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KHULNA UNIVERSITY
KHULNA - 9208
BANGLADESH

2015

Ligno-cellulosic hybrid fiber board: Effect of heat treatment for self-bonding

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This dissertation has been prepared for the partial fulfillment of the requirements of One (1) year professional M. Sc. (Masters.) degree in Forestry from Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh.

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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.

I, hereby, give consent for my thesis, if accepted, to be available for photocopying and for inter-library loans, and for the title and summary to be made available to outside organizations only for research and educational purposes.

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H. M. Mamunur Rashid

Dedicated
To My
Beloved Parents &
Loving Sister Meem

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 One (1) year professional M. Sc. (Masters) degree in Forestry. I have approved the style and format of the project thesis.

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H. M. Mamunur Rashid

ABSTRACT

Depleting natural resources, regulations on using synthetic materials, growing environmental awareness and economic considerations are the major driving forces to use annually renewable resources such as biomass for industrial applications.

Using unused available material such as Jial bhadi (*Lannea coromandelica*) along with coir fiber and coir dust (*Cocos nucifera*) for the production of binderless hybrid fiberboards is an important contribution for solving problems like deforestation. Furthermore, the increasing fuel cost and scarcity of petroleum sources lead to seek for substitutes of petroleum by-products like resins commonly used for the production of fiberboards.

Synthetic resins commonly used on fiberboards production present negative side effects like the health risks caused by the emission of volatile organic compounds such as formaldehyde, or problems concerning issues such as waste disposal or recycling. Binderless boards overcome these difficulties using lignin instead of resin as adherent obtaining in this way a board which does not present formaldehyde emissions and that is completely biodegradable.

The present study was conducted to evaluate the physical and mechanical properties of binderless lignocelulosic hybrid fiberboard from Jial bhadi (*Lannea coromandelica*) along with coir fiber and coir dust (*Cocos nucifera*). In this study Jial bhadi (*Lannea coromandelica*) and (*Cocos nucifera*) are multipurpose usable tree, that was used as fiber binderless lignocelulosic hybrid fiberboard manufacturing and deposited lignin in those material was used as binder.

In the present study Jial bhadi (*Lannea coromandelica*) along with coir fiber and coir dust (*Cocos nucifera*) were used to produce fiberboards without synthetic adhesives. These lignocellulosic materials were steam exploded through a thermo-mechanical vapor process in a batch reactor. After pretreatment the material was dried, ground and hot pressed to produce the boards.

The effects of pressing temperature and fiber mixture ratio on physicomechanical properties of the binderless hybrid fiberboards were evaluated and the conditions that optimize these properties were found. Physicomechanical properties of the fiberboards studied were: Density, water absorption (WA), thickness swelling (TS), linear expansion (LE), moisture content (MC), modulus of elasticity (MOE) and modulus of rupture (MOR).

Binderless fiberboards produced from at the Jial bhadi (*Lannea coromandelica*) along with coir fiber and coir dust (*Cocos nucifera*) optimum conditions found fulfilled the European standards for boards of internal use.

This research work was an effort to reduce our dependency upon petroleum derivates, to diminish deforestation and to increase the use of renewable and biodegradable materials with the intention of preserving the environment and to encourage a sustainable development of our society.

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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

ABBREVIATIONS

Anon	Anonymous
ANOVA	Analysis of Variance
APCC	Asian and Pacific Coconut Community
ASTM	American Society for Testing and Materials
AWPA	Australian Wood Panels Association
BBS	Bangladesh Bureau of Statistics
CBPB	Cement-bonded Particleboard
CLMP	Coconut Leaf Mid-Rib Particleboard
CLP	Coconut leaf pruning
cm	Centimeter
CPP_a	Coconut Coir Pith Particleboard (With Adhesive)
CPP_b	Coconut Coir Pith Particleboard (Adhesive-Less)
CSP	Coconut Stem Particleboard
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
LSD	Least Significant Difference
LVL	Laminated Veneer Lumber
m	Meter
mm	Millimeter
MDF	Medium density fiberboard
MF	Melamine formaldehyde
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MPa	Mega Pascal
MUF	Melamine urea formaldehyde
N/mm^2	Newton per square millimeter
OSB	Oriented Strand Board
PF	Phenol Formaldehyde
PMDI	P-methylenediphenyldiisocyanate
PRF	Phenol resorcinol formaldehyde
PVAC	Poly-vinyl acetate
RF	Resorcinol formaldehyde
rpm	Rotor per minute
SD	Standard deviation
UF	Urea formaldehyde
UTM	Universal Testing Machine
µm	Micro meter

CHAPTER 1

INTRODUCTION

1.1Background and Justification of the Study

It is hard to imagine a world without forests. Forests provide a wide range of benefits to people, including clean air and water, productive soils, biological diversity, goods and services, employment, recreation and solely being exposed to nature is beneficial for life. Forests also provide intangible benefits such as beauty, inspiration and wonder. Some of these benefits depend on none or minimal interference with forest. Other benefits can only be realized by harvesting the forest for wood and other products (Arias, 2008).

Wood is one of the lingo cellulosic materials and valuable forest resources on the earth. About 70% demand for timber and 90% for fuel wood of the country is met from the trees grown at villages in Bangladesh. 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 like particleboard, plywood, medium density fiberboard (MDF), wood plastic composite board (WPC) etc. can one of the most alternative representative source for mitigate timber demand (Anon, 1987). There has available low density and high density wood, non wood species exists in our country. These have no timber value but use as fuel wood or fencing. So these species can be brought under utilization that will help to reduce our demand of timber (Das, 1990).

A lignocellulosic composite is a reconstituted product made from a combination of one or more lignocellulosic materials, such as wood, bamboo, agricultural residues, and other plant substances, held together with a bonding agent. At present, formaldehyde-based adhesives, such as phenol–formaldehyde (PF) and urea–formaldehyde (UF) resins, are most commonly used, which may result in environmental and health hazards due to formaldehyde emission (Xiaoyan *et al.,* 2013). For this reason, production of lignocellulosic composites without the addition of adhesives is very essential. As is well known, lignin acts as a binder in lignocellulosic materials (Kumar *et al*, 2009). Lignin comprises as much as 40 percent of wood's mass, therefore lignin can be novel source of natural binder for reconstituting lignocellulosic composites in the absence of synthetic adhesives (Glasser, 1981).

Lignin is a phenolic and branched macro-molecule part of lignocellulosic materials, such as wood, annual plants or agricultural residues. As structural component of plants, lignin is one of the most abundant renewable products in nature. In relation to its structure and chemical composition, it is the most complex natural polymer with a great variety of functional groups that provide the active centers available for chemical and biological interactions (García, Martín *et al*., 1984).

The mass content of lignin in each plant depends on the origin of the vegetable species. In wood its content varies between 19 to 35% (Dence and Lin, 1992). Available lignin from the market comes from a series of processes, mainly from the paper industry, which could affect the native structure of lignin. The main functional groups of lignin are: phenolic hydroxyls, aliphatic hydroxyls, methoxyls, carbonyls, carboxyls and sulfonates (García, Martín *et al.*, 1984).

Jial Bhadi, (*Lannea coromandelica*) is a multifarious usable tree of Anacardiaceae family. Though it is a high density species but it has no timber value. It is a neglected but a novel source of renewable ligno-cellulosic raw material (Anon, 2005). 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 composite board production (Satyavati *et al.,* 1987).

Coconut coir dust or coir fiber is the by-product of the coconut oil industry, the disposal of which is a problem. Coconut coir dust is about 70% of the weight of the coconut husk. Actually the coir fibres in the coconut husk held together by the coir pith. It is rich in lignin and tannin and it also has ligno-cellulosic bonds, which is resistant to microbiological attack (Khan, 2007 and Greer, 2008). Coir pith or coir dust is mostly used as moisture retaining agent in potting mixtures for horticultural and agricultural applications and also used for producing domestic or industrial fuel, for producing hard boards and thermal insulator (Khan, 2007).

1.2 Objectives of the Study

- ✓ To assess the feasibility of lignocellulosic fiberboard using different parts of Jial Bhadi (*Lannea coromandelica*) as raw materials with mixture of coir (*Cocos nucifera*)
- ✓ To determine the effect of hybridization on physical and mechanical properties of producing lignocellulosic fiberboard.

