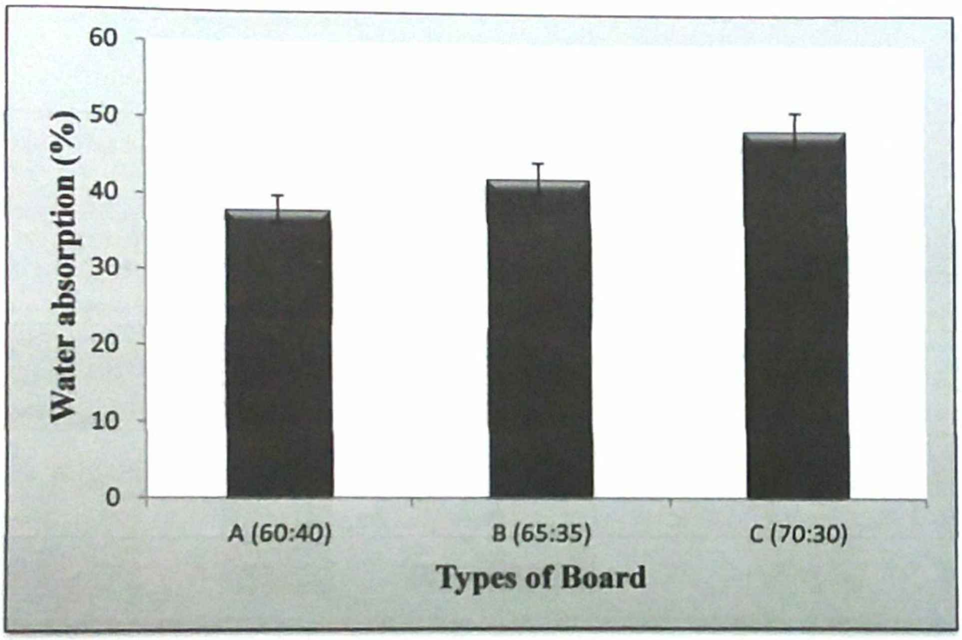

Fig. 4.3 Water absorption% (after 24 hr.) of WPC board with different ratio of WP and PP

It was found that the absorption of water of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 30.91%, 35.29% and 40.47% respectively after 24 hours immersion in water. Figure (4.3) show that the lower ratio of plastic has the higher percentage of water absorption then the other ratios. The causes behind this may be the hydrophilic nature of wood and hydrophobic nature of plastic. Also density is gradually increased with the increases plastic content in wood-plastic ratio. So decreases of plastic content may be the result of higher water absorption.

From the analysis of variance (Table A-3.5), it has been observed that there was significant difference ($P < 0.01$) in water absorption percentages among the different types of WPC boards. According to IS: 3087-1985 (Anon, 1985), the absorption of water by standard particleboard is 50% after 24 hours. The water absorption percentage by standard particleboard was not found as per ANSI A208.1–1993 (NPA, 1993) as well as Australian and Newzeland Standard (AS/NZS 1859.1: 2001.Int) (The Laminex Group, 2003), British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975).

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.

