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SUITABILITY OF JAIL BHADI, (*Lannea coromandelica*) AS A RAW MATERIAL FOR PARTICLEBOARD MANUFACTURING

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Wood

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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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DECLARATION

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Dedicated
To My
Beloved Parents

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APPROVAL

This project thesis has been submitted to the Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh, in partial fulfillment of the requirements of Four (4) years professional B. Sc. (Hons.) degree in Forestry. I have approved the style and format of the project thesis.

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ABSTRACT

The study investigated the potentiality of using Jial Bhadi, Jiga (*Lannea coromandelica*) as a raw material for the production of particleboard and its basic physical and mechanical properties. Jial Bhadi was chosen because less research work has been done on this species for particleboard manufacturing and it is low quality wood available in Bangladesh. For particle board manufacturing flat process has been used and Commercial Urea formaldehyde (UF) adhesive was used as a binder. Three types of particle sized boards were manufactured and their physical and mechanical properties were determined. The physical and mechanical properties were as: Density (0.75 gm/cm3) Moisture content (5.0%); Water absorption (61.92%); Thickness swelling (32.29%); Linear expansion (0.72%) after 24 hours immersion in water respectively. Modulus of rupture (MOR) and Modulus of elasticity (MOE) is (19.39N/mm2) and (1923.52 N/mm2). Based on the experiment it is also found that the Jial Bhadi, particleboard shows quite satisfactory results in case of physical and mechanical properties in comparison with the different woody and non-woody particleboard. Further study of Jial Bhadi may increase the potential use as alternative sources of raw materials for particleboard manufacturing based on its mechanical and physical properties.

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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 ONE: INTRODUCTION

1.1Background and justification of the study

Wood is one of earth's most valuable and abundant renewable natural resources, which can be used for indefinite period of times (Lahiry, 2001). It is a gift of nature and is the only working material that is self-generating (FAO, 1986). It is a material used by man for thousands of without precise knowledge of its properties (Wangaard, 1981). Wood from times immemorial has been the most useful of all the readily available materials to mankind (Husain, 1962). Wood is one of the lingo cellulosic materials and valuable forest 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. There are about 150 tree species grown in homestead and village groves of Bangladesh (Das, 1990). Only a few of them are being used by ply wood, tea chest and particle board industries. 16 timber are recommended for decorative veneer and ply wood, 17 for ply wood (Anon, 1985), 46 for manufacture of ply for general purpose, 36 for plywood and batten for tea chest, and 5 selective species, viz., Civit (*Swintonia floribunda*), Garjan (*Dipterocarpus spp*), Chapalish (*Artocarpus chaplasha*), Narikeli (*Pterygota alata*), and Pitali (*Trewia nudiflora*) are recommended for particleboard manufacturing plant of BFIDC (Anon, 1981). These timber species make the total of 120 which particularly from only 55 timber species out of 500 hard wood timber species available in the forest of Bangladesh (Anon, 1984). In addition Kadam (*Anthocephalus cinensis*), Chatian (*Alstonia scholaris*), Jute stick, etc. are used in the private particle board industries in Bangladesh. These species are now in short supply because of their extensive extraction. To reduce pressure on these species and to fulfill the demand of the particleboard industries in Bangladesh, it is essential to introduce an alternative species for manufacturing particleboard (Islam *et al*, 2006).

The population of the world is increasing day by day that creates a tremendous pressure on forest and forest products. This extra pressure damages our forest. It's one of the most important solution of treat shortage is to be provision of alternative source of raw materials from agricultural plant production. Thus people have placed a high emphasis on forest preservation and rational use of forestry and agricultural residues. This trend is mainly motivated and accelerated by dilemma of an ever-increasing consumption of wood particle based products relative to dwindling wood resources.

However some agricultural plants produce higher lingo-cellulosic materials that to be suitable substitute for certain particle based industries.

In this study Jial Bhadi, Jiga (*Lannea coromandelica*) is a multifarious usable tree of Anacardiaceae family was used as wood particle in particleboard manufacturing. It is a neglected but a novel source of renewable ligno-cellulosic raw material. These species in available and production is high 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. Therefore the study has carried out to determine the physical and mechanical properties after manufacturing particleboard from Jial Bhadi. 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 know about physical and mechanical properties of particle board made from Jial Bhadi.
- To carryout comparative study of quality of particleboard between Jial Bhadi and present market standard particleboard.
- To assess the suitability of Jial Bhadi, as an alternative source of raw material for manufacturing particleboard.

CHAPTRE TWO: LITERATURE REVIEW

2.1General 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. Hammer-milling involves smashing material into smaller and smaller pieces until they pass out through a screen. Most other early particleboard manufacturers used similar processes, though often with slightly different resins. Today's particleboard manufacturer provides high-quality products that consumers require due to up gradation of manufacturing techniques (Anon, 2007).

2.1.3 Types of Particleboard

There are different types of particleboards depending on –

2.1.3.1 Types of particles used

- Flake board: Flake is a small wood particle of predetermined dimensions, uniform thickness, essentially flat, and having the fiber direction essentially in the plane of the flakes, in overall character resembling a small piece of veneer (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).
- Shavings board: A particleboard in which wood shavings are the chief constituents. (Anon, 1970).
- Wafer board: It is a structural material made from rectangular wood flakes of controlled length and thickness bonded together with waterproof phenolic resin under extreme heat and pressure (Salehuddin, 1992).
- 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 (Salehuddin, 1992).

2.1.3.2 Pressing methods used

- 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).

2.1.3.3 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).

2.1.3.4 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 above 800 kg/m^3 or above 50 lb/ft^3 (Srivastava, 1969).

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

2.1.4.1.2 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).

2.1.4.2 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 fiberboard, 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. Animal glue is probably the natural adhesive most widely used, although casein glue is being used a great deal for structural laminating (Vick, 1999).

Synthetic adhesive or Synthetic resin adhesive: Adhesives of synthetic origin are called synthetic adhesives. These are man-made polymers which resemble natural resins in physical characteristics but which can be tailored to meet specific woodworking requirements. Synthetic adhesives can be categorized into two groups, namely thermosetting adhesives and thermoplastic adhesives (Natasa, 2011).