CHAPTER 2

LITERATURE REVIEW

2.1 Wood

Wood has played a major role through human history. Since early times humans have used wood to make shelters, cook food, construct tools, and make weapons. Society learned very early the great advantages of using wood, because it was widely distributed, multifunctional, strong and easy to work, aesthetic, sustainable and renewable.

2.1.1 Physical Composition

Wood is known as secondary xylem and composed of elongated cells. They perform in the transport of liquid and act as food reserves. They also provide necessary mechanical support for the tree (Eero Sojstrom, 1993).

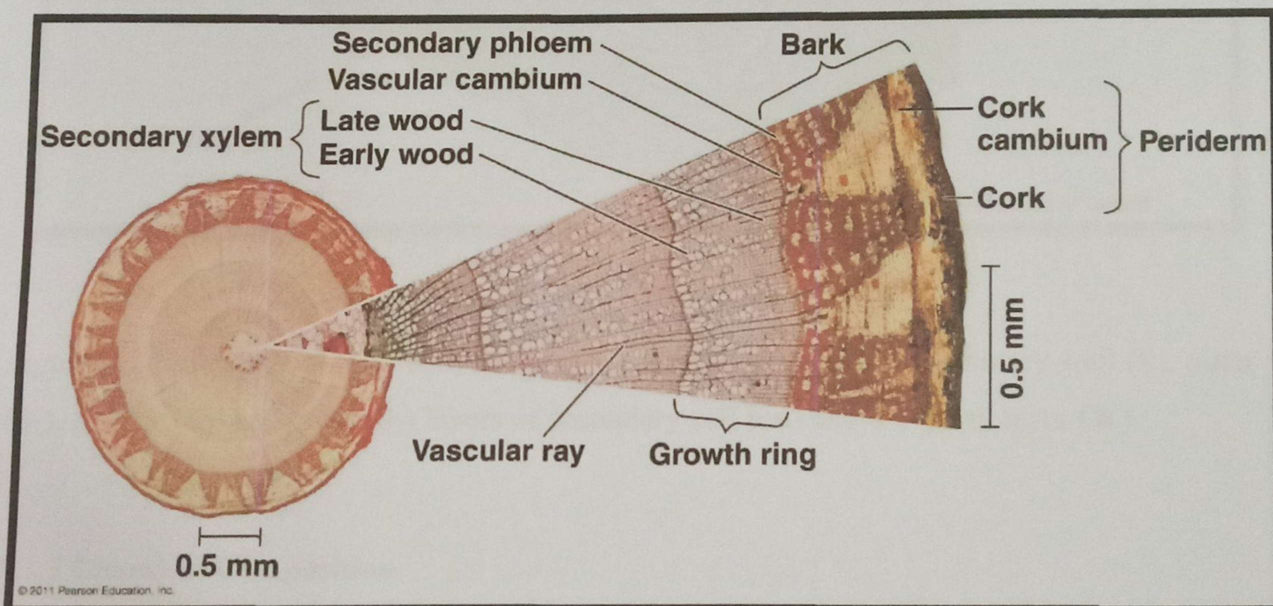

Figure 2.1 Diagram showing a section of a dicot stem

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).

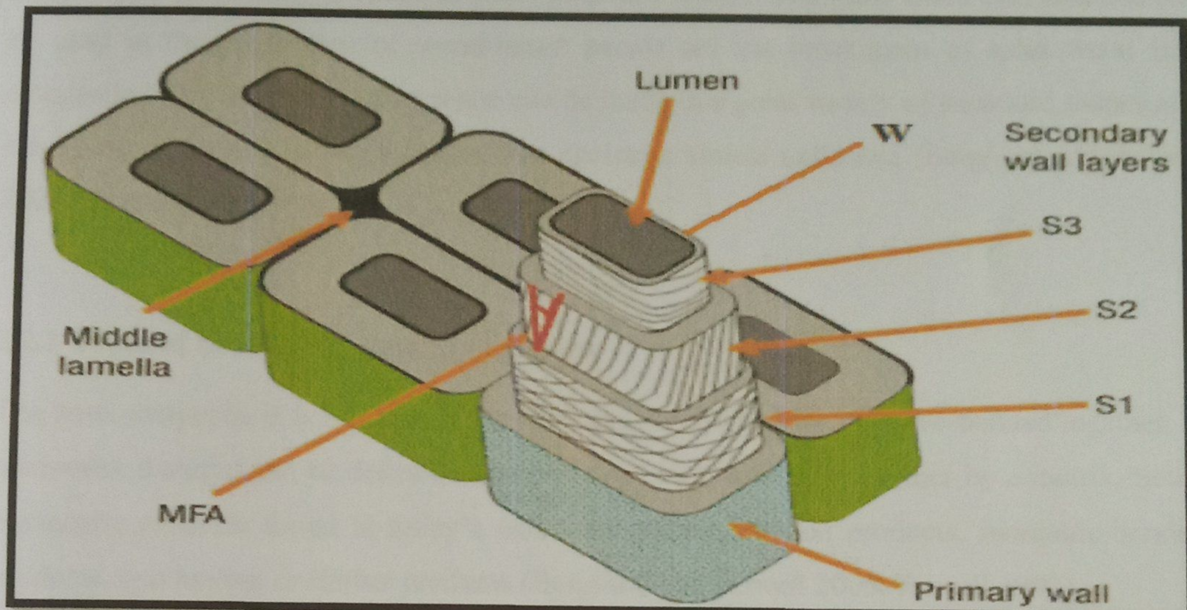

Figure 2.2 Structure of wood cell, showing the middle lamella (ML), primary wall (P), outer (S_1), middle (S_2) and inner (S_3) layers of secondary cell wall and the warty layer (W).

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 Boards

Historically, wood was used only in its solid form as large timbers and lumber. As the availability of large-diameter trees decreased, and consequently the price increased, the wood industry looked to replace large-timber products with reconstituted wood products made using smaller-diameter trees, and saw and pulp mill wastes. The basic wood elements that can be used in the production of wood-based panels are the breakdown of solid wood into composite components. The composite can be made in a great variety of sizes and shapes and can be used alone or in combination. The choice is almost unlimited (Berglund and Rowell 2005; Youngquist 1999).

2.2.1 Types of boards and their applications

The term composite is being used to describe any wood material adhesive-bonded together. A composite material can be defined as two or more elements held together by a matrix. Some composite products found in today's world are panels, molded products, inorganic-bonded products, and lumber or timber products (Berglund and Rowell 2005; Rowell 1992).

Classification of wood-based composites (Maloney 1996; Youngquist 1999)

Veneer-based material

- Plywood
- Laminated veneer lumber (LVL)
- Parallel-laminated veneer (PLV)

Laminates

- Laminated beams
- Overlaid materials
- Wood–non wood composites

Composite material

- Cellulosic fiberboard
- Hardboard
- Particleboard
- Waferboard
- Flakeboard
- Oriented strandboard (OSB)

Edge-adhesive-bonded material

- Lumber panels

Components

- I-beams
- T-beam panels
- Stress-skin panels

Wood–non wood composites

- Wood fiber–plastic composites
- Inorganic-bonded composites
- Wood fiber–agricultural fiber composites

Composites are used for a number of structural and nonstructural applications in product lines ranging from panels for interior covering purposes to panels for exterior uses and in furniture and support structures in many different types of buildings.

2.2.1.1 Laminated timbers

Glulam is a structural product that consists of two or more layers of lumber glued together with the grain all going parallel to the length by using small trees. In addition, lower quality wood can be used, thinner lumber can be dried much faster than large, thick beams, and a variety of curved shapes can be produced (Youngquist 1999).

2.2.1.2 Plywood

Ply wood is one kind of panels consisting of an assembly of plies (thin veneer) bonded together with the direction of the grain in alternate plies usually at right angles that is used as a structural underlayment in floors and roofs and in furniture manufacturing (Berglund and Rowell 2005; Youngquist 1999).