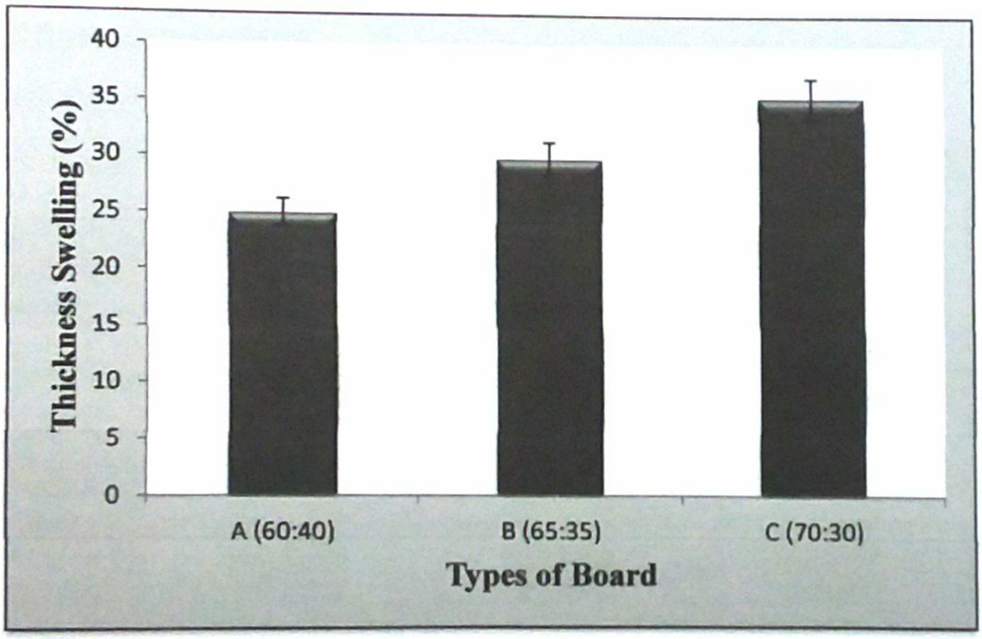

Fig. 4.4 Thickness swelling% (after 24 hr.) of WPC board with different ratio of WP and PP

The thickness swelling of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) was found to 24.94%, 29.84% and 35.43% 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 plastic contents in different boards. Figure 4.4 show that ratio C (70:30) has the higher thickness swelling than others.

Treatment of plant fibers with hydrophobic chemicals (i.e. Polypropylene) can reduce the moisture gain (Gassan and Bledzki, 2000; *Espert et al. 2003*). Similar result is found in this study, i.e. swelling properties decreases with the increasing of plastic content. From the analysis of variance (Table A-3.7), it has been observed that there was significant difference ($P < 0.01$) in thickness swelling percentages among the different types of particleboards. From the LSD (Least Significant Difference) analysis (Table A-3.8), 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) and IS: 3087-1985 (Anon, 1985) as well as British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975). But according to Australian and Newzeland Standard (AS/NZS 1859.1: 2001.Int), the thickness swelling of standard particleboard is 15 % after 24 hours immersion in water (for 18 mm thick board) (The Laminex Group, 2003).

4.1.1.5 LINEAR EXPANSION

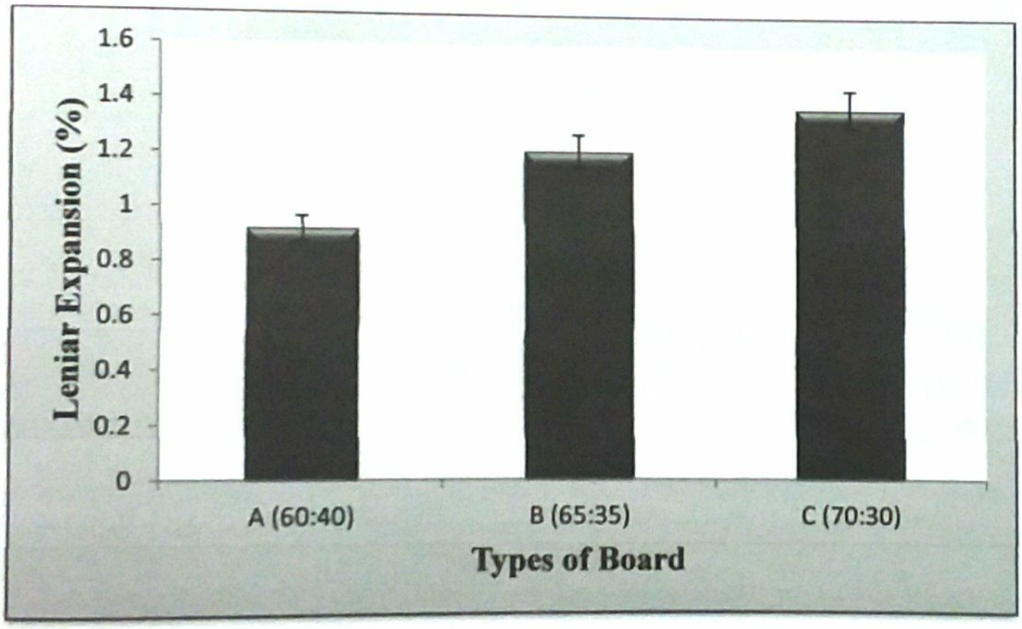

Fig. 4.5 Linear expansion % (after 24 hr.) of WPC board with different ratio of WP and PP

