Khulna University
Life Science School
Forestry and Wood Technology Discipline

Author(s): Khan Md. Masudur Rahman

Title: Manufacture and properties of Arhar (*Cajanus cajan*) stalks particleboard

Supervisor(s): Dr. Md. Ashaduzzaman, Associate Professor, Forestry and Wood Technology Discipline, Khulna University

Programme: Bachelor of Science in Forestry

MANUFACTURE AND PROPERTIES OF ARHAR (*Cajanus cajan*) STALKS PARTICLEBOARD

Khan Md. Masudur Rahman

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
LIFE SCIENCE SCHOOL
KHULNA UNIVERSITY
KHULNA-9208
BANGLADESH

2016

MANUFACTURE AND PROPERTIES OF ARHAR (*Cajanus cajan*) STALKS PARTICLEBOARD

Khan Md. Masudur Rahman

STUDENT ID: 110502

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE

LIFE SCIENCE SCHOOL

KHULNA UNIVERSITY

KHULNA – 9208

BANGLADESH

2016

MANUFACTURE AND PROPERTIES OF ARHAR (*Cajanus cajan*) STALKS PARTICLEBOARD

COURSE TITLE: PROJECT THESIS

COURSE NO: FWT-4114

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

Supervisor

27/4/2016

Dr. Md. Ashaduzzaman

Associate Professor

Forestry and Wood Technology Discipline

Khulna University

Khulna, Bangladesh.

Submitted By

27/04/2016

Khan Md. Masudur Rahman

Student ID: 110502

Forestry and Wood Technology Discipline

Khulna University

Khulna, Bangladesh.

TABLE OF CONTENTS

CONTENTS **PAGE NO.**

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Anon	Anonymous
ANOVA	Analysis of Variance
LSD	Least Significant Difference
APCC	Asian and Pacific Coconut Community
ASTM	American Society for Testing and Materials
AWPA	Australian Wood Panels Association
BBS	Bangladesh Bureau of Statistics
FAO	Food and Agricultural Organization of United Nations
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

DECLARATION

I, Khan Md. Masudur Rahman, hereby declare that this thesis paper is the result of my own works and it has not been submitted or accepted for a degree in any other university. I also declare that this thesis or any information of this paper cannot be used industrially or commercially without any prior permission of the author.

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.

Signature

27/04/2016

Khan Md. Masudur Rahman

Dedicated

To

My Beloved Father Late Khan Md. Aminuddin

ACKNOWLEGMENTS

First of all, I am very grateful to almighty God for successfully completion of my B. Sc. honor's project thesis. I would like to thank and express my gratitude to several people.

It is a great pleasure for me to express my gratitude, sincere appreciation, heart-felt indebtedness and profound respect to my honorable supervisor **Dr. Md. Ashaduzzaman,** Associate Professor, Forestry and Wood Technology Discipline, Khulna University, Khulna, for his continuous supervision, guidance, inspiration, valuable advices and thoughtful suggestions during the research period and for providing useful books and papers in preparing and writing up this thesis. Moreover, without his kind supervision and encouragement I could not come up with this paper.

I am also grateful to, Professor **Md. Obaidullah Hannan** and Professor **Dr. Md. Iftekhar Shames,** Forestry and Wood Technology Discipline, Khulna University, Khulna, who have supportively guided and helped me in so many things throughout the research work. They also give me the opportunity to use Pulp and Paper Lab and Bio-nano technology Lab. Thank for their valuable suggestions and encouragement.

Finally, I would like to express my appreciation and gratitude to my beloved Parents, Brothers and Sisters specially my loving heart brother **Khan Md. Hafizur Rahman** for encouraging me and sacrificed their happiness for my education at Khulna University.

The Author

29/04/2016

Khan Md. Masudur Rahman

ABSTRACT

This study investigated the potentiality of using Arhar (*Cajanus cajan)* as a raw material for the production of particleboard and its basic physical and mechanical properties. *Cajanus cajan* was chosen because less research work has been done on this species for particleboard manufacturing. 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 0.91gm/cm^3); Moisture content (5.51%), Water absorption (18.2 and 49.27%), Thickness swelling (15.26 and 31.14 %:), Linear expansion (0.10 and 0.65%) after 2 hours and 24 hours immersion in water respectively. Modulus of Rupture for mixture particleboards (MOR, 27.93 N/mm^2) and Modulus of Elasticity (MOE, 2438.45 N/mm^2). Further study of *Cajanus cajan* may increase the potential use as alternative sources of raw materials for particleboard manufacturing based on its mechanical and physical properties.

CHAPTER ONE

INTRODUCTION

CHAPTER ONE: INTRODUCTION

1.1 Background and Justification

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 (Anon, 1986). About 70% demand for timber and 90% for fuel wood of the country is met from the trees grown in village groves of Bangladesh (Anon, 1987). 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 (Anon, 1986), 17 for ply wood (Anon, 1985), 46 for manufacture of ply for general purpose (Anon, 1983), 36 for plywood and batten for tea chest (Anon, 1979), 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 fulfil 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. Among them *Cajanus cajan* may serve as an alternative sources in particle based industries.

In recent years, special attention has been given to agro-agricultural raw materials as part of the worldwide trends concerning environmental and economic viability (Perry, 2008).

Cajanus cajan mainly planted or cultivated for pulse crop, which is grown for 5 years (maximum) (Little, 1983). At the end of the pulse production each and every part of the *Cajanus cajan* i.e., the stem and branch has the ligno-cellulosic constitution which can be used as the raw material for particleboard production. It is a neglected but a novel source of renewable ligno-cellulosic raw material. But due to little knowledge about the technical feasibility of making particleboard from these novel sources of ligno-cellulosic raw material, these are now being underutilized. *Cajanus cajan* are using as fuel wood. If the study for finding the technical feasibility to convert them into particleboard, a new avenue can be opened to the particleboard manufacturing industries. So, in the economic values of these materials will be increased.

1.2 Objectives of the study

- ✓ To utilize of *Cajanus cajan* as an alternate source of raw material for particleboard manufacturing.
- ✓ To determine the physical and mechanical properties of *Cajanus cajan* particleboard.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO: LITERATURE REVIEW

2.1 General information about particleboard

2.1.1 Definition of particleboard

A particleboard is a board (or sheet) constituted from fragments of wood and/or other lingo-cellulosic materials (chips, shavings, flakes, splinters, sawdust, etc.), bonded with organic binders with the help of one or more agents like heat, pressure, humidity, catalyst, etc. (Srivastava, 1969). It may be classified as a panel product manufactured under pressure and heat from particles of wood or other lingo-cellulosic materials bonded entirely with a binder, generally a synthetic resin, to which other chemicals (e.g., fire retardant, fungicide, water retardant etc.) may be added to improve certain properties (Salehuddin, 1992).