2.2.1.3 Structural composite lumber (SCL)

Structural composite lumber (SCL) is manufactured by laminating strips of veneers or strands of wood glued parallel to the length. The three main types of SCL products are: Oriented strand lumber (OSL), parallel strand lumber (PSL) and laminated veneer lumber (LVL).

2.2.1.4 Composite beam

Composite structural beams can be produced by combining several wood elements by using builders. They are lightweight, uniform, and easy to use; have increased dimensional stability (Maloney 1996; Youngquist 1999).

2.2.1.5 Wafer- and Flakeboard

The wafer and flake boards are produce by several methods and randomly oriented throughout the panel. Wafers are almost as wide as they are long while flakes are much longer than they are wide (Youngquist 1999).

2.2.1.6 Particle boards

A particle board is a board or sheet constituted from fragments of wood or other ligno-cellusic material bonded with natural or synthetic resin by the help of one or more agents like heat, pressure etc. It is use as both furniture and structural panel.

2.2.1.7 Fiberboards

Fibreboard is a sheet materials made from fibres of wood or other lingo-cellusic materials which generally exceed 1.5mmm in thickness and bonded with natural or synthetic resin by the help of one or more agents like heat, pressure etc (Berglund and Rowell 2005; Youngquist 1999).

2.2.1.7.1 Low-Density Fiberboard (LDF)

Insulation boards are low-density fiberboard (LDF), have a density of between 160-500 Kg/m^3 and usually produced by a dry process. It is typically does not depends on binder rather than rely on hydrogen bonds to hold the board components together (Berglund and Rowell 2005; Youngquist 1999).

2.2.1.7.2 Medium-Density Fiberboard (MDF)

In medium density fibreboards (MDF), fiber and fiber bundles, planer shavings, plywood trims, saw dust mainly used as raw material. It is a high mechanical strength board with 500-800 Kg/m^3 density range and formed by using wet or dry process.

2.2.1.7.2 High-Density Fiberboard (HDF)

Flat sheets ranging from 1.6 to 12.7 mm in thickness with above 800 Kg/m^3 density is known as high density fibreboards (HDF). It is a homogeneous panel and strength is compared with solid wood.

2.2.1.8 Other types of composites

There are also a lot of wood-based composites that are a combination of wood and non-wood elements. Combinations of wood and inorganics, thermoplastics, fiberglass, metals, and other synthetic polymers have been produced; some are commercial, and some are still in the research phase (Youngquist 1999).

2.2.2 Process of fiberboard production

Different types of process are used for fiberboard production. There are mainly two process are used for fiberboard production.

2.2.2.1 The dry process

The most important groups of boards made with this process are medium density fiberboards (MDF) and high density fiberboards (HDF) with densities between 450- 800 kg/m3 and more than 800 kg/m3, respectively.

2.2.2.2 The wet process

The main group of fiberboards made with this process is hardboards (HB) with a density more than 900 kg/m3. The main difference between the wet and the dry process is the mat forming agent, which is water in the former and air in the latter.

2.2.3 Binderless fiberboards

There have been many attempts to produced binderless boards, one of which is the production of hardboards from rice straw without using synthetic resins(Fadl, Sefain *et al.* 1977); the boards were submitted to a thermal post-treatment at 180 °C improving their water resistance properties but diminishing their bending strength. Hardboards have been also produced from bagasse without pretreatment (Mobarak, Fahmy *et al.* 1982), obtaining bending strengths up to 130 MPa and water absorptions as low as 10%; the boards where molded at 25.5 MPa and 175 °C. Besides, in this study was evaluated the importance of the moisture in the material before molding. Other authors (Suchsland, Woodson *et al.* 1983, 1985; Suchsland, Woodson et al. 1987), have produced hardboards from mansonite pulp without adhesives, they found that the dry forming processes develop higher mechanical properties and lower water absorption in the boards compared with wet forming processes.

The hardboards were produced from severely treated pulps, which were refined afterwards. This pretreatment was chosen by the authors to force the separation of the fibers through the lignin-rich part of the material, obtaining fibers covered of lignin; which is very favorable for forming boards using only lignin as adhesive. Binderless boards have been also produced from steam exploded pulps of oil palm fronds (Laemsak and Okuma 2000; Suzuki, Shintani *et al.* 1998), the material was pretreated at temperatures between 210 and 235 °C for 5 or 10 min and subsequently press at pressures between 250 and 400 bars without washing the pulp; in this study, the authors found some evidences for believing that the main bonding strength of the boards is due to a lignin-furfural linkage. Steam exploded fibers from coniferous sawdust (Angles, Ferrando *et al.* 2001; Anglès, Reguant *et al.* 1999) as well as from Miscanthus sinensis (Velásquez, Ferrando *et al.* 2003a, b) have been used for the production of good quality binderless boards.

2.3 Lignin

Lignin is a phenolic and branched macro-molecule part of lignocellulosic materials, such as wood or agricultural residues. As structural component of plants, lignin is one of the most abundant renewable products in nature. In relation to its structure and chemical composition, it is the most complex natural polymer with a great variety of functional groups. Generally, lignin is considered to be a three-dimensional amorphous polymer, randomly arranged, made up of phenyl-propane units. Lignins from different woody plants exhibit differences to each other, even though their structure and composition respond always to a skeleton of phenyl-propane units (García, Martín *et al.* 1984).

The mass content of lignin in each plant depends on the origin of the species. In wood its content varies between 19 to 35% (Dence and Lin 1992). The main functional groups of lignin are: phenolic hydroxyls, aliphatic hydroxyls, methoxyls, carbonyls, carboxyls and sulfonates. The structural elements comprising lignin are linked by carbon-carbon and ether bonds of the type $\alpha - O - 4$, $\beta - O - 4$, $4 - O - 5$. Figure 2.2 shows the structural units and monomers of lignin.

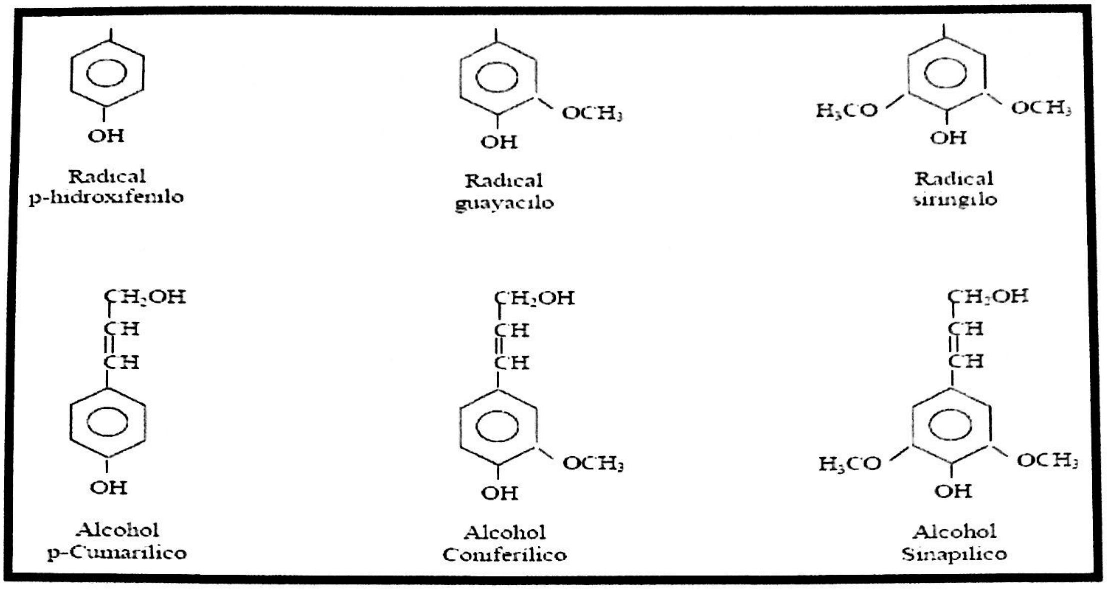

Figure 2.3 Basic monomers and units of lignin (García, Martín *et al.* 1984)

2.3.1 Types and features of lignin

Pulp and paper industry is the main source of lignin as byproducts. Wood hydrolysis represents other important source due to high availability of forest and vegetable residues. Lignins can be classified into two categories depending on its sulfur content: The first category comprised of commercial lignin with sulfur in its chemical structure, between which Kraft lignin and lingo-sulfonates are found. These types of lignin are the most common type. The second category includes sulfur free lignin obtained from different processes and most of them are not commercially available.