The linear expansion of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) was found to 0.92%, 1.21% and 1.38% respectively after 24 hours immersion in water and shown (Fig. 4.5). The higher slenderness ratio and the density of particles may impart the lower linear expansion than other types of boards. In case of above three boards the slenderness ratio is same but increasing ratio of plastic content increase density and high density board exhibits lower linear expansion. From the analysis of variance (Table A-3.9), it has been observed that there was significant difference ($P < 0.01$) in linear expansion percentages among the different types of WPC boards. 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. The linear expansion percentage after 24 hours immersion in water by standard particleboard was not found as per IS: 3087-1985 (Anon, 1985), Australian and Newzeland Standard AS/NZS 1859.1: 2001.Int (The Laminex Group, 2003), British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975).

4.1.2 MECHANICAL PROPERTIES

4.1.2.1 MODULUS OF RUPTURE (MOR)

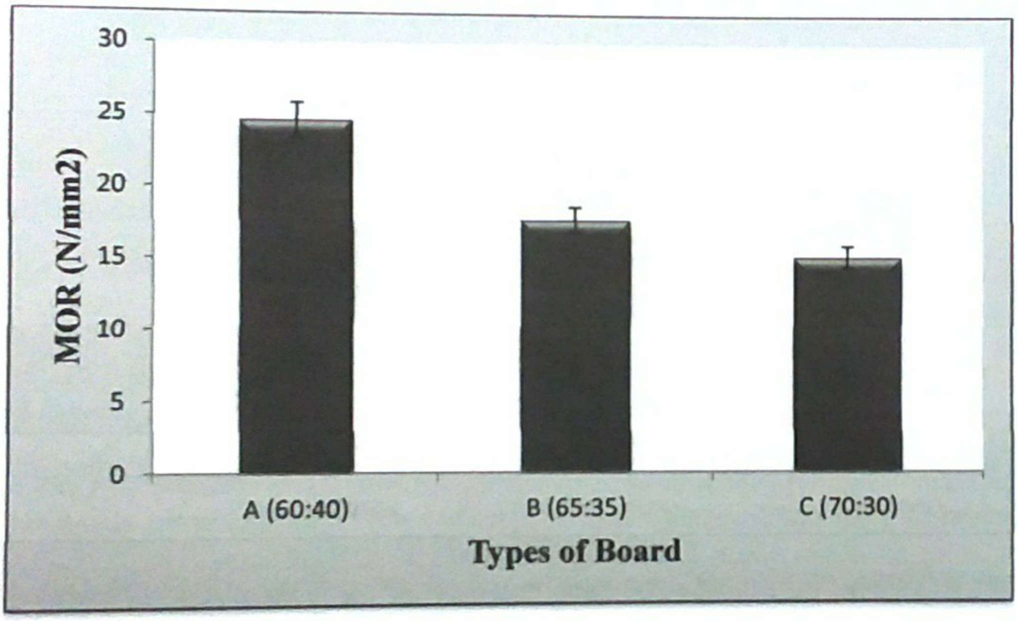

Fig. 4.6 Modulus of rupture (MOR) of WPC board with different ratio of WP and PP

The modulus of rupture (MOR) of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) was found to 24.59 N/mm², 17.69 N/mm² and 15.13 N/mm² respectively (Fig. 4.6). The MOR of ratios A (60:40) was found to higher than other types of boards which may due to the higher density for containing higher amount of polypropylene than other types of WPC boards. It has been remarked from the Fig. (4.6) that the MOR of wood plastic board arrived at the highest value 24.59 N/mm^2 high ratio of plastic contented and lower ratio of wood particle. On the other hand, as the ratio increases MOR of the boards are also increases. The highest strength of WPCs were measured when the lowest wood content is used and the strength decreased most severely when wood content increases (*Shao-Yuan et al. 2011*).