Thermosetting adhesives: These types of adhesives are usually based on formaldehyde. Thermosetting polymers make excellent structural adhesives because they undergo irreversible chemical change, and on reheating, they do not soften and flow again. They form cross-linked polymers that have high strength, have resistance to moisture and other chemicals, and are rigid enough to support high, long-term static loads without deforming. So this type of adhesive is widely used now-a-days. Phenol formaldehyde, resorcinol formaldehyde, melamine formaldehyde, isocyanate, urea formaldehyde, and epoxy are some examples of wood adhesives that are based on thermosetting polymers (Natasa, 2011).

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).

2.1.5 General Manufacturing Steps of Particleboard

2.1.5.1 Particle preparation

Particle preparation from the raw materials such as round wood log, jute stick, bagasse etc. is the first step of particleboard manufacturing. In the case of round log debarking is done at first. A wide range of hogs, chippers, hammer mills, ring flakers, ring mills, and attrition mills are used, singly or in combination, to convert the different raw materials to the required particles. To obtain particleboards with good strength, smooth surfaces, and equal swelling, it is important to use a homogeneous material with a high degree of slenderness (long, thin particles), no oversize particles, no splinters, and no dust (AWPA, 2001).

2.1.5.2 Particle classification/screening and conveying

Very small particles increase furnishes surface area and thus increase resin requirements. Oversized particles can adversely affect the quality of the final product because of internal flaws in the particles. While some particles are classified through the use of air streams, screen classification methods are the most common. In screen classification, the particles are fed over a vibrating flat screen or a series of screens. The screens may be wire cloth, plates with holes or slots, or plates set on edge. Oversized particles are again fed into the chippers (Youngquist, 1999).

The screened particles are conveyed to the next stage. The two basic methods of conveying particles are by mechanical means and by air. The choice of conveying method depends upon the size of the particles. In air conveying, care should be taken that the material does not pass through many fans, which reduces the size of the particles. In some types of flakes, damp conditions are maintained to reduce break-up of particles during conveying (Anon, 2006).

2.1.5.3 Particle drying

The particle drying operation is a critical step in the processing of composite products. The raw materials for these products do not usually arrive at the plant at a low enough moisture content for immediate use. Furnish that arrives at the plant can range from 10% to 200% moisture content. For use with liquid resins, for example, the particles must be reduced to about 2% to 7% moisture content. The main methods used to dry particles are rotary, disk, and suspension drying (Anon, 2006).

2.1.5.4 Blending

The addition of adhesive and other chemicals such as wax, hardeners etc. to the dry particle furnish is called blending. It is a critical step for both product quality and production efficiency. The resin adhesive and additives are usually added to the particle furnish as aqueous solutions or suspensions. Based on the weight of dry resin solids and oven-dry weight of the particles, the resin content with additives can range between 4% and 10%, but usually ranges between 6% and 9% for UF resins. Sometimes powered resins are also used. With aqueous solutions, basically three systems are used – a) the contact and friction system, i.e., simple mixing, b) the spreader roll system and c) spray nozzle system. But now-a-days the spray nozzle system is widely used at the industry level (Youngquist, 1999).

2.1.5.5 Mat formation and conveying

After the particles have been prepared, they must be laid into an even and consistent mat to be pressed into a panel. This is typically accomplished in a batch mode or by continuous formation. 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).

2.1.5.6 Hot pressing

After pre-pressing, the mats are hot-pressed into panels. Presses can be divided into platen and continuous types. Further development in the industry has made possible the construction of presses for producing increasingly larger panel sizes in both single- and multi-opening presses. Both of these types of presses can be as wide as 3.7 meter. Multi-opening presses can be as long as 10 meter and single-opening presses, up to 30.5 meter long. Hot-press temperatures for UF resins usually range from 140°C to 165°C. Pressure depends on a number of factors, but it is usually in the range of 1.37 to 4.43 MPa for medium-density boards. Press-time may 6-15 seconds per mm of board thickness. 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).

2.1.5.7 Conditioning and finishing

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 resin. This conditioning usually follows cooling in star coolers for boards with urea formaldehyde resins. Phenolic bonded particleboard is usually hot stacked for some days to ensure final cure of the resin (AWPA, 2001).

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).

2.1.6 Variables affecting the properties of Particleboard

Particle geometry and slenderness ratio (s): Particle geometry plays an important role in the board properties. The main aspect of particle geometry is the slenderness ratio (s), i.e., the ratio of length (l) over thickness (t) of particles with square or rectangular 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 seems best. However, surface quality and internal bond strength are higher with small particles, i.e. with lower slenderness ratio (Salehuddin, 1992).

Raw materials and compression ratio: Practically all the physical and mechanical properties of particleboard depend on the board density as well as raw materials density. Particleboard must be compressed during hot pressing from 5 percent to 50 percent. Lower-density raw materials have greater compression ratio, i.e., ratio of natural non-compressed raw materials density to the compressed raw materials density in the manufactured board, leading to greater particle to particle contact and better adhesive bond. So higher modulus of rupture, modulus of elasticity, internal bond and tensile strength properties are achieved (Salehuddin, 1992).

Glue mixing proportion and blending: Glue mixing proportion is an important factor that affects the properties of particleboard. Generally glue mixing proportion for particleboard is different for different types of glue. (Youngquist, 1999).

2.1.7 Advantages of Particleboard

- The most important advantage of particleboard is that it can be made in large dimensions.
- Particleboard can be made from wastes lingo-cellulosic materials, small pieces of wood and inferior species thus ensuring complete utilization of raw materials.
- Particleboard can be made into a wide range of variety for the specific end-use such as fire resistant particleboard, moisture resistant particleboard etc. by incorporating various additives in the manufacturing process.
- Particleboard is less costly than wood and plywood.
- Easy to work with – cuts, drills and routs cleanly without splintering or chipping.
- Free of knots and grain – making finishing easier and less time-consuming.

2.2 DETAIL ABOUT JIGA (*Lannea coromandelica)*

2.2.1 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)

2.2.2 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).

2.2.3 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).

2.2.4 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).

2.2.5 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).

2.2.6 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).

2.2.7 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).

2.2.8 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).