2.3.2 Potential uses of lignin

The potential uses of lignin are based on its ability to perform functions such as chemical dispersant, binder, sequestration agent, emulsifier and emulsions stabilizer (Rodríguez, García *et al.* 1990). Moreover, lignin is used for specific applications and as a copolymer of phenolic resins (Northey 1992).

Lignin has also been successfully used as partial substitute of phenol in phenolic resins manufacture and as part of panel products by mixing it with phenol formaldehyde resins or used directly for fibreboard production as a natural binder (Alonso, Oliet *et al.* 2004; Velásquez, Ferrando *et al.* 2003). It is more readily available, less toxic and cheaper than phenol and considered as potentially attractive application from the economical and environmental points of view. Moreover, lignin is obtained from renewable resources and can be use without previous treatments (Pizzi and Mittal 2003; Adams 1995; Dong and Frike 1996; González, Riera et al.1989).

2.3.3 Advantages and disadvantages in the use of lignin

Lignin is an amorphous polymer that has so far been used little in industrial applications because its native structure varies depending on the plant from which it was extracted and also due to its super condensate structure. For this reason, it has a highly variable formulation from batch to batch. While as we have seen, lignin has a great industrial potential, its market currently is still low due to complex chemical structure, high quantity of impurities, high cost for crude liquor purification and processing etc.

In the other hand, lignin is obtained from the pulp and paper industry as a residue and in this way lignin came from a renewable resource. Non modified lignin has a much lower cost than synthetic resins and it is easily used. Also has possibility of reducing the volume of residues generated by the pulp and paper industry.

2.4 Ligno-cellulosic materials for binderless fiberboard manufacturing

2.4.1 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)

2.4.2 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).

2.5 Detail about Jiyal bhadi (*Lannea coromandelica*)

2.5.1 General Information

English Name: Odina

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

Scientific classification

Kingdom	:	Plantae – Plants
Phylum	:	Magnoliophyta
Class	:	Angiospermae
Order	:	Sapindales
Family	:	Anacardiaceae
Genus	:	Lannea
Species	:	*Lannea coromandelica*

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

2.5.2 Description

Jial bhadi, (*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).

2.5.3 Distribution

Jial bhadi, (*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).

2.5.4 Plant Morphology

Jial bhadi, (*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).

2.5.5 Leaves and 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).

2.5.6 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 (Das, 1990).

2.5.7 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).

2.5.8 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 the 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).

2.5 About Coconut Palm (*Cocos nucifera* L.)

2.5.1 General Description

Coconut palm (*Cocos nucifera* L.) is a monocotyledon belonging to the family Arecaceae/Palmae (Anon, 2009[a]). It is the sole species of the genus Cocos belonging to the subfamily Cocoideae which includes 27 genera and 600 species (Evans, 2002). The coconut tree is often described as "the tree of life", "the heavenly tree", "the tree of abundance", "nature's supermarket" and "the prince of palms" (Anon, 2009[a]).

Coconut trees are generally unbranched, erect, cylindrical, pillar-like stem reaching up to 8-30 m in height. Being a monocotyledon, the coconut palm has no tap root. Adventitious roots develop from the bole (Anon, 2009[a]). The flowers of the coconut palm are polygamomonoecious, with both male and female flowers in the same inflorescence. Flowering occurs continuously, with female flowers producing seeds.

2.5.2 Scientific classification of (*Cocos nucifera* L.)

Kingdom	:	Plantae – Plants
Subkingdom	:	Tracheobionta – Vascular plants
Superdivision	:	Spermatophyta – Seed plants
Division	:	Magnoliophyta – Flowering plants
Class	:	Liliopsida – Monocotyledons
Subclass	:	Arecidae
Order	:	Arecales
Family	:	Arecaceae/Palmae – Palm family
Genus	:	Cocos L. – coconut palm
Species	:	*Cocos nucifera* L. – coconut palm

(USDA, 2009 and Anon, 2009[a])

2.5.3 Origins

The origins of this plant are the subject of controversy, with most authorities claiming it is native to South Asia (particularly the Ganges Delta), while others claim its origin is in north-western South America.

2.5.4 Natural habitat and distribution

Coconut palms require warm conditions for successful growth, and are intolerant of cold weather. Optimum growth is with a mean annual temperature of 27°C and growth is reduced below 21°C. The coconut palm (*Cocos nucifera* L.) is grown in about ninety countries along the humid tropical belt. It is widespread throughout the tropics, typically being found along sandy shorelines. According to Anon (2009[a]), they are now almost ubiquitous between 26°N and 26°S latitude. Indonesia has the largest coconut growing area in the world (Anon, 1970 and Crall. C, 1986).

In Bangladesh, coconut is planted on a large scale along the coastal belt of the country particularly in the Noakhali, Patuakhali, Barisal and Khulna districts.

2.5.5 Coconut palm (Cocos nucifera L.) at a glance

Common Name	: Coconut Palm.
Botanical Name	: Cocos nucifera L.
Family	: Arecaceae/Palmae.
Plant Type	: Solitary Palm Tree.
Origin	: The Pacific Islands, but widely distributed world-wide in tropics.
Height	: 8-30 meter, depending on variety.
Rate of Growth	: Moderate.
Salt Tolerance	: High.
Soil Requirements	: Widely adaptable.
Water Requirements	: High drought tolerance, avoid flooding and long standing water.
Nutritional Requirements	: Moderate, but fertilize regularly for best growth.
Light Requirements	: High.
Form	: Solitary palm, canopy of 20-30 leaves.
Leaves	: Pinnately compound, reduplicate, slightly twisted, eventually drooping with 150-200 leaflets.
Inflorescence	: 1-1.5 meter long.
Fruits	: Green, yellow, orange, eventually brown.
Pests or diseases	: Most varieties are susceptible to lethal yellowing, potassium deficiency, bud rot, gandomera, Palm Aphid and Coconut Mite.
Uses	: Specimen plant, reclamation plant, avenue plant, edible copra, stem as construction materials, husk of fruit or coir is used for making mats, rope and brushes, shell is used as fire material and charcoal, green and dried leaves are used for making mats, baskets, and thatching and many others.
Propagation	: Fresh seed, germinates in 4-9 months.

(Anon. 2009[a])

2.2.6 Coconut Coir or coir dust

Coconut coir dust or coir pith is the by-product of the coir fibre industry, the disposal of which is a problem. It is about 70% of the weight of the coconut husk. It is described as brown spongy particles of low weight, which falls out when the fibre is shredded from the husk. Actually the coir fibres in the coconut husk held together by the coir pith. It is rich in lignin and tannin and it also has ligno-cellulosic bonds, which is resistant to microbiological attack (Anon. 2009[a]).

2.5.7 Chemical composition of coir pith

Table 2.1: Chemical composition of coir pith

Constituents	Percent (Dry Basis)	
	A	B
Moisture	15. 38	20. 0
Ash	6. 19	-
Cellulose	24 .25	-
Pentosan	27. 31	10. 4
Furfural	17. 40	-
Lignin	**54. 78**	**33.3**
N	-	0.3
CaO	-	0.4
P_2O_5	-	0.5
K_2O	-	0.9

(**a.** Gonzales, 1970 and **b.** Joachim, 1930)

2.5.8 Uses of coconut coir dust

Coir pith or coir dust is mostly used as moisture retaining agent in potting mixtures for horticultural and agricultural applications and also used for producing domestic or industrial fuel, for producing hard boards, thermal insulator, hydro seeding and shotcreting (Anon. 2009[a]).