2.1.2 Brief history and development of particleboard

Particleboards are not more than a few decades old production. Before particleboard, modern plywood, as an alternative to natural wood, was invented in the 19th century, but by the end of the 1940s there was not enough lumber around to manufacture plywood affordably. By that time particleboard was intended to be a replacement. But before that scarcity in raw materials of plywood, first efforts were made in the early 1920's for manufacturing of particleboard. But it was unsuccessful as for the lack of suitable adhesives. Then new techniques introduced in the 1930's in resin applications with the growing demand paved the way for the industrial production of particleboard in the early 1940's (Moslemi, 1985). The first commercial piece was produced during World War II at a factory in Bremen, Germany. It used waste material such as planer shavings, off-cuts or sawdust, hammer-milled into chips, and bound together with a phenolic resin. 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

2.1.3.1.1 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).

2.1.3.1.2 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).

2.1.3.1.3 Shavings board: A particleboard in which wood shavings are the chief constituents. (Anon, 1970).

2.1.3.1.4 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).

2.1.3.1.5 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

2.1.3.2.1 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,

2.1.3.2.2 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

2.1.3.2.3 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

2.1.3.3.1 Single layer or homogeneous board,

2.1.3.3.2 Three layer board, where course particles in the core layer are sandwiched between fine particles in the face layers, and

2.1.3.3.3 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

2.1.3.4.1 Low density particleboard: Density below 590 kg/m^3 or 37 lb/ft^3,

2.1.3.4.2 Medium density particleboard: Density ranges from 590 to 800 kg/m^3 or 37 to 50 lb/ft^3 and

2.1.3.4.3 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 fibreboard, which comprise the finished product. ASTM (1997) defines an adhesive as a substance capable of holding materials together by surface attachment. The bond attained must meet the strength requirements for the structure as a whole and this bond must remain unaffected by the condition to which it will be exposed throughout its life (Youngquist, 1999).

2.1.4.2.1.1 Types of adhesive/binder

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

Natural adhesive: Adhesives of natural origin- such as animal, casein, soybean, starch and blood glues are still being used to bond wood in some plants and shops, but are being replaced more and more by synthetics. 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 3.43 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 stabilise 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 compaction 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% to 50%. Lower-density raw materials have greater compaction 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 General information about arhor (*Cajanus cajan)*

2.2.1 General description of *Cajanus cajan*

English Name: pigeon pea, pigeon pea, Congo pea, red gram.

Taxonomy

Kingdom: Plantae

Class: Equisetopsida

Subclass: Magnoliidae

Superorder: Rosanae

Order: Fabales

Family: Fabaceae/ Leguminosae

Subfamily: Faboideae

Genus: Cajanus

Species: *Cajanus cajan* (Beentje, 2010)

Botanical name: *Cajanus cajan*

Synonyms:

- ✓ *Cajanus indicus* Spreng.
- ✓ *Cajanus flavus* DC.
- ✓ *Cytisus cajanus* L.
- ✓ *Cajanus cajan* (L.) Druce. (Brink and Belay, 2006)

2.2.2 Botanical description of *Cajanus cajan*

Cajanus cajan is a glandular-pubescent, short-lived perennial (1-5 years) shrub, usually grown as an annual, 0.5-4 m high, with thin roots up to 2 m deep; stems up to 15 cm in diameter; branches many, slender(Akinnifest *et al.*, 1999).

Leaves: The leaves are alternate along the stems and are composed of three leaflets (tri-foliolate) and they are positioned alternately along the stem. The petiole (the stalk which connects the leaf to the stem) is 1-8 cm long and grooved above. The leaflets are elliptical (like a stretched circle when flat) to lance-shaped (lanceolate) and are 2.5-13.5 cm long to 1-5.5 cm wide. The leaflets are green above and a silvery grey-green beneath and are covered on their lower surfaces in small yellow glands (Duke, 1981).

Flowers: The stalked flowers are arranged along an unbranched axis (a raceme). The racemes are axillary (arising from the point between the main stem and a leaf). The flowers are yellow and are papilionaceous, typical of species belonging to the Leguminosae subfamily

Papilionoideae, and resemble, for example, the pea (*Pisum sativum*) flower. Each flower has 10 stamens, 9 of which are fused into a partial tube, with the tenth stamen free. The ovary is positioned above the sepals, petals and stamens. The style is curved (Mabberly, 2008).

Fruit: The fruit is a straight or sickle-shaped pod 2-13 cm long x 0.5-1.5 cm wide containing up to 9 seeds. The seeds are 4-9 mm x 3-8 mm and can be white, brown, and purplish, black or mottled (Mabberley, 2008).

2.2.3 Biophysical limits

Altitude: 0-2000 m, Mean annual temperature: 18-38 ^{0}C, Mean annual rainfall: 400-2500 mm (Cobley and Steele, 1976).

Temperature: *Cajanus cajan* is very heat-tolerant. It prefers hot moist conditions. Under Hawaiian conditions grows between 18 and 30°C. Will grow at temperatures above 35°C under adequate soil conditions of moisture and fertility. Does not tolerate frost, but will grow in temperatures to just above frost level. Will seed as a perennial at 1840 m down to a minimum night temperature of 10°C. Tall plants may escape light frosts because of the height of the foliage (Mabberly, 2008).

Water: *Cajanus cajan* is one of the most drought tolerant legume crops, with a wide range of rainfall tolerance, but prefers more than 625 mm and in elevated areas exceeding 2 000 m cold nights and cloudy weather interfere with fertilization of flowers. Flowers well where rainfall is 1 500 to 2 000 mm. On deep, well-structured soil will grow where rainfall is 250 to 375 mm (Cobley and Steele, 1976).

Soil: Tolerates a wide range of soils, from sands to heavy black clays. Tolerates a wide range of pH, but the most favourable range is pH 5.0 to 7.0. It is sensitive to salt spray, high salinity and to water logging. Will grow in sand provided it does not contain more than 0.0005 g of sodium chloride per gram of soil (Beentje, 2010).

2.2.4 Uses of *Cajanus cajan*

Cajanus cajan is grown as a pulse crop (crop harvested for dry seed) or eaten green as a vegetable. The grain is popularly consumed in India, Asia, and Africa. India is the largest importer and producer, where seed is sold as dhal (Cobley and Steele, 1976). It can also be grown as forage intercropped with sorghum and/or millet (Cook *et al.*, 2005). Plantings are used as live fences and windbreaks in many regions. C. *cajan* sticks are an important household fuel in many areas. It has several advantages over traditional trees, such as its rapid growth potential, possibility of producing other crops on the same land, and production of a seed crop. Farmers sow it instead of grain because of its wood. Its productivity levels more than make up for the comparatively poor fuel characteristics. The woody part of *Cajanus cajan* stalks is also used in light construction such as in roofing, wattling on carts, tubular wickerwork lining for wells and baskets (Little, 1983).

CHAPTER THREE

MATERIALS AND METHODS

CHAPTER THREE: MATERIALS AND METHODS

3. 1 Manufacturing of particleboards

3.1.1 Methods and procedures

3.1.1.1 Collection of raw materials

Cajanus cajan was used as the raw material for manufacturing the particleboards. It was about one year old and height was about 1.5-2.5 m. It was collected from Sonadanga to Zero point road side of Khulna. The Urea-Formaldehyde was collected from local market, which is available as raw material.

3.1.1.2 Preparation of raw materials:

At first *Cajanus cajan* 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 100±3°C for 4 hours. Then the chips were run into grinder to produce particles.