2.2.9 PROPAGATION

Seed - it only has a short viability and so needs to be sown as soon as possible

Cuttings - very easy, even large branches usually root

2.2.10 CULTIVATION DETAIL

Succeeds in tropical and subtropical zones at elevations up to 1,800meters. Grows best in areas where the mean annual temperature falls within the range 32 - 40°c, but can tolerate 8 - 47°c. Plants are killed at temperatures below -2.5°c.Prefers a mean annual rainfall of 1,200 - 2,000mm, tolerating 600 - 3,800mm.Grows best in a sunny position. Succeeds in most soils of moderate fertility, tolerating poor soils. Prefers a pH in the range 5 - 6.5, but tolerates 4.5 – 8.In its more common, dry woodland environment, the tree is usually small and somewhat ungainly - in moister conditions, however, it can become a handsome, spreading tree. The valuable heartwood is generally only formed in sufficient quantity from trees grown in moister conditions. The tree is resistant to fire. A dioecious species, both male and female forms need to be grown if seed is required.

2.2.11 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).

Edible Uses

- ✓ Young leaves and sprouts - raw or cooked
- ✓ Eaten as a vegetable
- ✓ Eaten as a lalab (a vegetable salad served with sambal) with rice
- ✓ The gum obtained from the trunk is often used in confectionery
- ✓ The powdered bark is used as a flavouring

Medicinal uses

The bark and the leaves are used as medicine

Agroforestry Uses:

The plant can be grown as a hedge. It is easily propagated by cuttings and so can be grown as a living fence.

Other Uses

- ✓ The bark contains tannins.
- ✓ It is used for the impregnation of fishnets.
- ✓ A soluble resin, called 'Jingan gum' is obtained from the stems.
- ✓ It is used for calico printing; as a size for paper; for mixing with lime when whitewashing; protecting nets etc.
- ✓ It is obtained by making shallow, short cuts all over the bark.
- ✓ Especially after injuries of the bark and trimmings, masses of glassy-white exudate of hardening gum appear - which may give leafless trees an eerie appearance.
- ✓ A good quality gum. The gum is of inferior quality
- ✓ The bark yields a coarse cordage fibre.
- ✓ The heartwood is light red when freshly cut, turning reddish-brown on exposure.
- ✓ The wood is moderately hard, close-grained.
- ✓ It is used for spear shafts, scabbards, wheel-spokes, oil presses, grain pounders etc.

CHAPTER THREE: MATERIALS AND METHODS

3. 1 Manufacturing of particleboards

3.1.1 Methods and procedures

3.1.1.1 Collection of raw materials

Jial Bhadi, Jiga (*Lannea coromandelica*) was used as the raw material for manufacturing the particleboards and collected from Khulna university campus beside of Second Academic Building, Khulna University. Age of the tree is 10-13 years; height is 7-9 m. The Urea-Formaldehyde was collected from wood industry, which is available as raw material.

3.1.1.2 Preparation of raw materials:

At first Jial Bhadi stalks were debarked and then cut into small pieces to 5-7 inch. Then the small pieces were air dried for 28-30 days. After air drying the small pieces were chipped to 1.5-2.0 inch. The chips were dried in an electric oven at 103°C for 24 hours. Then the chips were run into grinder to produce small particles.

3.1.1.3 Screening:

For the purpose particles were screened through a mesh screen to separate the fine and coarse particles. At first the particles was screened by sieve no.16 and then again screened by sieve no 8.The particle which passed through sieve no 8 where taken was fine particles.

3.1.1.4 Particle Drying:

The particles were dried in an oven (Model No: DHG-9101-ISA and S.N.-5054) at 103°C for 24 hours to dry them. At this stage the particle moisture content was 3-4 %.

3.1.1.5 Adhesive preparation and mixing with particles:

Urea formaldehyde (UF) is one of the most common adhesives for particleboard manufacturing in Bangladesh. Urea formaldehyde (UF) resin is the main ingredient of the adhesive. 10% Urea-formaldehyde adhesive were mixed with the particles.

3.1.1.6 Mat Formation:

The glued particles were then kept on a steel sheet for mat formation. The mat was formed four times higher than the particleboard thickness.

So the mat was 30-32 mm as the target board thickness was 8mm.

3.1.1.7 Hot pressing:

The mat was covered with another steel sheet and then inserted manually into the hot press. The temperature was created and the pressure was raised by hydraulic jack. The temperature was raised to a maximum of 160^{0}C. The pressure was raised to 4Mpa and continued to 10 minutes. Then the board was kept 15 minutes for curing the resin at the same pressure, so that the board may balance with environmental condition. At first the temperature was created 150°C and the pressure was raised to 4Mpa but the board quality was no satisfactory. Then I increased the temperature and fixed the pressure and at last I get the standard quality of the board. The temperature was raised to a maximum of 160°C and the pressure was raised to 4Mpa continued to 10 minutes. Then the board was kept 15 minutes for curing the resin at the same pressure.