2.5.9 Uses of Coconut Tree from its parts

- Coconut Roots can be use for beverage, dye stuff, and medicine purposes.
- Coconut Trunk uses for buildings parts. Out of the Coconut Trunk, handy and durable wood is obtained to make various pieces of furniture and novelty items. Paper pulp can also be extracted from the trunk.
- Coconut Shell, a part of Coconut Fruit produce items such as handicrafts items, charcoal for cooking, and many more.
- Coconut Husk also a part of Coconut Fruit is also used to obtain Coir. An elastic fiber used for rope, matting, and coarse cloth.
- Coconut Leaves for thatch.
- Coconut Leaves produce good quality of paper pulp, midrib brooms, hats and mats, fruit trays, fans, midrib decors, lamp shades, bag, and utility roof materials. In a provincial City of Cebu, Coconut Leaves are used to wrap white rice called Puso.
- Coconut Spathe and Guinit can produce helmets, caps, "bakya" straps, and handbags.
- Coconut Inflorescence is also used to produce Coconut Juice, Coconut Toddy or Tuba. The fermented juice is the common alcoholic drink in the coconut region. Other products out of the Coconut Tree's inflorescence are gin and vinegar.
- Coconut Meat is a good source of protein and an effective natural laxative. It is also a source of other products such as coco flour, desiccated coconut, coco milk, coco chips, candies, latik, copra, and animal feeds. Also used as a main ingredient for salad and other sweet delicacies.
- Coconut Water - are used mostly for re-hydration and kidney cleansing. Read more about Coconut Water Benefits. Researchers are even still doing on going study on different products that can be produce on Coconut Water to aid us.
- Nowadays, Coconut Oil is more popularly used for its benefits for the skin, hair, and face. It's extracted from copra and notable for its anti microbial properties.

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials and Equipment

3.1 Equipments

3.1.1 Chipper

A locally made small lab scale chipper was used to reduce fibrous material quickly and gently of the raw materials as chips. The chipper was used to chipping the raw materials except coir pith. The rpm of the chippers' motor was 1420.

3.1.2. Steam explosion reactor/ Auto clave

For mechanical pulping of material steam explosion is needed. The steam explosion reactor is used to facilitate the impregnation of steam of the material. In this research activity mechanical pulping was done in auto clave, which raise temperature at maximum 121°C.

3.1.3 Hot press

A digital hydraulic hot press was used to press the mat to produce binder less fiber board. It has multi layer plate. The both platen were movable up and down. Maximum temperature range within 400°C.and pressure up to 4MPa commonly occur.

3.1.4 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 fiber boards.

3.1.5 Oven

A lab scale ventilated oven (Name: Gallennkamp, Size 1, made in UK) was used to determine the moisture content (%) of raw materials.

3.1.6 Moisture meter

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

3.1.7 Electric balance

An air tight digital balance (Model: AB 204, made in Switzerland) was used to measure the weight of the raw materials.

3.1.8 Slide calipers

A digital slide calipers was used for determining shrinkage swelling (%) of the produced board.

3.2 Methods and Procedures

3.2.1 Collection of raw materials

The raw material Jial bhadi, (*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 binderless fiberboard (Anon, 2006).

3.2.2 Preparation of raw materials

As coir was collected directly from industry so no preparation was required. But after collection of *Lannea coromandelica,* it will chip approximately 250 mm in length and 12mm in width. Then it will bring for hydrolysis treatment.

3.2.3 Fiber preparation

Lannea coromandelica chips, 150 g dry base, are fed to the steam explosion reactor. The chips are then treated with saturated vapor at the desired conditions of temperature and time. After the set time is reached, the chips were taken for fiber extraction. Fiber extraction was done by beating of traditional hammer.

3.2.4 Experimental design

Table: Variables for manufacturing fiber board from Jiga (*Lannea coromandelica*), coir fiber and coir dust (*Cocos nucifera*)

Board Types	Ratio%			Pressure constant	Pressing Time constant	Temperature °C	Treatment
	Wood Fiber	Coir Fiber	Coir Dust				
A	60%	30%	10%	4 Mpa	20 min	200°C	A
						190°C	B
						180°C	C
B	50%	40%	10%	4 Mpa	20 min	200°C	D
						190°C	E
						180°C	F
C	40%	50%	10%	4 Mpa	20 min	200°C	G
						190°C	H
						180°C	I
Total Number of Treatment							9

3.2.5 Manufacturing place

The fiber board was manufacture at wood lab that is controlled under by Forestry and wood technology discipline, Khulna University, Khulna.

3.2.6 Mat forming

Mat was form into 3-4 times thicker than the target board thickness, but some time it may be thicker 20 times depending on the fiber geometry and density of the raw material (Salehuddin, 1992 and Youngquist, 1999). All fiber boards were produced under wet process.

3.2.7 Hot pressing and conditioning

Inserting the mat into the hot press, the pressure was raise manually by digital hydraulic hot press up to 4 MPa. For this fiber board manufacturing constant press time was 20 minutes, and temperature ranges was 180 - 200°C (Arias, 2008).

After pressing the average thickness of the boards were 10.68 mm (AWPA, 2001 and Youngquist, 1999). After stopping temperature the boards were remained fixed for cooling or conditioning. The hot boards are removed from the press for culling (AWPA, 2001).

3.2.8 Specifications of Manufactured fiberboards

Table: Specifications of manufacturing fiber board from Jiga and Coir

Dimensions (mm)	300 x 200
Thickness (mm)	9 (Average)
Layer	Single
Board Types	9
Replications	3 (for each type)
Total board manufactured	27
Binder	Lignin bonded

3.2.9 Preparation of samples for testing

For testing physical properties, three samples were collected from each board of each type. So the total numbers of samples were nine (9) for each types of fiber board for testing of physical properties. The Density and Moisture Content was determine on the same nine (9) samples and the Water Absorption, Thickness Swelling and Linear Expansion were determined on the other nine (9) samples of each type. The MOR and MOE were determined on the separate samples at same manner. The dimensions of samples for testing the physical properties were (50 mm x 35 mm) and for testing the mechanical properties were (180 mm x 35 mm).

3.2.10 Determination of Physical Properties

At first all the specimens were weighted and green dimension are taken at room temperature. Then all the samples were kept into oven for 24 hours. After drying oven dry weight and dry dimension are also measured. Next, the samples were soaked into water for 24 hour.

Finally, the wet dimension will be taken and all the physical properties are calculated by using following formula-

3.2.10.1 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.

3.2.10.2 Moisture content

It was calculated by the following formula-

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

3.2.10.3 Water absorption

The water absorption was calculated by the following formula-

$$A_w = \frac{m_2 - m_1}{m_1} \times 100$$ (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).

3.2.10.4 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).

3.2.10.5 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).

3.2.11 Determination of Mechanical Properties

Mechanical properties were carried out in the laboratory of Civil Engineering Department of Khulna University of Engineering and Technology, Khulna, Bangladesh.

3.2.11.1 Modulus of rupture (MOR)

The MOR was calculated from the following equation-

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

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).

3.2.11.2 Modulus of elasticity (MOE)

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

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

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).

3.2.12 Analysis of data

All the data, produced during the laboratory tests for characterization of physical and mechanical properties of each type of fiber boards, was analyze by using Microsoft Office Excel 2007 and SPSS) 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 experimental factors and their levels were chosen based on the literature review and previous experiences on production of lignocellulosic binderless hybrid fiberboard using different parts of Jial bhadi (*Lannea coromandelica)* as raw materials with mixture of coir fiber and coir dust (*Cocos nucifera*) to determine the effect of hybridization on physical and mechanical properties of producing lignocellulosic fiberboard. The results of different physical and mechanical properties that were found during different laboratory tests are delineated (with standard error bar) here.

The investigation group on lignocellulosic binder less hybrid fiberboards, they are:

- Pressing temperature (Tp): 180, 190, 200 °C
- Mixture Ratio (Wood Fiber: Coir fiber: Coir dust) = (60 : 30 : 10) , (50 : 40 : 10), (40 : 50 : 10)

4.2.1 Physical and mechanical response variables

In this section, I will discuss the physical and mechanical properties. Each of the response variables will be analyzed separately using the tools of the experimental design and afterwards the interactions between the experimental factors will be analyzed, if there is any. The results obtained are shown in table 4.1. For each response variable a variance analysis was performed at a confidence level of 95%.