3.1.1.3 Screening:

For the purpose particles were screened through screener to separate the fine and coarse particles. At first the particles were screened by sieve no.16 and then again screened by sieve no. 8. The particles which passed through sieve no.8 were taken as 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 100±3°C for 2 hours to dry them. At this stage the particle moisture content was 7-8 %.

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. Flour as extender and Ammonium Chloride (NH_4Cl) as hardener were used in the adhesive. Eight percent (8%) Urea-formaldehyde adhesive were mixed with the particles. The composition of the adhesive solution was as follows-

Table 3.1.1.5: The composition of the ingredients in the prepared adhesive-

Ingredients	Percentages (%)
Urea formaldehyde (UF)	35
Water	55
Flour	9.5
Ammonium Chloride (NH_4Cl)	0.5

(Hasan, 2011).

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 24mm as the target board thickness was 6mm.

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 150^{0}C. The pressure was raised to 4Mpa and continued to 8 minutes. Then the board was kept 20 minutes for curing the resin at the same pressure, so that the board may balance with environmental condition.

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 *Cajanus cajan*

Dimensions (mm)	200mm×150mm
Thickness (mm)	6mm
Temperature	150°C
Pressure	4 Mpa
Board Types	3 (Fine, Coarse, Mixture (50:50))
Replications	6 (for each type)
Total board manufactured	9
Adhesive	Urea formaldehyde (UF)- 8%

3.1.3 Flow chart of the particleboard formation process

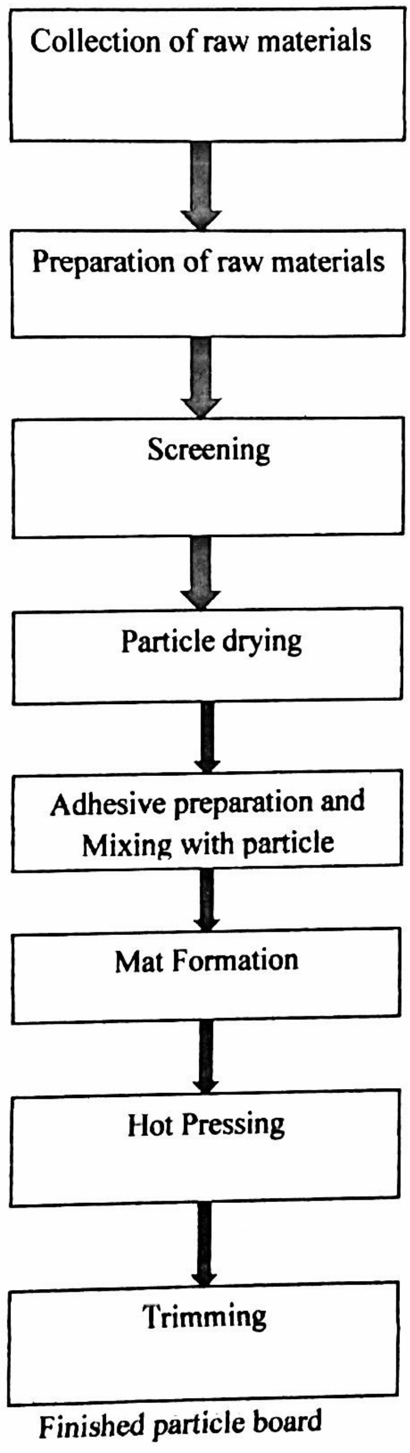

Figure 3.1.3: Flow Diagram of particle board Manufacturing Process

Figure 3.1.5: Chips of *Cajanus cajan*

Figure 3.1.4: *Cajanus cajan* plant

Figure3.1.6: Coarse particles

Figure 3.1.7: Fine particles

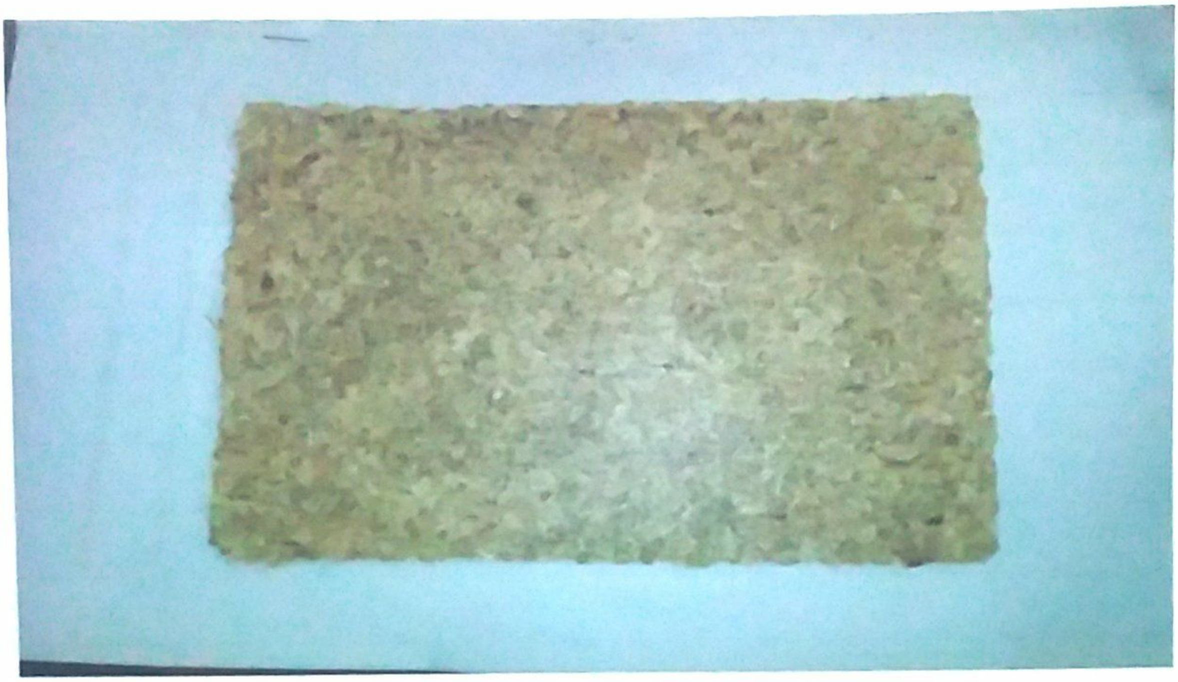

Figure 3.1.8: *Cajanus cajan* particleboard (fine particles)

Figure 3.1.9: *Cajanus cajan* particleboard (Coarse particles)

Figure 3.1.10: *Cajanus cajan* particleboard (fine: coarse)

3.3 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).

3.4 Preparation of samples for testing

Six replications of each type of boards were manufactured as stated earlier. For testing physical properties, six (6) samples were collected from each board of each type. So the total number of sample was eighteen (18) for each type of particleboard for testing of physical properties. For testing mechanical properties, six (6) samples were collected from each board of each type. So the total number of sample was eighteen (18) 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 35 mm).

3.5 Determination of physical properties:

All the samples were 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 2 hours and 24 hours. Finally, the wet dimension are taken and all the physical properties are calculated by using following formula-

3.5.1 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.