3.1.1.8 Trimming:

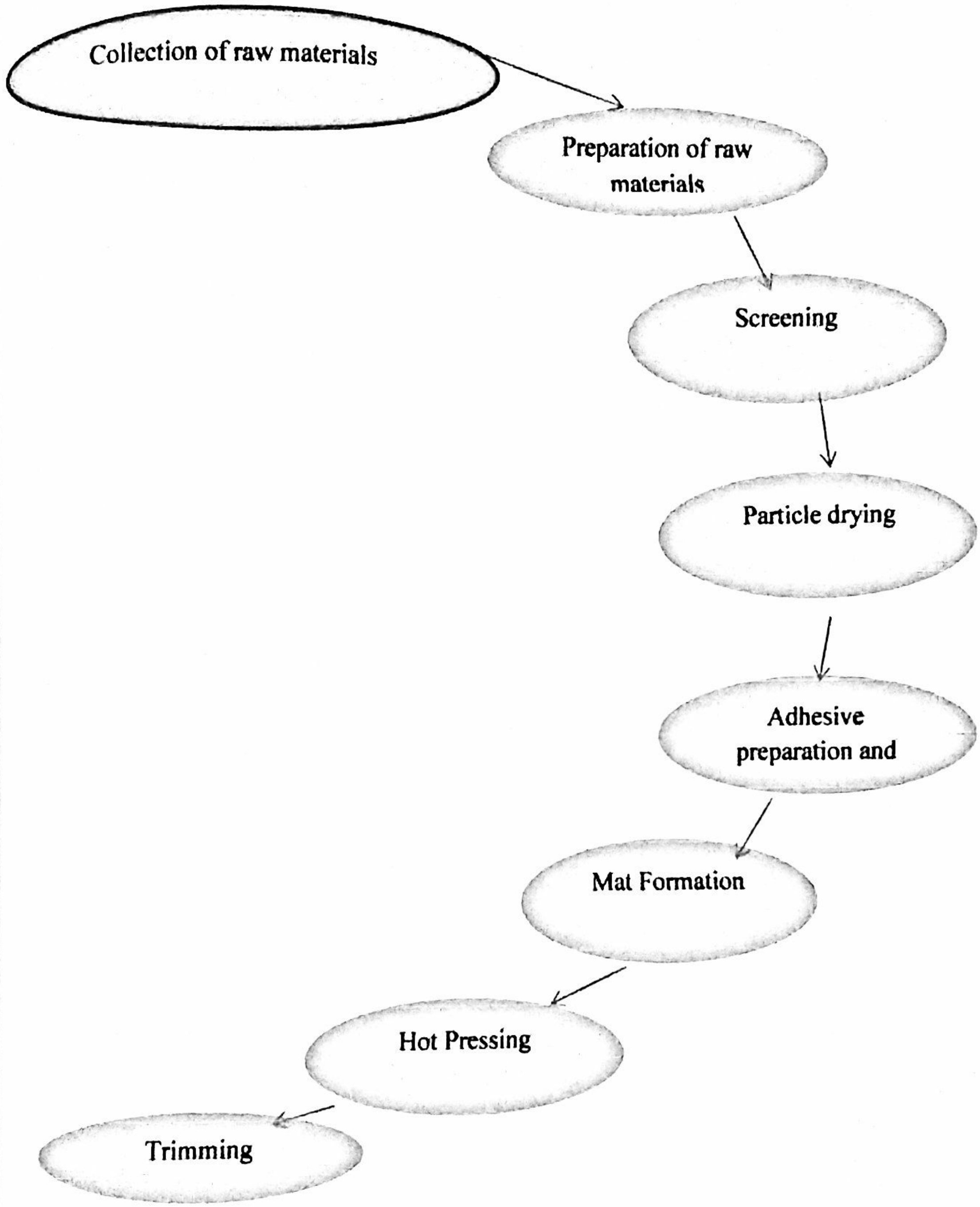
After the board is manufactured, the edges of the board were trimmed by hand saw to obtain the desired length and width. The well pressed boards are then cut into standard sizes to test its physical and mechanical properties.

3.1.2 Specification of manufactured particleboards

Table 3.1.2 Specifications of manufacturing particleboard from Jial Bhadi, Jiga (*Lannea coromandelica*)

Dimensions (mm)	180mm×150mm
Thickness (mm)	8mm
Temperature	160°C
Pressure	4Mpa
Board Types	3 [Fine, Coarse, Mixture (50:50)]
Replications	3 (for each type)
Total board manufactured	9
Adhesive	Urea formaldehyde (UF)- 10%

3.1.3 Flow chart of the particleboard formation process



Finished particle board

Figure 3.1.3: Flow Diagram of particle board Manufacturing Process

Figure: Chips of Jiga species

Figure: Fine Particles

Figure: Coarse Particles

Figure: *Lannea coromandelica* particleboard (Fine particles)

Figure: *Lannea coromandelica* particleboard (Coarse particles)

Figure: *Lannea coromandelica* particleboard (Fine: Coarse particles)

3.4 Laboratory Tests

The laboratory tests for characterization of physical properties and mechanical properties for each type of particleboards were carried out respectively in the laboratories 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 A208.1–1999) (ANSI, 1999) as well as the Indian standard for particleboards (IS: 3087-1985) (Anon, 1985).

3.5 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. 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 (150 mm x 38 mm).

3.6 Determination of Physical properties:

All the samples are cut into (50 mm x 35 mm) dimension for testing physical properties. At first all the specimens are weighted and green dimension are taken at room temperature. Then all the samples were dried in oven for 24 hours. After drying oven dry weight and dry dimension are also measured. The samples are soaked into water for 24 hours. Finally, the wet dimension are taken and all the physical properties are calculated by using following formula-

3.6.1 Density

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.

3.6.2 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-

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

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

3.6.3 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-

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

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

3.6.4 Thickness swelling

Thickness swelling was calculated by the following formula-

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

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)

3.6.5 Linear expansion

The Linear Expansion was calculated by the following formula-

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

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

3.7 Determination of mechanical Properties

According to the procedure of ASTM standard D-1037, all samples were carefully prepared and tested to evaluate mechanical properties of the particle board. Mechanical properties were measured by using universal testing machine (UTM) (model: WE-100, made by Time Group Inc.).

3.7.1 Modulus of rupture (MOR)

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).

3.7.2 Modulus of elasticity (MOE)

The modulus of elasticity (MOE) was calculated from the following equation-

$$\mathrm{MOE} = \frac{P'L^3}{4\Delta bd^3}$$ (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).

3.8 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 software. ANOVA (Analysis of Variance) and LSD (Least Significant Difference) and SPSS (Statistical Package of Social Survey) software to analyze the data.

CHAPTER FOUR: RESULTS AND DISCUTIONS

4.1.1 Density

Density is used to describe the mass of a material per unit volume. It has been found that the density of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 0.75gm/cm^3, 0.79 gm/cm^3 and 0.80gm /cm^3 respectively. From the analysis of variance, it has been found that there was significant difference (F= 10.18, df =8 and p<0.05) among the density of three different particleboard.