Table 4.1: Response factor with process factor

Physio mechanical properties (continuation)										
Process factor			Response factor							
Run	Ratio% (Wood Fiber: Coir fiber: Coir dust)	Temperature	Density	MC [%]	WA [%]	TS [%]	LE [%]	MOE	MOR
A	(60 : 30 : 10)	200ºC	1013.26	7.09516	17.0711	23.8055	0.86023	3115.19	28.17989
B	(60 : 30 : 10)	190 ºC	937.525	7.83823	21.4618	25.2097	1.09762	3015.46	26.2116
C	(60 : 30 : 10)	180 ºC	916.595	8.46275	26.3328	26.7397	1.12724	2912.22	23.56964
D	(50 : 40 : 10)	200 ºC	904.723	9.02703	29.248	28.5359	1.27381	2879.09	21.33589
E	(50 : 40 : 10)	190 ºC	890.253	9.96354	33.2343	29.9174	1.7414	2759.23	20.72893
F	(50 : 40 : 10)	180 ºC	866.986	10.3253	35.0908	34.9541	1.81481	2614.32	19.05509
G	(40 : 50 : 10)	200 ºC	841.922	10.8618	38.0776	37.8705	1.88893	2423.56	17.60782
H	(40 : 50 : 10)	190 ºC	800.538	11.8531	40.376	40.9311	1.97608	2207.88	16.8761
I	(40 : 50 : 10)	180 ºC	780.41	12.557	44.2364	45.2232	2.08009	2059.46	15.59973

4.1.2 Density

Density is quantity that is used to describe the mass of a material per unit volume (Irle and Barbu, 2010). ANOVA table for density is shown in (table appendix 1) the model as fitted presents the value of R-square of 0.648. Two factors (temperature and ratio of Wood Fiber: Coir fiber: Coir dust) were found to be statistically important at a confidence level of 95%. The modeled (figure 4.1) shows that increasing wood fiber, either by increasing the temperature increases the density due to a reduction in the compression resistance of the board materials. The same results have been obtained with other materials (Hsu, W. *et al.* 1988; Sekino 1999; Velásquez, Ferrando *et al.* 2003). To allow a good distribution of lignin between the fibers during the pressing process, it is necessary to apply enough heat and pressure to melt the lignin through the whole board.

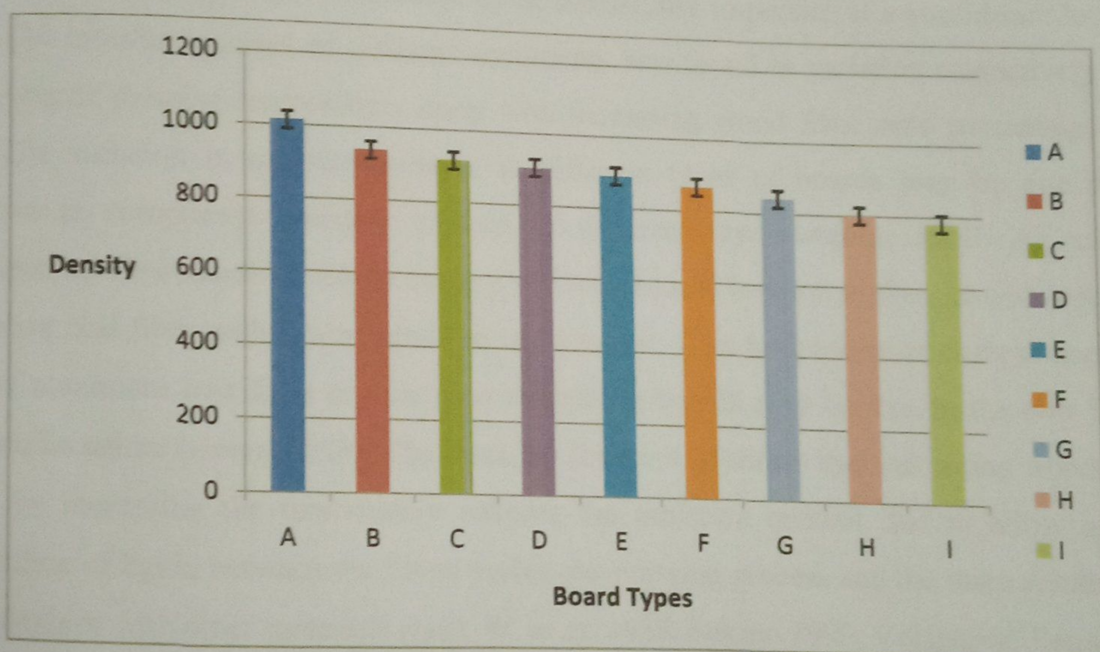

Fig. 4.1 Density variation chart for binderless fiber board

According to ANSI A208.1–1993 (NPA, 1993), all types of boards manufactured are fall into the high density (HD) grade (< 800 kg/m^3) and according to Indian Standard IS: 3087-1985 (Anon, 1985), the density of standard fiberboard 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 fiberboard is 800 kg/m^3 and 750 – 950 kg/m^3, respectively.

Density is gradually increased with the increases wood fiber content with increasing of time. Previous studies (Suchsland, Woodson *et al.* 1983) have shown that high density fiberboards fall into the ranges of 900 – 1100 kg/m^3, the higher the density better the mechanical properties will be. So we can say the same ratio of Wood Fiber: Coir fiber: Coir dust along with increasing temperature increase density in binderless fiber board due to good lignin distribution.

4.1.3 Moisture Content

Espert et al. (2003) stated that wood consists mostly of vessels in which moisture is absorbed. ANOVA tables for Moisture content (MC) is shown in (table appendix 3 and 4). The fitted models gave R's-squared of 0.302 for MC. Two factors (temperature and ratio of Wood Fiber: Coir fiber: Coir dust) were found to be statistically important at a confidence level of 95%. The moisture content of different treatments was found in variation respectively with increasing of pressing temperature along with increasing wood fiber ratio percentage (Fig. 4.2). The variation in moisture content in different types of boards may be due to the variation in component moisture content of different raw materials itself. Among the treatments of fiberboards moisture content of those boards become higher, in which contain maximum coir fiber with lowest pressing temperature. The high moisture content occurs in case of maximum coir fiber or coir dust containing boards may be due to the coir fiber's hydrophilic nature (Greer, 2008). The modeled (figure 4.2) shows that increasing wood fiber, either by increasing the temperature reduces the moisture content due to allow a good distribution of lignin between the fibers during the pressing process and the same results have been obtained with other materials (Hsu, W. *et al.* 1988; Sekino 1999; Velásquez, Ferrando *et al.* 2003).

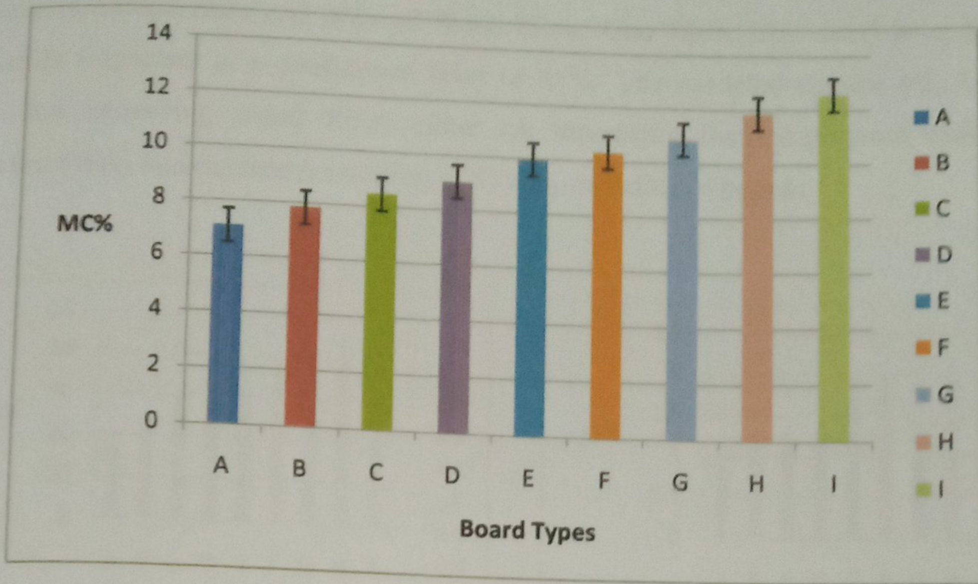

Fig. 4.2 Moisture content (MC) % variation chart for binderless fiber board

The maximum moisture content in the standard fiberboards 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 fiberboard is 5-8% (for 18 mm thick board) (The Laminex Group, 2003). Some of the boards with high density consider those criteria of standards.