3.5.2 Moisture content

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

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

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

3.5.3 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-

$$A_w = \frac{m_2 - m_1}{m_1} \times 100 \quad \text{(ASTM D1037-99, 1997)}$$

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.).

3.5.4 Thickness swelling

Thickness swelling was calculated by the following formula-

$$G_t = \frac{t_2 - t_1}{t_1} \times 100 \quad \text{(ASTM D1037-99, 1997)}$$

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

3.5.5 Linear expansion

The Linear Expansion was calculated by the following formula-

$$LX(\%) = \frac{L_A - L_B}{L_B} \times 100 \quad \text{(ASTM D1037-99, 1997)}$$

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

3.6 Determination of mechanical Properties

All the samples were cut into (150 mm x 35 mm) dimension for testing mechanical properties of the particleboards. Mechanical properties were measured by using universal testing machine (UTM) (model: WE-100, made by Time Group Inc.).

3.6.1 Modulus of rupture (MOR)

The MOR was calculated from the following equation-

$$\text{MOR} = \frac{3PL}{2bd^2}$$ (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).

3.6.2 Modulus of elasticity (MOE)

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

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

3.7 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 DISCUSSION

CHAPTER FOUR: RESULTS AND DISCUTIONS

4.1 Physical properties

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 *Cajanus cajan* are 0.88 , 0.87 and 0.91 gm/cm^3 respectively. From the analysis of variance, it has been found that there was significant difference ($F= 3.745$, $df=2$ and $p<0.05$) among the density of three different particleboards.

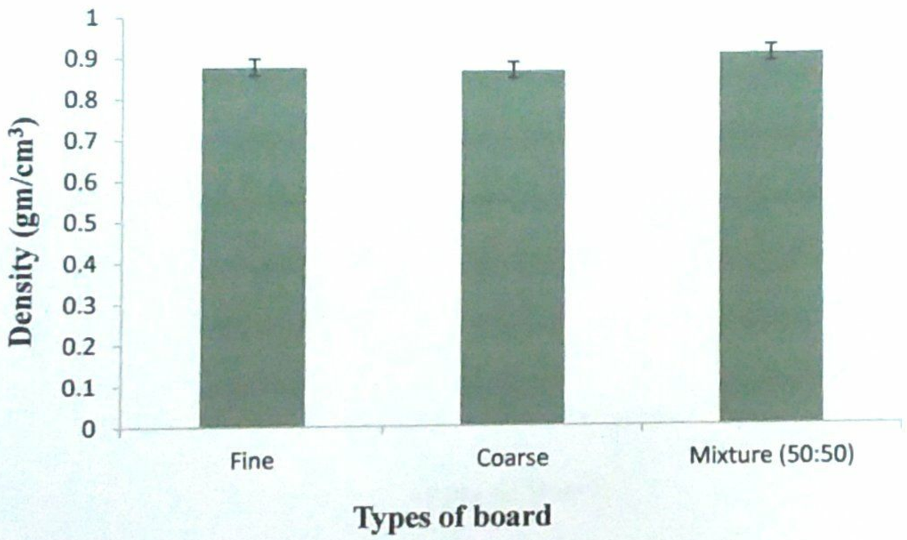

Figure 4.1.1: Density (gm/cm^3) of particleboards of different particle size

It was found that the density of *Anthocepalus chinensis* particleboard (16mm thickness) and *Bombax ceiba* particleboard (15mm thickness) 0.72 and 0.74 gm/cm^3 respectively (Sattar and Akhtaruzzaman, 1997 and Mafuz, 2006). It was also found that the density of dhaincha particleboard was 0.6 gm/cm^3 (Islam *et al.*, 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 particleboard 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 *Cajanus cajan* 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 *Cajanus cajan* are 5.51, 5.62 and 5.57% respectively. From the analysis of variance, it has been found that there was no significant difference (F=1.052, df=2 and p>0.05) among the moisture content of three different particleboards.

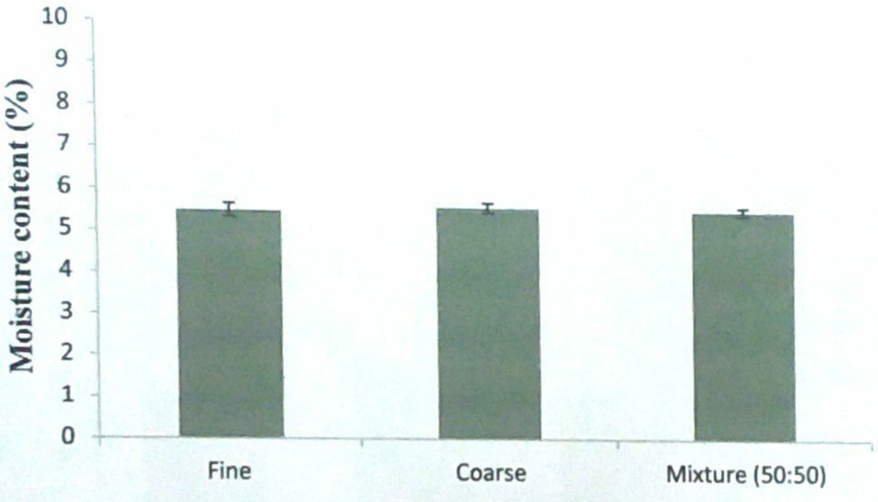

Figure 4.1.2: Moisture content (%) of particleboards of different particle size

It was found that the moisture content of dhaincha particleboard was 6.5% (Islam *et al.*, 2006). 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%. Therefore, moisture content of *Cajanus cajan* particleboard is less than dhaincha particleboard and follows both type of standards.

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 *Cajanus cajan* are 19.86, 21.60 and 18.27% respectively after 2 hours immersion in water.. It has been also found that the absorption of water of particleboards of three different particle size fine, coarse and their mixture (50:50) are 52.79, 54.84 and 49.27% respectively after 24 hours immersion in water. From the analysis of variance, it has been found that there was significant difference among the absorption of water of three different particleboards after 2 hours ($F=12.966$, $df=2$ and $p<0.05$) and 24 hours ($F=13.071$, $df=2$ and $p<0.05$) immersion in water.