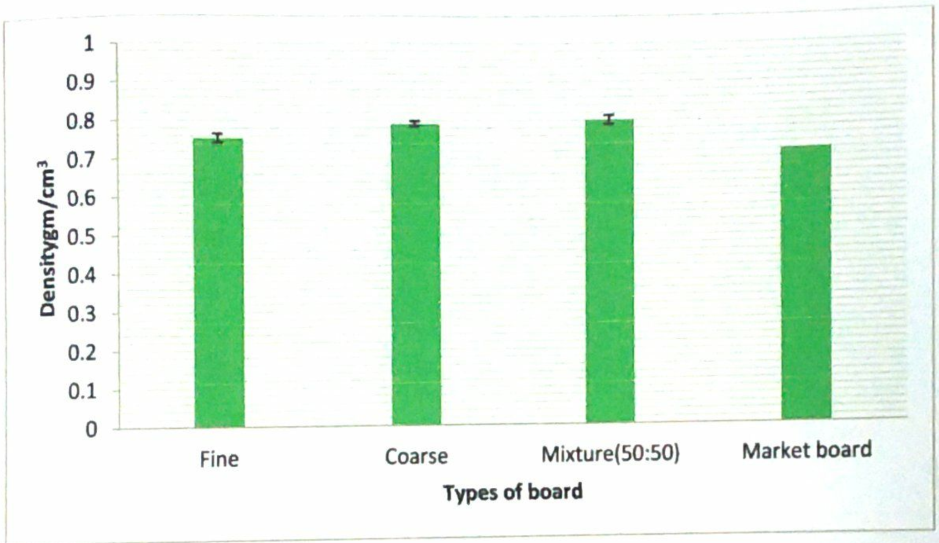


Figure 4.1.1: Density (gm/cm^3) of particleboards of different particle size

It was also found that the average density of Jial Bhadi, Jiga (*Lannea coromandelica*) particleboards from fine, coarse and mixture particle are 0.75gm/cm^3, 0.79 gm/cm^3 and 0.80gm /cm^3 and market particleboard was 0.72 gm/cm^3 respectively.

It was found that the density of *Anthocepalus chinensis* particleboard (16mm thickness) and *Bombax ceiba* particleboard (15mm thickness) 0.72 gm/cm^3 and 0.74 gm/cm^3 respectively (Mafuz, 2006). According to the Australian Standard and New-Zealand Standard (AS/NZS, 1859), particleboard density is 0.66-0.70 gm/cm^3. According to ANSI A208.1-1999 (ANSI, 1999) the density of particleboards is 0.80 gm/cm^3. According to IS specification 3087 (Anon, 1985) the density of standard particleboard is 0.50-0.90 gm/cm^3 and according to German Stanadard Din 68761 (Verkor, 1975) the density of particleboard standard is 0.60-0.90 gm/cm^3. Therefore, the particleboard made from Jial Bhadi, Jiga (*Lannea coromandelica*) follows all of the standards.

4.1.2 Moisture content

Moisture content is a vital physical property that causes change of other physical and mechanical properties of the boards. It has been found that the moisture content of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 5.06%, 5% and 5.62% respectively. From the analysis of variance, it has been found that there was significant difference (F=5.19, df=8 and $p<0.05$) among the moisture content of three different particleboard.

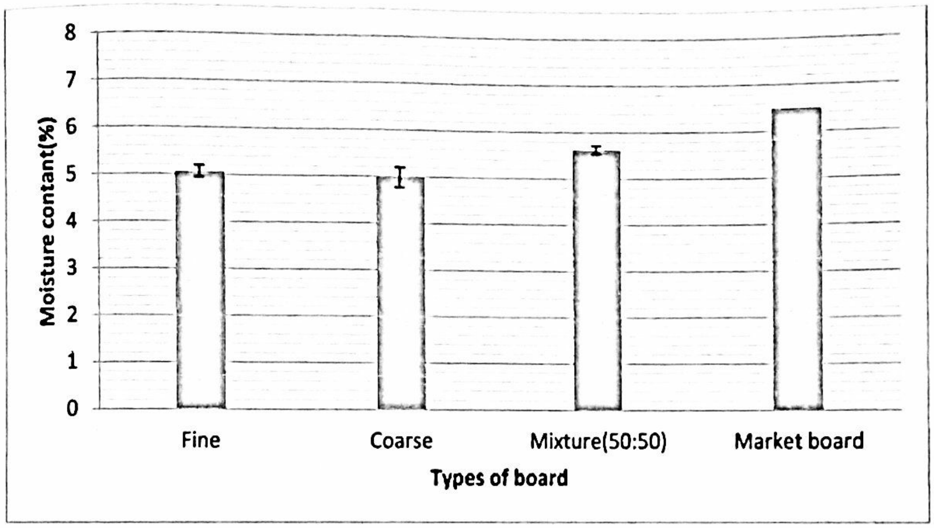


Figure 4.1.2: Moisture content (%) of particleboards of different particle size

It has been found that the moisture content of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 5.06%, 5% and 5.62% respectively and market particleboard was 6.5 respectively.

According to Australian and New Zealand Standard (AS/NZS, 1859) the moisture content of standard particleboard is 5-8%. According to the American National Standards institution (ANSI, 1999) the moisture content of the particleboard is 4-13%.

4.1.3 Water absorption

It has been found that the absorption of water of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 64.92%, 63.47% and 61.92% respectively after 24 hours immersion in water. From the analysis of variance, It has been found that there was no significant difference (F=o.83, df=8 and p>0.05) among the absorption of water of three different particleboard after 24 hours immersion in water.

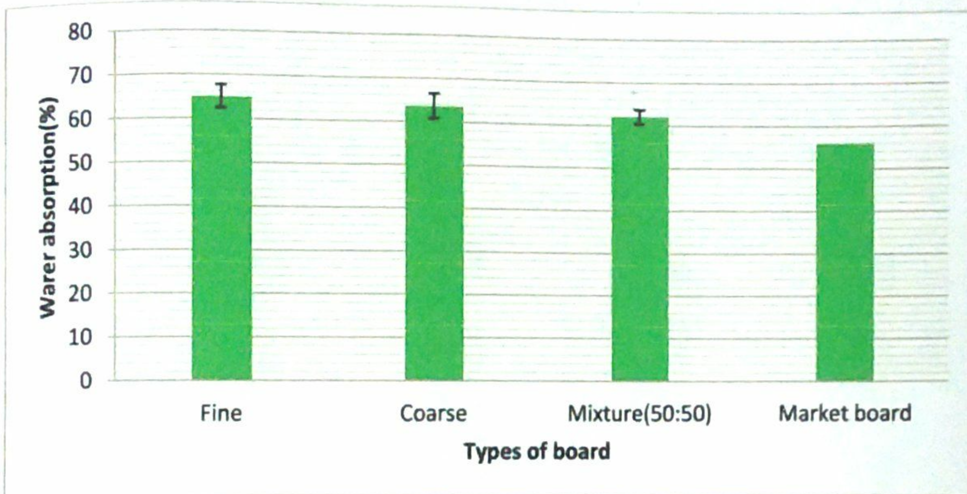


Figure 4.1.3: Water absorption (%) of particleboards of different particle size

Here the absorption of water of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 64.92%, 63.47% and 61.92% respectively after 24 hours immersion in water and the market particleboard was 56% respectively.