From the analysis of variance (Table A-3.11), it has been observed that there was significant difference ($P < 0.01$) in MOR among the different types of particleboards. According to ANSI A208.1–1993 (NPA, 1993), the MOR of standard particleboard is 16.5- 23.5 N/mm² for high density grade, 11.0- 16.5 N/mm² for medium density grade and 3.0- 5.0 N/mm² for low density grade. According to IS: 3087-1985 (Anon, 1985), the MOR of standard particleboard is 10.98 N/mm². But according to Australian and Newzeland Standard AS/NZS 1859.1: 2001.Int (The Laminex Group, 2003), British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975), the MOR of standard particleboard is 16 N/mm² (for 18 mm thick board), 13.80 N/mm² and 17.65 N/mm², respectively.

4.1.2.2 MODULUS OF ELASTICITY (MOE)

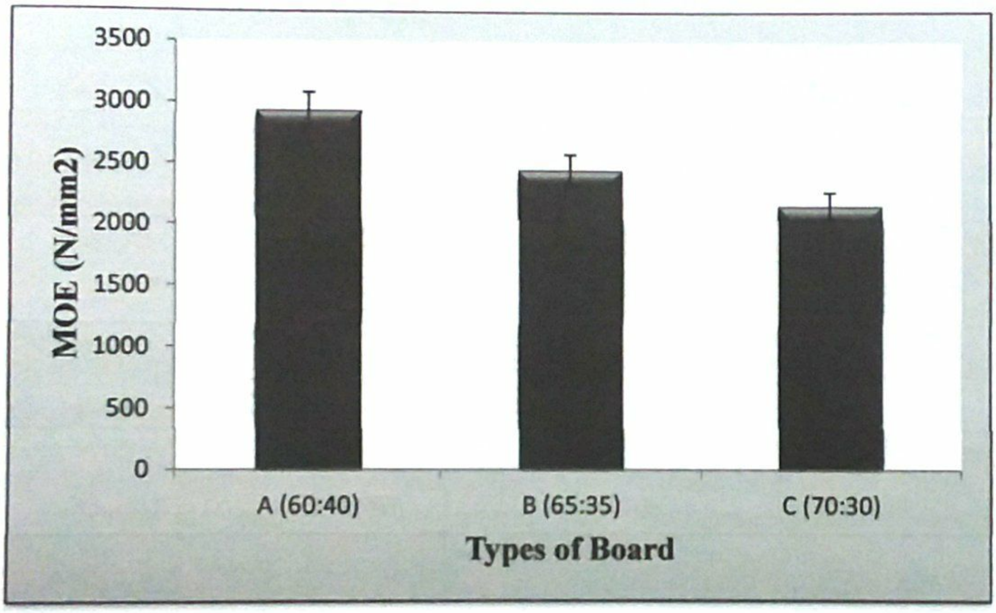

Fig. 4.7 Modulus of elasticity (MOE) WPC board with different ratio of WP and PP

The modulus of elasticity (MOE) of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) was found to 2937.13 N/mm², 2452.26 N/mm² and 2165.86 N/mm², respectively (Fig. 4.7). The variation that was found in MOE among the different types of particleboards may be due to the same reasons for variation in MOR among the different types of particleboards. From the analysis of variance (Table A-3.13), it has been observed that there was significant difference ($P < 0.01$) in MOE among the different types of particleboards.

According to ANSI A208.1–1993 (NPA, 1993), the MOE of standard particleboard is 2,400-2,750 N/mm² for high density grade, 1,725- 2,750 N/mm² for medium density grade and 550-1,025 N/mm² for low density grade. But according to Australian and Newzeland Standard (AS/NZS 1859.1: 2001.Int), the MOE of standard particleboard is 2500 N/mm² (for 18 mm thick board) (The Laminex Group, 2003).