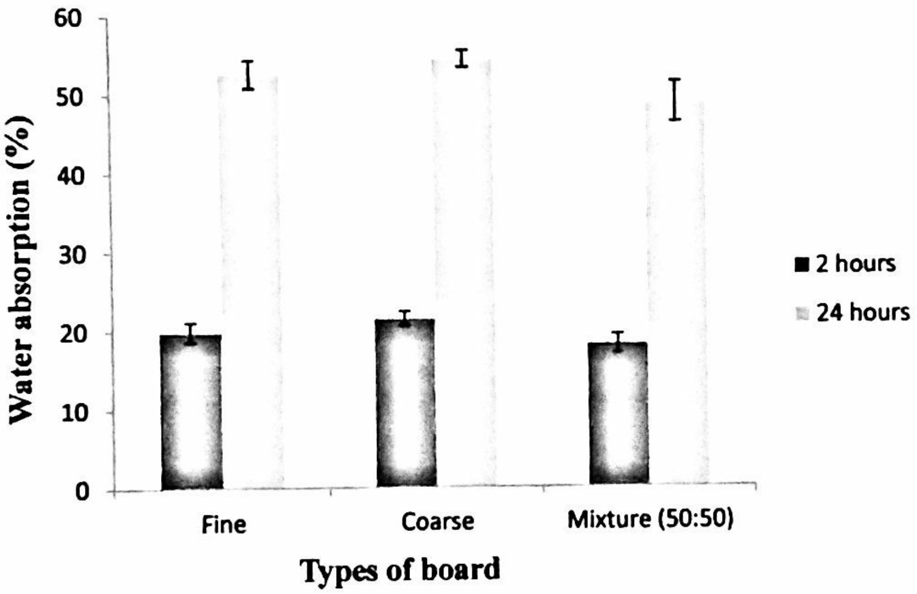

Figure 4.1.3: Water absorption (%) of particleboards of different particle size

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 and Mafuz, 2006). It was also found that absorption of water by dhaincha particleboard is 26.8 and 69.49% for 2 hours and 24 hours respectively (Islam *et al.*, 2006). 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 *Cajanus cajan* particleboards is lower than the dhaincha particleboard after 2 and 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 *Cajanus cajan* are 16.79, 17.76 and 15.26% respectively after 2 hours immersion in water.. It has been also found that the thickness swelling of particleboards of three different particle size fine, coarse and their mixture (50:50) are 32.45, 34.18 and 31.14% respectively after 24 hours immersion in water. From the analysis of variance, it has been found that there was significant difference among the thickness swelling of three different particleboards after 2 hours ($F= 7.450$, $df=2$ and $p<0.05$) and 24 hours ($F= 11.572$, $df=2$ and $p<0.05$) immersion in water.

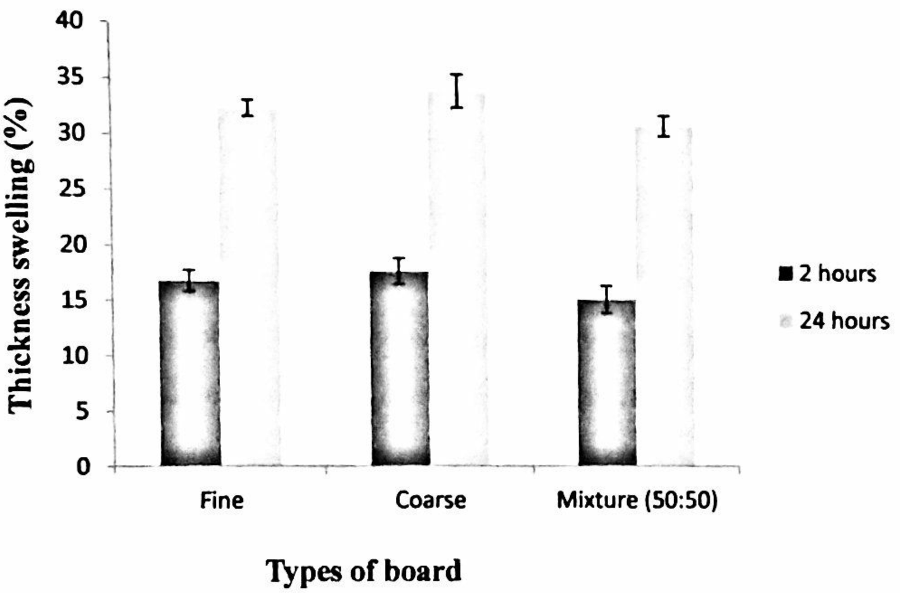

Figure 4.1.4: Thickness swelling (%) of particleboards of different particle size

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, 27and 32% respectively after 24 hours immersion in water (Sheikh *et al.*, 1993 and Mafuz, 2006). It was also found that thickness swelling percentage in thickness of dhaincha particleboard is 1.8 and 9.5% after 2 and 24 hours respectively (Islam *et al.*, 2006). 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 *Cajanus cajan* 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 *Cajanus cajan* are 0.10, 0.14 and 0.15% respectively after 2 hours immersion in water.. It has been also found that the linear expansion of particleboards of three different particle size fine, coarse and their mixture (50:50) are 0.75, 0.65 and 0.75% respectively after 24 hours immersion in water. From the analysis of variance, it has been found that there was no significant difference among the linear expansion of three different particleboard after 2 hours ($F= 2.969$, $df=2$ and $p>0.05$) and 24 hours ($F= 2.009$, $df=2$ and $p>0.05$) immersion in water.

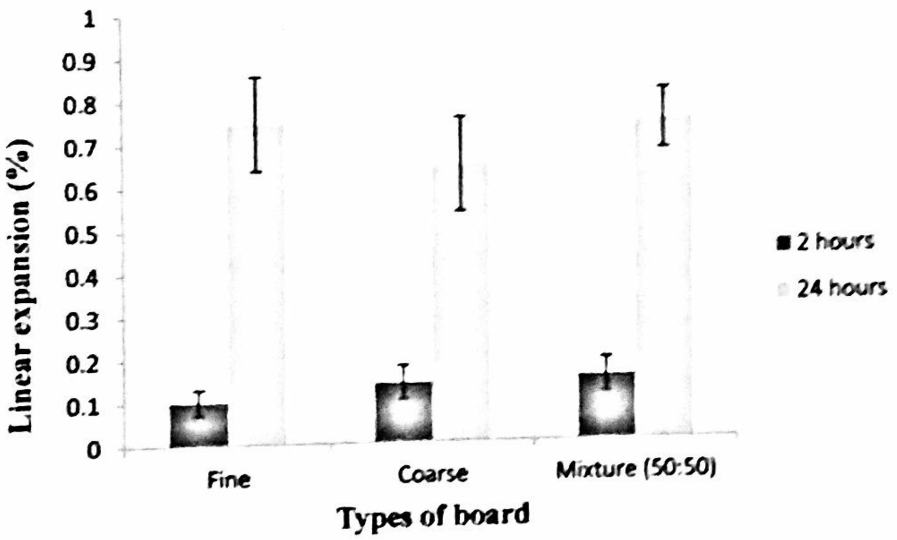

Figure 4.1.5: Linear expansion (%) of particleboards of different particle size

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 *Cajanus cajan* are 23.67 , 25.15 , and 27.93 N/mm^2 respectively. From the analysis of variance, it has been found that there was significant difference ($F=10.566$, $df=2$ and $p<0.05$) among the modulus of rupture of three different particleboards.