It was found that the absorption of water of *Anthocepalus chinensis* (16mm thickness), *Bombax ceiba* (15mm thickness), *Dalbergia sissoo* (15mm thickness), *Excoecaria agallocha* (18mm thickness) and *Gmelina arborea* (15mm thickness) particleboards 51%, 56%, 52%, 52% and 46% respectively after 24 hours immersion in water (Sheikh et al. 1993). According to IS specification 3087 (Anon, 1985) the absorption of water by a standard particleboard is 25% and 50% after 2 hours and 24 hours, respectively. Percentage of the absorption of water of Jial Bhadi, Jiga (*Lannea* *coromandelica*) particleboards is higher than the market particleboard particleboard after 24 hours immersion in water.

4.1.4 Thickness swelling

It has been found that the thickness swelling of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 35.16 %, 32.29% and 30.94% respectively after 24 hours immersion in water. From the analysis of variance, it has been found that there was no significant difference (F=3.28 df =8 and p>0.05) among the thickness swelling of three different particleboard after 24 hours immersion in water.

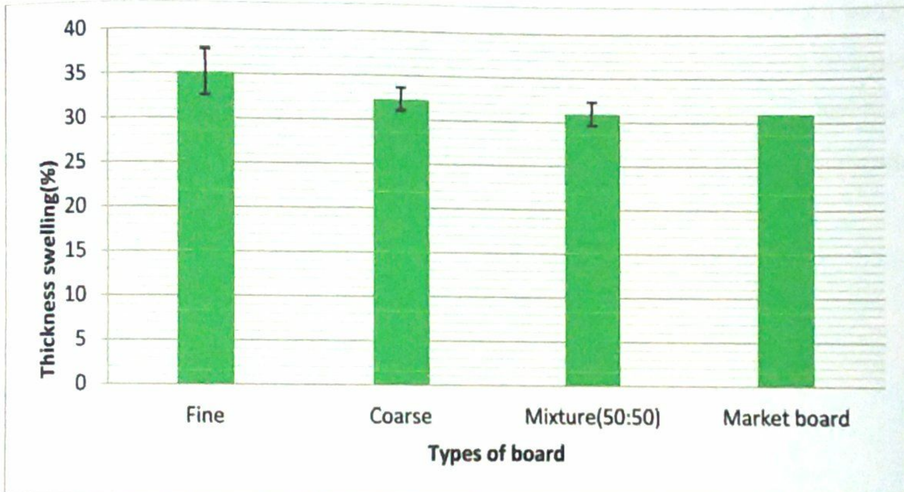


Figure 4.1.4: Thickness swelling (%) of particleboards of different particle size

the thickness swelling of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 35.16 %, 32.29% and 30.94% respectively after 24 hours immersion in water and the market board was 31% respectively.

It was found that the thickness swelling of *Anthocepalus chinensis* (16mm thickness), *Bombax ceiba* (15mm thickness), *Dalbergia sissoo* (15mm thickness), *Excoecaria agallocha* (18mm thickness) and *Gmelina arborea* (15mm thickness) particleboards 31%, 24%, 21%, 28%, 27% and 32% respectively after 24 hours immersion in water (Sheikh et al. 1993).

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).

According to IS specification 3087 (Anon, 1985), German Standard Din 68761 (Verkor, 1975) thickness swelling 10% and 6 % respectively after 2 hours immersion in water. Thickness swelling of Jial Bhadi, Jiga (*Lannea coromandelica*) particleboard is higher than the IS specification and German Standard particleboard.

4.1.5 Linear expansion

It has been found that the linear expansion of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 0..72%, 0.79% and 0.75% respectively after 24 hours immersion in water. It has been found that there was significant difference (F= 18.5, df=8 and $p<0.05$) among the linear expansion of three different particleboard after 24 hours immersion in water.

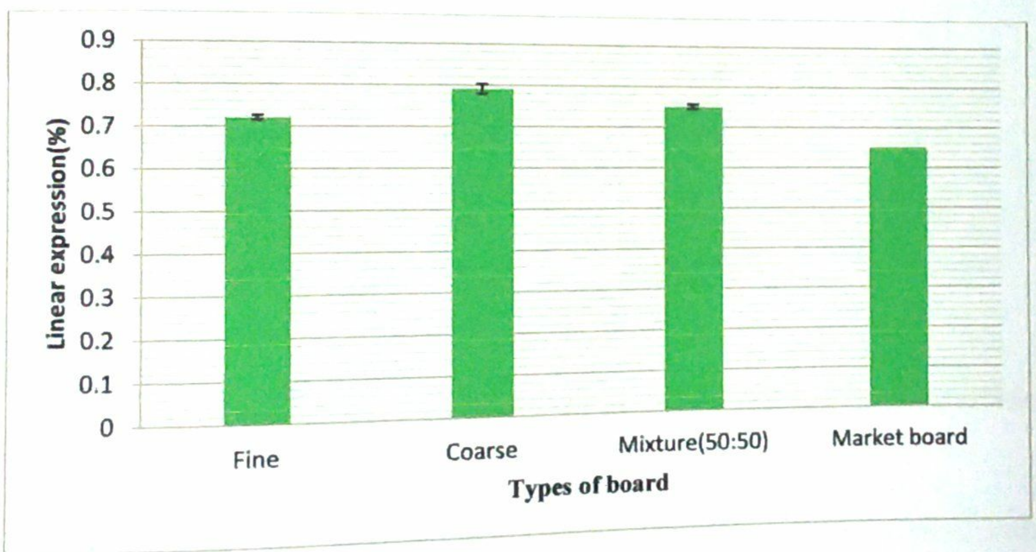


Figure 4.1.5: Linear expansion (%) of particleboards of different particle size

the linear expansion of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 0.72%, 0.79% and 0.75% respectively after 24 hours immersion in water and the market particleboard was 0.65% respectively.