Table 4.1: Result summary for Physical and Mechanical Properties

Board/ Standard Types	Physical Properties					Mechanical Properties	
	Density (kg/m^3)	MC (%)	WA (%) (24 hr.)	TS (%) (24 hr.)	LX (%) (24 hr.)	MOR (N/mm²)	MOE (N/mm²)
A(60:40)	1029.02	5.1521	30.491	24.944	0.9196	24.585	2937.1
B(65:35)	929.05	6.4545	35.287	29.844	1.2110	17.690	2452.3
C(70:30)	840.70	7.0930	40.473	35.434	1.3752	15.127	2164.9
ANSI A208.1–1993	a	-	-	-	0.35^b	3.0 - 23.5	550 - 2,750
IS: 3087-1985	500-900	-	50	-	-	10.98	-
AS/NZS 1859.1: 2001.Int	640	5-8	-	15	-	16	2500
BS: 5669	-	-	-	-	-	13.80	-
GS DIN 68 761	600-750	-	-	-	-	17.65	-

[a]High density = > 800 kg/m^3, Medium density = 640 to 800 kg/m^3 and Low density = < 640 kg/m^3, [b]Immersion time not specified.

4.2 DISCUSSION

It can be seen from the above that the density of three different ratio A (60:40), B (65:35) and C (70:30) are 1029.02 kg/m^3, 929.05 kg/m^3 and 840.70 respectively which satisfied the ANSI 1993 standard as a high density grade particleboard (> 800 kg/m^3) and the IS standard as a standard particleboard. But among them A (60:40) ratio board represents maximum density. The moisture content of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 5.15%, 6.46% and 7.09% respectively which were between the range of Australian and Newzeland Standard (5-8%). The water absorption of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 30.91%, 35.29% and 40.47% respectively after 24 hours immersion in water which satisfy the IS standard maximum level 50%. The thickness swelling of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) was found to 24.94%, 29.84% and 35.43% respectively after 24 hours immersion in water. Among them A (60:40) ratio show 24.94% thickness swelling which is little higher then than the value specified in the Australian and Newzeland Standard up to 15%. The linear expansion of three different ratios was found to 0.92%, 1.21% and 1.38% respectively after 24 hours immersion in water. The linear expansion was 0.92 % after 24 hours for ratio A (60:40) which is near to the ANSI standard (time is not specified).

The modulus of rupture (MOR) of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board are 24.59 N/mm², 17.69 N/mm² and 15.13 N/mm² respectively which satisfy the ANSI A208.1–1993 standard (3.0 - 23.5) N/mm². But A (60:40) ratio not satisfy IS: 3087-1985, AS/NZS 1859.1: 2001.Int, BS: 5669, GS DIN 68 761 standards. The modulus of elasticity (MOE) of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board was found to 2937.13 N/mm², 2452.26 N/mm² and 2165.86 N/mm² respectively which satisfy the ANSI standard for any type of density grade as well as the Australian and Newzeland Standard with little variation.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The increasing demand of wood and wood products creates immense pressure on the limited forest resources of Bangladesh. Therefore, it is now especially important to utilize forest resources in more effective and economic ways. WPC board manufacturing industries are established to reduce the pressure on the solid wood. In this work, particles and fibres from Jial Bhadi, Jiga (*Lannea coromandelica*) along with polypropylene as additives used to make experimental WPC panels. The important advantages of Jial Bhadi, Jiga (*Lannea coromandelica*) tree are that it is a very fast growing tree and harvesting can be recommended at the age of 5 to 8 years for WPC board manufacturing. It requires very poor or no management techniques or procedure. The planting method of Jial Bhadi, Jiga (*Lannea coromandelica*) tree is very simple and can be planted by direct branch. In the light of the preliminary results of this study both physical and mechanical properties of the samples were provided satisfactory results with the standard. If Jial Bhadi, Jiga (*Lannea coromandelica*) is used commercially for manufacturing WPC board, it will be an appropriate alternate source of raw material for WPC board industries. In this situation, the government and WPC board industry owners may take initiatives for utilizing Jial Bhadi, Jiga (*Lannea coromandelica*) as an alternate source of raw material for manufacturing of WPC board in future.