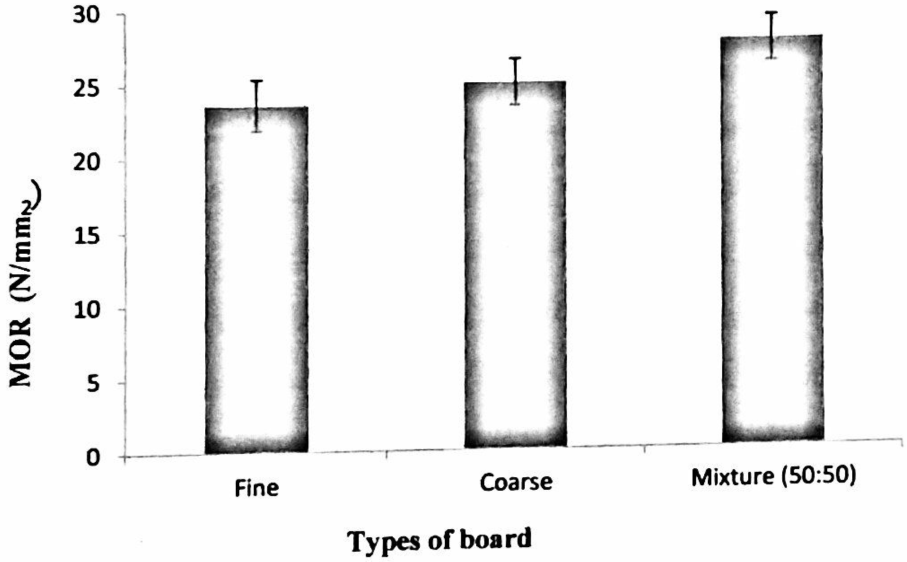

Figure 4.2.1: Modulus of rupture (N/mm^2) of particleboards of different particle size

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, 15.10, 14.81, 12.16 and 13.14 N/mm^2 respectively(Sheikh *et al.*, 1993). It was also found that the modulus of rupture of dhaincha particleboard is 16.5 N/mm^2 (Islam *et al.*, 2006). 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), MOR of standard particleboards 10.98 and 17.65 N/mm^2 respectively. Therefore, it shows that the MOR of *Cajanus cajan* particleboard is higher than the dhaincha, *Anthocepalus chinensis, 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 *Cajanus cajan* are 1964.37 , 2141.76 and 2438.45 N/mm^2 respectively. From the analysis of variance, it has been found that there was significant difference (F= 7.432, df=2 and $p<0.05$) among the modulus of elasticity of three different particleboards.

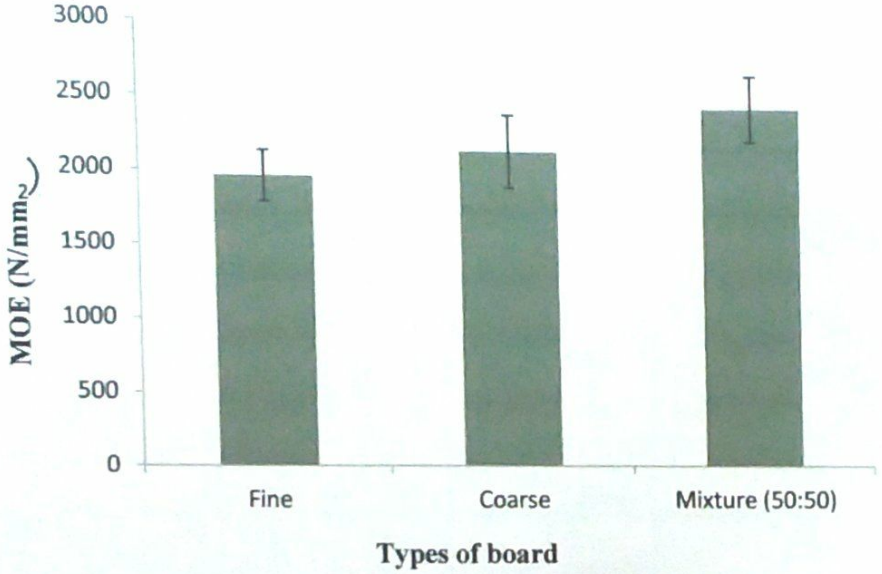

Figure 4.1.1: Modulus of elasticity (N/mm^2) of particleboards of different particle size

According to ANSI A208.1–1993 (NPA, 1993), the MOE of standard particleboard is 2,400-2,750 , 1725-2750 and 550-1025 N/mm^2 for high grade, medium grade and low grade respectively. The value of MOE of *Cajanus cajan* particleboard follows the standard of ANSI for medium grade particleboard.

4.3 Physical and mechanical properties of particleboard according to different standards

The physical and mechanical properties of *Cajanus cajan* stem particleboard manufacturing with different particle size are compared with the different standardized particleboard properties found around the world (Table 4.3). From the table 4.3, 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 different standardized properties of particleboard.

Table 4.3.1: Physical and Mechanical properties of particleboard 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/mm²)	MOE (N/mm²)
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
Cajanus cajan particleboard	Fine	0.88	5.51	52.79	32.45	0.75	23.67	1964.37
	Coarse	0.87	5.62	54.84	34.18	0.65	25.15	2141.76
	Mixture	0.91	5.57	49.27	31.14	0.75	27.93	2438.45

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

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

CHAPTER FIVE: CONCLUSION AND RECOMENDATIONS

5.1 Conclusion

In this research, an attempt is made to understand the mechanical and physical properties of particleboard manufactured from arhor (*Cajanus cajan*). Agricultural waste materials and annual plant particle have become alternative raw materials for the production of particleboard. The most frequently referred alternative non-wood materials can be arhor, jute sticks, wheat straw, kenaf, rich husk, til residues, dhaincha, bamboo etc.

Therefore, from the above presented results and discussion it has been observed that all physical and mechanical properties of *Cajanus cajan* particleboard meet the requirements of the international standard like ANSI; ISO; AS/NZS, GS. Based on the experiment it is also found that the arhor particleboard shows quite satisfactory results in case of physical and mechanical properties in comparison with the different woody and non-woody particleboard.

From the analysis of physical and mechanical properties among three types of boards there are significant differences in density, water absorption, thickness swelling, modulus of rupture and modulus of elasticity except moisture content and linear expansion.

From this point of view, manufacturing of particleboard using *Cajanus cajan* has great potentiality to meet the increasing demand for wood based products as well as the size of particles affect the properties of particleboard. So from the study, it can be said that *Cajanus cajan* could be a potential raw material for particleboard manufacturing.

5.2 Recommendations

Cajanus cajan 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) etc., with different pressure and temperature which may have the ability to enhance the physical and mechanical properties of arhor particleboard and also to give new variation to the particleboard manufactured from *Cajanus cajan*. In this situation, the government and particleboard industry owners may take initiatives for utilizing arhor as an alternate source of raw material for manufacturing of particleboard in future. So, further study may be conducted in future.

REFERENCES

REFERENCES

Anon, 1985. Specification for wood particleboards (medium density) for general purpose (First revision). IS: 3087-1985. Indian Standard Institution, New Delhi, 19pp.

ANSI (American National Standards Institute), 1999, American National Standard for particleboard. ANSI/A208.1. Composite Panel Association, Gaithersburg, MD

ASTM (American Society for Testing Materials), 1997. Standard Test Methods for Evaluating Properties of Wood –Base Fiber and Particle Panel Materials, ASTM D1037-99, ASTM, West Conshohocken, PA: 699-706.

Anon, 1987. Forest sector planning in Bangladesh, Project Profile No. 3. FAO Forestry Department, Rome, 4pp.