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: 3087-1995(Anon, 1985).

4.2 Mechanical properties

4.2.1 Modulus of rupture (MOR)

It has been found that the modulus of rupture of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 16.367N/mm^2, 17.32N/mm^2, and 19.396N/mm^2 respectively. From the analysis of variance, it has been found that there was no significant difference (F=1.78, df=8 and p>0.05) among the modulus of rupture of three different particleboard.

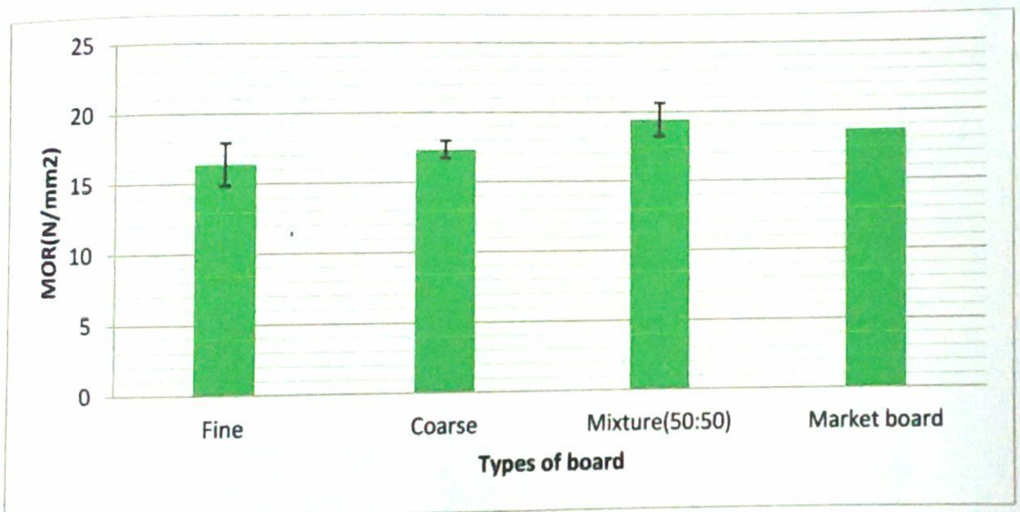


Figure 4.2.1: Modulus of rupture (N/mm2) of particleboards of different particle size

Here the modulus of rupture of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 16.367N/mm^2, 17.32N/mm^2, and 19.396N/mm^2 and the market board was 18.63N/mm^2 comparatively.

It was found that the modulus of rupture of *Anthocepalus chinensis* (16mm thickness), *Bombax ceiba* (15mm thickness), *Dalbergia sissoo* (15mm thickness), *Excoecaria agallocha* (18mm thickness) and *Gmelina arborea* (15mm thickness) particleboards 18.63 N/mm^2, 15.10 N/mm^2, 14.81 N/mm2, 15.49 N/mm^2, 12.16 N/mm^2 and 13.14 N/mm^2 respectively. According to ANSI A208.1-1993(NPA,1993) the MOR of standard particleboard is 16.5-23.5 N/mm^2 for high density grade, 11.0-16.5 N/mm^2 for medium density grade and 3.0-5.0 N/mm^2 for low density grade. According to IS specification 3087 (Anon, 1985) and German Standard DIN 68 761 (Verkor, 1975) the MOR of standard particleboards 10.98 and 17.65 N/mm2 respectively. Therefore, it shows that the MOR of Jial Bhadi, Jiga (*Lannea coromandelica*) particleboard is higher than the *Bombax ceiba, Dalbergia sissoo, Excoecaria agallocha* and *Gmelina arborea.*

4.2.2 Modulus of elasticity (MOE)

It has been found that the modulus of elasticity (MOE) of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 1490.52 N/mm^2, 1632.38 N/mm^2 and 1923.52 N/mm^2 respectively. From the analysis of variance, it has been found that there was significant difference ($F= 5.19$, $df=8$ and $p<0.05$) among the modulus of elasticity of three different particleboard.

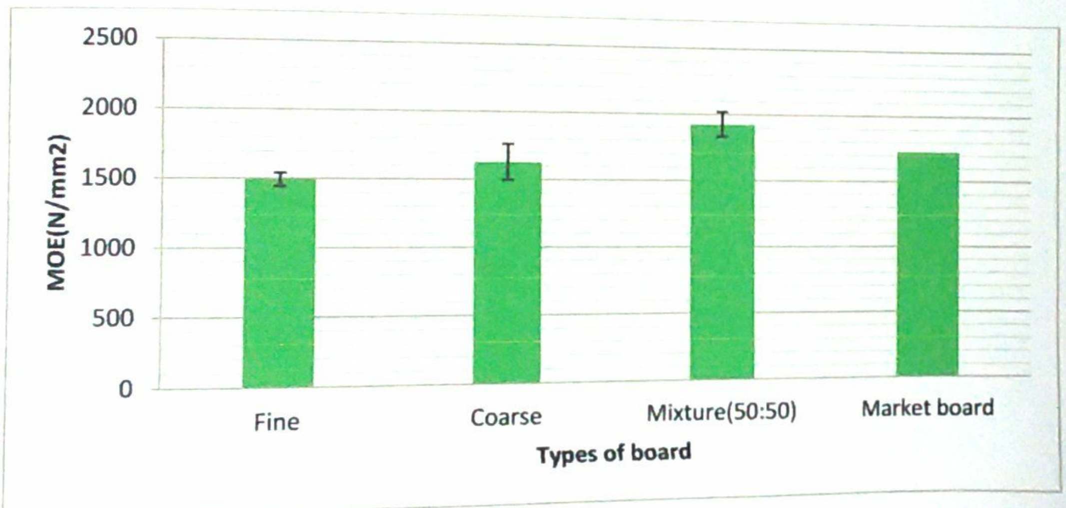


Figure 4.1.1: Modulus of elasticity (N/mm^2) of particleboards of different particle size

the modulus of elasticity (MOE) of particleboards of three different particle size fine, coarse and their mixture (50:50) manufactured from Jial Bhadi, Jiga (*Lannea coromandelica*) are 1490.52 N/mm^2, 1626.38 N/mm^2 and 1923.52 N/mm^2 and the market board was 1725 N/mm^2 comparatively.