4.1.4 Physical properties (WA, LE and TS)

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 stability of composites.

Water absorption (WA), linear expansion (LE) and thickness swelling (TS) are the physical properties related with the dimensional stability of the boards. These properties give us an idea of how the boards will behave when used under conditions of severe humidity, they are especially important to boards for external use. WA, LE and TS were analyzed together because came from the same assay. ANOVA tables for WA, LE and TS are shown in (table appendix 3, 4 and 5) respectively.

The fitted models gave R's-squared of 0.857for WA, 0.457 and 0.696 for TS respectively. Two factors (temperature and ratio of Wood Fiber: Coir fiber: Coir dust) were found to be statistically important at a confidence level of 95%. The modeled (figure 4.3, 4.4 and 4.5) shows that increasing wood fiber, either by increasing the temperature reduces water absorption (WA) and thickness swelling (TS) the properties of boards.

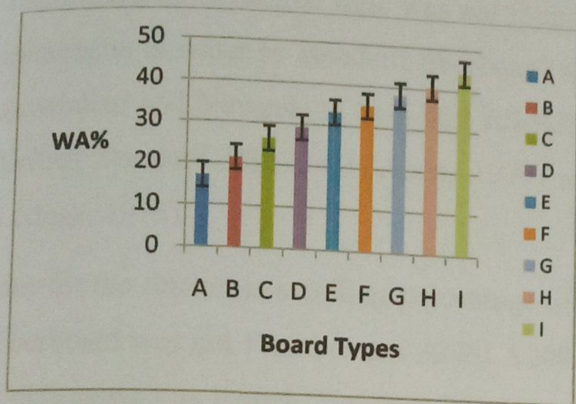

Fig. 4.3 WA% variation chart

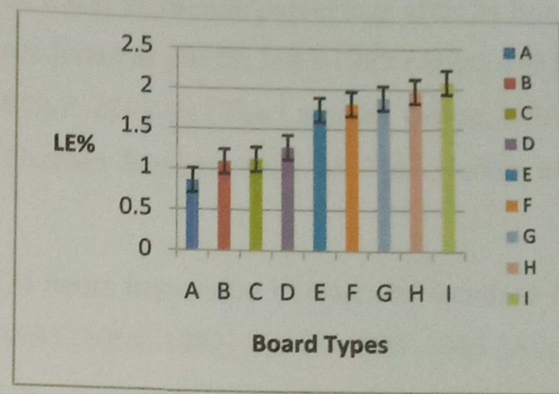

Fig. 4.4 LE% variation chart

This is because high temperature and wood fiber ratio percentage influences the general trend for the pressing process is to get lower WA, linear expansion (LE) and TS at high pressing temperatures and short times, possibly to overcome the heat and mass transfer limitations in the pressing process (Jianying, Ragil *et al.* 2006).

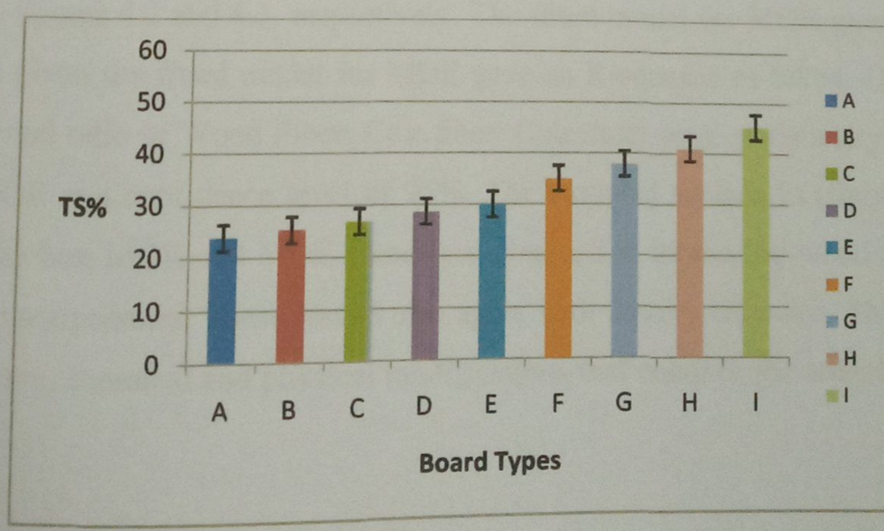

Fig. 4.5 TS% variation chart for binderless fiber board

According to IS: 3087-1985 (Anon, 1985), the absorption of water by standard fiberboard is 50% after 24 hours. The water absorption percentage by standard fiberboard 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). ANSI A208.1–1993 (NPA, 1993), has declared the maximum average linear expansion of standard fiberboard is 1.05 %, but the specified time was not found. The linear expansion percentage after 24 hours immersion in water by standard fiberboard 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).

But for the thickness swelling percentage after 24 hours immersion in water by standard for fiberboard 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 fiberboard is 20 % after 24 hours immersion in water (for 18 mm thick board) (The Laminex Group, 2003).

4.1.5 Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)

The modulus of rupture (MOR) and modulus of elasticity (MOE) are analyzed together because they came from the same bending assay. ANOVA tables for MOR and MOE are shown in (appendix tables 4.6 and 4.7), respectively. The statistical plots for MOR and MOE are shown in figures 4.2 and 4.3, respectively. The fitted model for MOR gave an R-squared of 0.734 and given the fitted model for MOE gave an R-squared of 0.884. Only two factor (temperature and ratio of Wood Fiber: Coir fiber: Coir dust) were statistically significant for MOR and MOE at a confidence level of 95%. The modeled surface in (figure 4.6 and 4.7) shows that, the best MOR and MOE values are obtained at increasing wood fiber, either by increasing the temperature. These results also agree with density behavior. This is because at high temperature, chemical and physical modifications that enhance the adhesive behavior of the lignin.

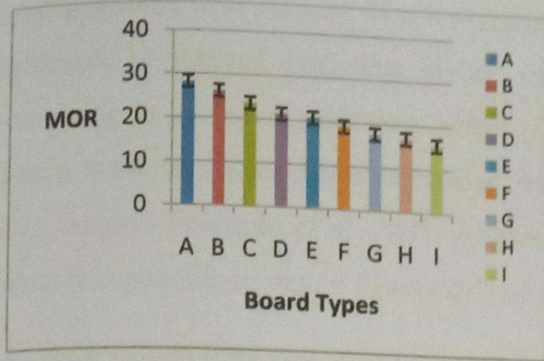

Fig. 4.3 MOR variation chart

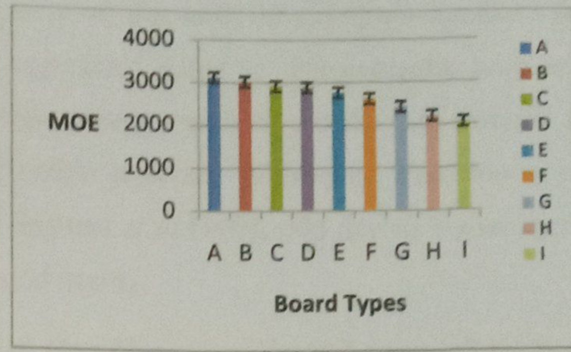

Fig. 4.4 MOE variation chart

According to ANSI A208.1–1993 (NPA, 1993), the MOR of standard fiberboard is 16.5- 27.5 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 fiberboard is 18.98 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 fiberboard is 26 N/mm².

But ANSI A208.1–1993 (NPA, 1993), the MOE of standard fiberboard is 2,400- 2,950 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 The Laminex Group, 2003). We can see that high temperature and ratio of Wood Fiber: Coir fiber: Coir dust preferred for developing the mechanical properties of the fiberboards.