Anon, 1986. Bangladesh standard specification for veneered decorative plywood. BDS1158:1986. Bangladesh Standard and Testing Institution, 116/A, Tejgaon Industrial Area, Dhaka-1208, Bangladesh. 9pp

Anon, 1983. Bangladesh Standard Specification for plywood for general purpose (First revision) BDS 799: 1983. 3-DIT Avenue, Motijheel Commercial Area, Dhaka-2, Bangladesh. 21pp.

Anon, 1979. Specification for wood chipboard and methods of test for particleboard, BS 5669. British Standards Institution, 28pp.

Anon, 1981. Unpublished report of Particleboard and Veneering plant, BFIDC, Kalurghat, Chittagong, Bangladesh.

Anon, 1984. Draft research proposal, end-use classification of lesser used of un-used wood species. Bangladesh Forest Research Institute, Chittagong, Bangladesh, 43pp.

Anon. 1970. Composite Wood and Improved Wood. pp. 329-356. Chapter XV. In: Venkataramany, P. and Venkataramanan, S. V. (eds.), Indian Forest Utilization.Vol. 1. Forest Research Institute and Colleges, Dehra Dun, India.

AWPA (Australian Wood Panels Association), 2001. Manufacture. Australian Wood Panels Association Incorporated, Coolangatta Qld, 1-6pp.

ASTM (American Standards Testing Method), 1997. Standard methods for testing small clear specimens of timber. ASTM D143. West Conshohocken, PA: American Society for Testing and Materials.

Anon. 1986. The useful plants of India. Publications & Information Directorate, CSIR, New Delhi, India.

Akinnifesi F.K, Araújo M.A, Moura EG. 1999. Root distribution of *Cajanus cajan* and alley cropped maize in response to inter-hedgerow spacing: Forest, Farm, and Community Tree Research Reports. 4:64-67.

Biswas D. 2008. Bamboo as an alternative to wood for composites manufacture. PhD dissertation. Institute of Forestry and Environmental Sciences,Chittagong University, Chittagong Bangladesh.

Beentje, H. 2010. The Kew Plant Glossary: an Illustrated Dictionary of Plant Terms. Royal Botanic Gardens, Kew.

Brink, M, Belay, G. 2006. Cereals and Pulses: Volume 1 of Plant Resources of Tropical Africa. PROTA.

Cook B.G., B.C. Pengelly, S.D. Brown, J.L. Donnelly, D.A. Eagles, M.A. Franco, J.Hanson, B.F. Mullen, I.J. Partridge, M. Peters, and R. Schultze-Kraft. 2005. Tropical forages: an interactive selection tool. *Cajanus cajun*. CSIRO, DPI& F(Qld), CIAT, and ILRI, Brisbane, Australia.

Cobley L.S, Steele W.M. 1976. An Introduction to the Botany of Tropical Crops. Longman Group Limited.

Desch, H. E. and Dinwoodie, J. M. 1996. Timber Structure, Properties, Conversion and Use. 7th edition, Macmillan Press Limited, London, 102-127pp.

Duke, J. A. 1981. Handbook of Legumes of World Economic Importance. New York: Plenum Press.

Das, D.K. 1990. List of Bangladesh Village Tree Species Unpublished report, Forest Research Institution, Chittagong, Bangladesh.

FAO, 1986. *Wood preservation manual*. FAO Forestry Paper 76, FAO, Rome,1- 135pp.

Husain, M.S. 1962. Wood preservation in National Economy. *Wood Preservation Series*, non-technical bulletin no. 1, Pakistan Forest Research Laboratory, Chittagong 1-6pp.

Islam M.N. Mahfuz A.A, Hannan M.O, Islam M.A, 2006, Manufacturing and Properties particleboard from Dhaincha (Sesbania aculeate), Journal of Biological Science, 6: 417-419pp.

Little E.L, 1983. Common fuel wood crops. Communi-Tech Association, Morgantown, West Virginia.

Lahiry, A.K. 2001. Aplied Wood Preservation. Magnum opus. Dhaka, 342-344 pp.

Moslemi, A.A. 1985. Particleboard; (volume –1: Materials & Volume – 2 Technology.)

Mabberley, D.J. 2008. Mabberley's Plant-book: a Portable Dictionary of Plants, their Classification and Uses. Third edition. Cambridge University Press,

Natasa A., Songklod J., Vallayuth F. and Piyawade B., 2011. Effect of thermal- treatment of wood fibres on properties of flat-pressed wood plastic composites.

NPA (National particleboard Association). 1993. Particleboard, ANSI A208.1-1993. Gaithersburg, MD: National Particleboard Association

Perry LM. 1980. Medicinal plants of East and South East Asia : attributed properties and uses. MIT Press. South East Asia.

Sheikh M.W, Biswas D, and Azizullah M.A. (1993). Studies on peeling, Drying and Gluing of Veneer and Particleboard of ten Village Tree Species of Bangladesh: Bulletin 5, Composite Wood Products Series, Bangladesh Forest Research Institution, 19pp.

Salehuddin, A. B. M. 1992. Wood and Fibre Composite Materials. Gen. Tech. Rep. UNDP/FAO BGD/85/011. Institute of forestry, Chittagong University, Chittagong, Bangladesh and Food and Agriculture Organization of the United Nations, Rome, Italy, 24-35pp.

Sattar M.A and Akhtaruzzaman A.F.M 1997. End-use Classification of lesser Used or Unused Wood Species; Bulletin1, Forest Products Branch, Bangladesh Forest Research Institute, 10-34pp.

Shrivastava, M.B. 1969. Introduction to Forestry. The Papua New Guinea University of Technology Leo.

Vick C. B. 1999. Adhesive Bonding of Wood Materials. In: Forest Products Laboratory (ed.), Wood handbook—Wood as an engineering material. Gen. Tech. Rep. FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, 9:1-24pp.

Verkor S.A and Leduge G. 1975. German Standard DIN 68761, Cited in FAO Port Follo of Scale Wood Based Panel Plants, Koningin Astridlaan, B-8520?LAUWE/BEL, 54pp.

Wangaard, F.F. 1962. Wood: *its structure and p* (Placeholder2) *roperties.* Forest Products Laboratory, Forest Service, USDA, 1-459pp.

Youngquist, J. A. 1999. Wood-based Composites and Panel Products. pp. 1-31. Chapter 10. In: Forest Products Laboratory (ed.), Wood handbook—Wood as an engineering material. Gen. Tech. Rep. FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

APPENDIX

DATA ANALYSIS

APPENDIX

1. Analysis of Variance for Density

ANOVA					
Density					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.004	2	.002	3.745	.048
Within Groups	.008	15	.001		
Total	.011	17			

Multiple Comparisons							
Dependent Variable: Density							
	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	Fine	Coarse	.00167	.01302	.900	-.0261	.0294
		Mixture	-.03000*	.01302	.036	-.0578	-.0022
	Coarse	Fine	-.00167	.01302	.900	-.0294	.0261
		Mixture	-.03167*	.01302	.028	-.0594	-.0039
	Mixture	Fine	.03000*	.01302	.036	.0022	.0578
		Coarse	.03167*	.01302	.028	.0039	.0594

*. The mean difference is significant at the 0.05 level.