It was found that the modulus of elasticity (MOE) of *Bambusa balcooa* and *Bambusa vulgaris* 2286.75 N/mm^2 and 2244.45 N/mm^2 respectively (Biswas, 2008). According to ANSI A208.1–1993 (NPA, 1993), the MOE of standard particleboard is 2,400- 2,750 N/mm^2, 1725-2750 and 550-1025 N/mm^2 for high grade, medium grade and low grade respectively. The value of MOE of Jial Bhadi, Jiga (*Lannea coromandelica*) particleboard is follows the standard of ANSI for medium grade particleboard.

4.3 Physical and Mechanical properties of particleboards according to different standards.

The physical and mechanical properties of Jial Bhadi, Jiga (*Lannea coromandelica*) particleboard manufacturing with different particle size are compared with the Market board and different standardized particleboard properties found around the world. From the table, it has been observed some of the physical properties i.e. density, moisture content, water absorption, thickness swelling, linear expansion and mechanical properties i.e. MOR, MOE are comparable to the market board and different standardized properties of particleboard.

Table 4.3.1 Physical and Mechanical properties of particleboards according to different standards.

Standards/Boards		Physical properties					Mechanical properties	
		Density (gm/cm^3)	MC (%)	WA (%) (24 hr.)	TS (%) (24 hr.)	LX (%) (24 hr.)	MOR (N/mm^2)	MOE (N/mm^2)
Indian Standard (IS:3087-1985)		0.50-0.90	-	50	10 (2hrs)	-	10.98	-
German Standard Din 68761		0.60-0.75	-	-	6 (2hrs)	-	17.65	-
American National Standards Institute (ANSI/A208.1.)		0.80	-	-	-	0.35	16.5-23.5	2400-2750
Australian Standard and New-Zealand Standard (AS/NZS)		0.66-0.70	5-8	-	15	-	18	2400-2700
Jial Bhadi, Jiga Particleboards	Fine	0.75	5.06	64.92	35.16	0.72	16.36	1490.52
	Coarse	0.79	5	63.47	32.29	0.79	17.32	1626.38
	Mixture	0.80	5.62	61.92	30.94	0.75	19.39	1923.52
Market board		0.72	6.5	56	31	0.65	18.63	1725

Source: (Anon, 1985); (Verkor, 1975); (ANSI, 1999); (AS/NZS, 1859)

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

From this point of view, manufacturing of particleboard using Jial Bhadi, Jiga (*Lannea coromandelica*) has great potentiality to meet the increasing demand for wood based products as well as to facilitate the conservation of our forests. In this work, particles from Jial Bhadi along with Urea formaldehyde as additives used to make experimental Particleboard. The important advantages of Jial Bhadi tree are that it is a very fast growing tree and It requires very poor or no management techniques or procedure. Therefore, from the above presented results and discussion it has been observed that all physical and mechanical properties of Jial Bhadi particleboards meet the requirements of the international standard like ANSI; ISO; AS/NZS, GS. Based on the experiment it is also found that the Jial Bhadi particleboard shows quite satisfactory results in case of physical and mechanical properties in comparison with the different woody and non-woody particleboard. If Jial Bhadi is used commercially for manufacturing Particleboard, it will be an appropriate alternate source of raw material for Particleboard industries.

5.2 RECOMMENDATIONS

Jial Bhadi, Jiga (*Lannea coromandelica*) has satisfied the physical and mechanical properties of the international standards. It would be better to use different adhesives like Phenol Formaldehyde (PF), Melamine Formaldehyde (MF), Poly vinyl chloride (PVC), Poly-vinyl acetate (PVCA) etc, with different pressure and temperature which may have the ability to enhance the physical and mechanical properties of Jial Bhadi particleboard and also to give new variation to the particleboard manufactured from Jial Bhadi. In this situation, the government and particleboard industry owners may take initiatives for utilizing Jial Bhadi as an alternate source of raw material for manufacturing of particleboard in future. So, further study may be conducted in future.

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APPENDIX

1. Analysis of Variance for Density

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.003622	2	0.001811	10.1875	0.011773	5.143253
Within Groups	0.001067	6	0.000178			
Total	0.004689	8				

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Type	N	Mean	Grouping
Mixture	3	0.8000	A
Coarse	3	0.79000	A
Fine	3	0.75333	B

2. Analysis of Variance for Moisture content

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.734422	2	0.367211	5.305667	0.047124	5.143253
Within Groups	0.415267	6	0.069211			
Total	1.149689	8				

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Type	N	Mean	Grouping
Mixture	3	5.6200	A
Fine	3	5.060	A
Coarse	3	4.977	A

3. Analysis of Variance for Water absorption

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	16.4738	2	8.2369	0.825707	0.482201	5.143253
Within Groups	59.8534	6	9.975567			
Total	76.3272	8				

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Type	N	Mean	Grouping
Fine	3	64.92	A
Coarse	3	63.47	A
Mixture	3	61.92	A

4. Analysis of Variance for Thickness swelling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	66.7478	2	33.3739	3.275087	0.109271	5.143253
Within Groups	61.1414	6	10.19023			
Total	127.8892	8				

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Type	N	Mean	Grouping
Mixture	3	38.94	A
Fine	3	35.16	A
Coarse	3	32.29	A

5. Analysis of Variance for Linear Expansion

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0074	2	0.0037	18.5	0.002717	5.143253
Within Groups	0.0012	6	0.0002			
Total	0.0086	8				

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Type	N	Mean	Grouping
Coarse	3	0.7900	A
Mixture	3	0.75000	B
Fine	3	0.72000	B

6. Analysis of Variance for Modulus of Rupture (MOR)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	14.42887	2	7.214433	1.776773	0.247719	5.143253
Within Groups	24.36248	6	4.060414			
Total	38.79135	8				

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Type	N	Mean	Grouping
Mixture	3	19.40	A
Coarse	3	17.320	A
Fine	3	16.36	A

7. Analysis of Variance for Modulus of Elasticity (MOE)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	294239.1	2	147119.6	5.195045	0.049058	5.143253
Within Groups	169915.3	6	28319.21			
Total	464154.4	8				

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Type	N	Mean	Grouping
Mixture	3	1923.5	A
Coarse	3	1626	A B
Fine	3	1490.5	B