5.2 RECOMMENDATIONS

From my study it has been found that the density of three different ratios A (60:40), B (65:35) and C (70:30) of Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) 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, with different additives like tale, wax etc, for setting up an optimization formula for manufacturing Wood Plastic Composite (WPC) board manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*).

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APPENDIX

TABLES OF DATA ANALYSIS

TABLE A-1: ANOVA FOR DENSITY

Source	DF	Sum of Squares	F Value	Pr > F
Treatment	2	106524.159279	29.53	0.0001
Error	14	27057.769222		
Corrected Total	17	133581.928501		

TABLE A-2: LSD FOR DENSITY

Alpha= 0.05
Least Significant Difference= 52.265

Lettering	Mean	Treatment	Board Type
A	1029.02	t1	A(60:40)
B	929.05	t2	B(65:35)
C	840.70	t3	C(70:30)

TABLE A-3: ANOVA FOR MOISTURE CONTENT

Source	DF	Sum of Squares	F Value	Pr > F
Treatment	2	11.74197272	2.76	0.0001
Error	15	31.93467416		
Corrected Total	17	43.67664687		

TABLE A-4: LSD FOR MOISTURE CONTENT

Alpha= 0.05
Least Significant Difference= 1.7956

Lettering	Mean	Treatment	Board Type
A	7.0930	t3	C(70:30)
B	6.4545	t2	B(65:35)
C	5.1521	t1	A(60:40)

TABLE A-5: ANOVA FOR WATER ABSORPTION

Source	DF	Sum of Squares	F Value	Pr > F
Treatment	2	299.06924486	2.62	0.0001
Error	15	857.58226129		
Corrected Total	17	1156.65150615		

TABLE A-6: LSD FOR WATER ABSORPTION

Alpha= 0.05
Least Significant Difference= 9.3048

Lettering	Mean	Treatment	Board Type
A	40.473	t3	C(70:30)
B	35.287	t2	B(65:35)
C	30.491	t1	A(60:40)

TABLE A-7: ANOVA FOR THICKNESS SWELLING

Source	DF	Sum of Squares	F Value	Pr > F
Treatment	2	330.62695066	5.50	0.0001
Error	15	450.62596623		
Corrected Total	17	781.25291690		

TABLE A-8: LSD FOR THICKNESS SWELLING

Alpha= 0.05
Least Significant Difference= 6.7449

Lettering	Mean	Treatment	Board Type
A	35.434	t3	C(70:30)
B	29.844	t2	B(65:35)
C	24.944	t1	A(60:40)

TABLE A-9: ANOVA FOR LINEAR EXPANSION

Source	DF	Sum of Squares	F Value	Pr > F
Treatment	2	0.63882946	13.71	0.0008
Error	15	4.88903434		
Corrected Total	17	5.23805419		

TABLE A-10: LSD FOR LINEAR EXPANSION

Alpha= 0.05
Least Significant Difference= 0.7026

Lettering	Mean	Treatment	Board type
A	1.3752	t1	C(70:30)
B	1.2110	t2	B(65:35)
C	0.9196	t3	A(60:40)

TABLE A-11: ANOVA FOR MOR

Source	DF	Sum of Squares	F Value	Pr > F
Treatment	2	287.12923961	27.11	0.0001
Error	12	150.85221958		
Corrected Total	14	437.98145919		

TABLE A-12: LSD FOR MOR

Alpha= 0.05
Least Significant Difference= 3.9025

Lettering	Mean	Treatment	Board Type
A	24.585	t1	A(60:40)
B	17.690	t2	B(65:35)
C	15.127	t3	C(70:30)

TABLE A-13: ANOVA FOR MOE

Source	DF	Sum of Squares	F Value	Pr > F
Treatment	2	1828175.68426	6.22	0.0001
Error	12	2204195.62763		
Corrected Total	14	4032371.31188		

TABLE A-14: LSD FOR MOE

Alpha= 0.05
Least Significant Difference= 313.22

Lettering	Mean	Treatment	Board Type
A	2937.1	t1	A(60:40)
B	2452.3	t2	B(65:35)
C	2164.9	t3	C(70:30)