The main relationship between the optimums for the mechanical and physical properties was high temperature and ratio of Wood Fiber: Coir fiber: Coir dust in the improved Density, MC, LS, WA and TS with maximizing MOR and MOE. These relationship tendencies suggest that there must be an agreement between the operational factors that result in the production of boards that fully satisfy the European standards.

It was possible to produce hybrid binderless fiberboards from Bhadi (*Lannea coromandelica*) as raw materials with mixture of coir (*Cocos nucifera*) that meet the European standards for fiberboards of internal use, thus giving an aggregated value to this energetic crop and contributing to its full exploitation. Bhadi (*Lannea coromandelica*) can the best material to produce binderless fiberboards compared with other materials (Velásquez, Ferrando *et al.* 2003). Angles, Ferrando *et al.* 2001; Anglès, Reguant *et al.* 1999), said due to higher lignin content it is possible to obtain fiberboards of good quality.

Both, high temperature and ratio of Wood Fiber: Coir fiber: Coir dust had great influence on the final physicomechanical properties of the fiberboards obtained.

4.2 Discussion

It can be seen from the above that the density of produced satisfied the ANSI 1993 standard as a high density grade fiberboard (> 800 kg/m^3) and the IS standard as a standard fiberboard and the moisture content among those boards maximum satisfy the range of Australian and Newzeland Standard (5-8%). But among them board types **A** represents maximum density and less moisture content.

Other physical properties of these binderless fiber boards like WA, TS and LE for different treatments exhibit satisfactory results. According to the (table 4.1) comparing with the standards for WA (after 24 hours immersion in water which satisfy the IS standard maximum level 50%), TS (after 24 hours immersion in water specified thickness swelling in the Australian and Newzeland Standard up to 20%) and LE (ANSI A208.1–1993 NPA, 1993, has declared the maximum average linear expansion of standard fiberboard is 1.05 %, but the specified time was not found), board types **A** represents improve quality.

The modulus of rupture (MOR) and modulus of elasticity (MOE) for those binderless fiberboards (satisfy the ANSI A208.1–1993 standard 3.0 - 23.5 N/mm^2 for MOR, and IS: 3087-1985, AS/NZS 1859.1: 2001.Int, BS: 5669, GS DIN 68 761 standards for MOE. After all among them board types **A** represents maximum standard properties which satisfy the ANSI standard for any type of density grade as well as the Australian and Newzeland Standard with little variation for other properties.

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. Binderless lignocelulosic hybrid fiberboard manufacturing industries can be established to reduce the pressure on the solid wood. In this work, fibres from Jial bhadi, (*Lannea coromandelica*) along with coir fiber and coir dust (*Cocos nucifera*) used to make experimental binderless lignocelulosic hybrid panels. The important advantages of Jial Bhadi (*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 binderless lignocelulosic hybrid fiberboard board manufacturing. It requires very poor or no management techniques or procedure. The planting method of Jial Bhadi (*Lannea coromandelica*) tree is very simple and can be planted by direct branch. On the other hand coir fiber and coir dust (*Cocos nucifera*) is a waste material from oil industry. So it is readily available and can be used for the purpose.

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 (*Lannea coromandelica*) and coir fiber and coir dust (*Cocos nucifera*) is used commercially for manufacturing binderless lignocelulosic hybrid panels, it will be an appropriate alternate environmental friendly source of raw material for binderless lignocelulosic hybrid panels industries. In this situation, the government and board industry owners may take initiatives for utilizing Jial Bhadi (*Lannea coromandelica*) and coir as an alternate source of raw material for manufacturing of binderless board in future and that could minimize current context of raw material crisis.

5.2 Recommendations

From my study it has been found that the density along with other properties of these produced boards has satisfied the physical and mechanical properties of the international standards. Only pressing temperature and mixing ratio was the variable factor in this research. But further study can also be carried out with different pressing time, pretreatment temperature along with different types of raw material mixing ratio, for setting up an optimization formula for manufacturing binderless lignocelulosic hybrid panel from Jial bhadi (*Lannea coromandelica*), coir fiber and coir dust (*Cocos nucifera*).

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APPENDIX

TABLES OF DATA ANALYSIS

Table appendix 1: ANOVA for Density

Tests of Between-Subjects Effects					
Dependent Variable:Density					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	245153.034ᵃ	8	30644.129	10.364	.000
Intercept	4.216E7	1	4.216E7	1.426E4	.000
Ratio	197965.407	2	98982.704	33.477	.000
Temperature	39889.797	2	19944.899	6.746	.003
Ratio * Temperature	7297.830	4	1824.457	.617	.653
Error	133053.690	45	2956.749		
Total	4.254E7	54			
Corrected Total	378206.724	53			
a. R Squared = .648 (Adjusted R Squared = .586)					

Table appendix 2: ANOVA Moisture content

Tests of Between-Subjects Effects					
Dependent Variable:Moc					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	160.751ᵃ	8	20.094	3.870	.002
Intercept	5160.786	1	5160.786	993.947	.000
Ratio	141.035	2	70.518	13.581	.000
Temperature	19.340	2	9.670	1.862	.167
Ratio * Temperature	.376	4	.094	.018	.999
Error	233.650	45	5.192		
Total	5555.187	54			
Corrected Total	394.401	53			
a. R Squared = .408 (Adjusted R Squared = .302)					

Table appendix 3: ANOVA for Water absorption

Tests of Between-Subjects Effects					
Dependent Variable:WA					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3843.587[a]	8	480.448	40.745	.000
Intercept	54199.011	1	54199.011	4.596E3	.000
Ratio	3362.838	2	1681.419	142.595	.000
Temperature	452.128	2	226.064	19.172	.000
Ratio * Temperature	28.622	4	7.155	.607	.660
Error	530.621	45	11.792		
Total	58573.219	54			
Corrected Total	4374.208	53			

a. R Squared = .879 (Adjusted R Squared = .857)

Table appendix 4: ANOVA Liner expansion

Tests of Between-Subjects Effects					
Dependent Variable:LS					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	9.712[a]	8	1.214	4.727	.000
Intercept	128.071	1	128.071	498.611	.000
Ratio	8.312	2	4.156	16.180	.000
Temperature	1.112	2	.556	2.166	.126
Ratio * Temperature	.288	4	.072	.280	.889
Error	11.558	45	.257		
Total	149.341	54			
Corrected Total	21.271	53			

a. R Squared = .457 (Adjusted R Squared = .360)

Table appendix 5: ANOVA Thickness swelling

Tests of Between-Subjects Effects

Dependent Variable:TS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2712.493[a]	8	339.062	16.165	.000
Intercept	57305.753	1	57305.753	2.732E3	.000
Ratio	2386.005	2	1193.002	56.876	.000
Temperature	287.435	2	143.717	6.852	.003
Ratio * Temperature	39.054	4	9.763	.465	.761
Error	943.899	45	20.976		
Total	60962.145	54			
Corrected Total	3656.392	53			

a. R Squared = .742 (Adjusted R Squared = .696)

Table appendix 6: ANOVA for Modulus of rupture

Tests of Between-Subjects Effects

Dependent Variable:MOR

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	881.742[a]	8	110.218	19.254	.000
Intercept	23855.516	1	23855.516	4.167E3	.000
Ratio	788.387	2	394.194	68.862	.000
Temperature	80.935	2	40.468	7.069	.002
Ratio * Temperature	12.420	4	3.105	.542	.705
Error	257.599	45	5.724		
Total	24994.857	54			
Corrected Total	1139.341	53			

a. R Squared = .774 (Adjusted R Squared = .734)

Table appendix 7: ANOVA for Modulus of Elasticity

Tests of Between-Subjects Effects					
Dependent Variable:MOE					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.467E6[a]	8	808363.353	25.029	.000
Intercept	3.836E8	1	3.836E8	1.188E4	.000
Ratio	5730135.506	2	2865067.753	88.708	.000
Temperature	692458.806	2	346229.403	10.720	.000
Ratio * Temperature	44312.512	4	11078.128	.343	.847
Error	1453390.850	45	32297.574		
Total	3.915E8	54			
Corrected Total	7920297.675	53			
a. R Squared = .816 (Adjusted R Squared = .784)					

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)