2. Analysis of Variance for Moisture content

ANOVA					
Moisture content					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.036	2	.018	1.052	.373
Within Groups	.259	15	.017		
Total	.296	17			

Multiple Comparisons							
Dependent Variable: Moisture content							
	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	Fine	Coarse	.05000	.07592	.520	-.1118	.2118
		Mixture	.11000	.07592	.168	-.0518	.2718
	Coarse	Fine	-.05000	.07592	.520	-.2118	.1118
		Mixture	.06000	.07592	.442	-.1018	.2218
	Mixture	Fine	-.11000	.07592	.168	-.2718	.0518
		Coarse	-.06000	.07592	.442	-.2218	.1018

3. **Analysis of Variance for Water absorption (2 hrs.)**

ANOVA					
Water absorption					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	33.426	2	16.713	12.966	.001
Within Groups	19.335	15	1.289		
Total	52.761	17			

Multiple Comparisons							
Dependent Variable: Water absorption							
	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	Fine	Coarse	-1.74833*	.65549	.018	-3.1455	-.3512
		Mixture	1.58833*	.65549	.029	.1912	2.9855
	Coarse	Fine	1.74833*	.65549	.018	.3512	3.1455
		Mixture	3.33667*	.65549	.000	1.9395	4.7338
	Mixture	Fine	-1.58833*	.65549	.029	-2.9855	-.1912
		Coarse	-3.33667*	.65549	.000	-4.7338	-1.9395

*. The mean difference is significant at the 0.05 level.

4. **Analysis of Variance for Water absorption (24 hrs.)**

ANOVA					
Water absorption					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	95.277	2	47.638	13.071	.001
Within Groups	54.669	15	3.645		
Total	149.946	17			

Multiple Comparisons							
Dependent Variable: Water absorption							
	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	Fine	Coarse	-2.05333	1.10221	.082	-4.4026	.2960
		Mixture	3.51833*	1.10221	.006	1.1690	5.8676
	Coarse	Fine	2.05333	1.10221	.082	-.2960	4.4026
		Mixture	5.57167*	1.10221	.000	3.2224	7.9210
	Mixture	Fine	-3.51833*	1.10221	.006	-5.8676	-1.1690
		Coarse	-5.57167*	1.10221	.000	-7.9210	-3.2224

*. The mean difference is significant at the 0.05 level.

5. **Analysis of Variance for Thickness swelling (2 hrs.)**

ANOVA					
Thickness swelling					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	19.315	2	9.658	7.450	.006
Within Groups	19.446	15	1.296		
Total	38.761	17			

Multiple Comparisons							
Dependent Variable: Thickness swelling							
	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	Fine	Coarse	-.86500	.65737	.208	-2.2661	.5361
		Mixture	1.63333*	.65737	.025	.2322	3.0345
	Coarse	Fine	.86500	.65737	.208	-.5361	2.2661
		Mixture	2.49833*	.65737	.002	1.0972	3.8995
	Mixture	Fine	-1.63333*	.65737	.025	-3.0345	-.2322
		Coarse	-2.49833*	.65737	.002	-3.8995	-1.0972

*. The mean difference is significant at the 0.05 level.

6. **Analysis of Variance for Thickness swelling (24 hrs.)**

ANOVA					
Thickness swelling					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	27.901	2	13.951	11.572	.001
Within Groups	18.084	15	1.206		
Total	45.985	17			

Multiple Comparisons							
Dependent Variable: thickness swelling							
	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	Fine	Coarse	-1.73000*	.63393	.016	-3.0812	-.3788
		Mixture	1.31000	.63393	.056	-.0412	2.6612
	Coarse	Fine	1.73000*	.63393	.016	.3788	3.0812
		Mixture	3.04000*	.63393	.000	1.6888	4.3912
	Mixture	Fine	-1.31000	.63393	.056	-2.6612	.0412
		Coarse	-3.04000*	.63393	.000	-4.3912	-1.6888

*. The mean difference is significant at the 0.05 level.

7. **Analysis of Variance for Linear expansion (2 hrs.)**

ANOVA					
Linear expansion					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.008	2	.004	2.969	.082
Within Groups	.021	15	.001		
Total	.030	17			

Multiple Comparisons							
Dependent Variable: Linear expansion							
	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	Fine	Coarse	-.04333	.02182	.066	-.0898	.0032
		Mixture	-.04833*	.02182	.043	-.0948	-.0018
	Coarse	Fine	.04333	.02182	.066	-.0032	.0898
		Mixture	-.00500	.02182	.822	-.0515	.0415
	Mixture	Fine	.04833*	.02182	.043	.0018	.0948
		Coarse	.00500	.02182	.822	-.0415	.0515

*. The mean difference is significant at the 0.05 level.

8. Analysis of Variance for Linear expansion (24 hrs.)

ANOVA					
Linear expansion					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.040	2	.020	2.009	.169
Within Groups	.149	15	.010		
Total	.189	17			

Multiple Comparisons							
Dependent Variable: Linear expansion							
	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	Fine	Coarse	.09833	.05762	.109	-.0245	.2212
		Mixture	-.00333	.05762	.955	-.1262	.1195
	Coarse	Fine	-.09833	.05762	.109	-.2212	.0245
		Mixture	-.10167	.05762	.098	-.2245	.0212
	Mixture	Fine	.00333	.05762	.955	-.1195	.1262
		Coarse	.10167	.05762	.098	-.0212	.2245

9. **Analysis of Variance for MOR**

ANOVA					
MOR					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	56.265	2	28.133	10.566	.001
Within Groups	39.938	15	2.663		
Total	96.203	17			

Multiple Comparisons							
Dependent Variable MOR							
	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	Fine	Coarse	-1.48167	.94208	.137	-3.4897	.5263
		Mixture	-4.26500*	.94208	.000	-6.2730	-2.2570
	Coarse	Fine	1.48167	.94208	.137	-.5263	3.4897
		Mixture	-2.78333*	.94208	.010	-4.7913	-.7753
	Mixture	Fine	4.26500*	.94208	.000	2.2570	6.2730
		Coarse	2.78333*	.94208	.010	.7753	4.7913

*. The mean difference is significant at the 0.05 level.

10. Analysis of Variance for MOE

ANOVA					
MOE					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	688474.571	2	344237.286	7.432	.006
Within Groups	694756.581	15	46317.105		
Total	1383231.152	17			

Multiple Comparisons							
Dependent Variable: MOE							
	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	Fine	Coarse	-177.39667	1.24254E2	.174	-442.2376	87.4443
		Mixture	-474.07667*	1.24254E2	.002	-738.9176	-209.2357
	Coarse	Fine	177.39667	1.24254E2	.174	-87.4443	442.2376
		Mixture	-296.68000*	1.24254E2	.031	-561.5209	-31.8391
	Mixture	Fine	474.07667*	1.24254E2	.002	209.2357	738.9176
		Coarse	296.68000*	1.24254E2	.031	31.8391	561.5209
*. The mean difference is significant at the 0.05 level.							