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FEASIBILITY STUDY OF PHYSICAL AND MECHANICAL PROPERTIES OF CEMENT-BONDED BOARD FROM BETEL NUT (*Areca catechu*)

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Dedicated To My Parents

DECLARATION

I, Rupak Kumar Ghosh, declare that this thesis paper is 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 any kind of photocopying and for inter-library loans.

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APPROVAL

Project thesis submitted to the Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh, in partial fulfillment of the requirements for the professional MS (Masters) degree in Forestry. I have approved the style and format of the project thesis.

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ABSTRACT

The study was conducted to evaluate the properties of cement bonded board made from *Areca catechu* stem. The particles used to make cement bonded boards were divided in to three types on the basis of treatment. They are fine, coarse and coarse fine. The ratios of particles weight and cement which were used to manufacture the cement bonded particles boards were 1:2 and 1:3 for fine coarse and coarse fine particles. The laboratory tests for characterization of physical and mechanical properties were carried out for each type of board. In case of physical properties Moisture content, Density, Water absorption, Thickness swelling and linear expansion were evaluated. Modulus of Elasticity (MOE) and Modulus of Rapture (MOR) were evaluated for Mechanical properties. From all the cement bonded boards made with the ratio of 1:3 showed the best performance. From the analysis of data it was found that there were significant difference in density, moisture content, absorption of water, linear expansion, MOR and MOE among fine, coarse and fine coarse particles and boards of different ratios. There were no significant difference in linear expansion and thickness swelling between fine, coarse and fine coarse particles and ratios. Hence it can be conclude that cement bonded particle board from betelnut can be an alternative material for manufacturing cement bonded board.

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ABBREVIATIONS

AD	Air-dry dimension
Anon	Anonymous
APCC	Asia and Pacific Coconut Community
APFSOS	Asia Pacific Forestry Sector Outlook Study
ASTM	American Society For Testing and Materials
BFRI	Bangladesh Forest Research Institute
cm^3	Cubic Centimeter
EMC	Equilibrium Moisture Content
FAO	Food and Agricultural Organization
ft.	Feet
g	Gram
GD	Green dimension
ha	Hectare
Kg	Kilogram
m^3	Cubic meter
mm	millimeter
OD	Oven dry dimension
RBD	Randomized Block Design
SD	Standard Deviation
N	Newton

Chapter One

Introduction

CHAPTER ONE

INTRODUCTION

Background and Justification of the study:

A wood particle bonded together with an inorganic material such as ordinary Portland cement (OPC) is referred to as cement-bonded particleboard (CBP). Particleboard manufactured using mineral cement as the binding agent is gradually gaining importance in many countries of the world. The emergence of interest in this board, particularly among the developing nations can be associated with the local availability of cement in many of these countries and the possibility to adapt the board manufacturing process to a low level of technology. The board superiority to resin bonded particleboard with respect to combustibility, durability, weather ability and dimensional stability makes it a useful constructional materials in areas where fire and moisture preclude the use of resin bonded particleboard. In addition the problem of formaldehyde release often associated with urea-formaldehyde bonded board, which has received a great deal of attention from various regulatory bodies of the world does not occur with cement bonded particleboard. It is a board with considerable potential as a sheet construction element for commercial and industrial building as well as for low cost houses (Simatupang *et al*, 1991).

Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure (Waterman *et al*, 2007). Composites are considered to be compositions of materials in which the constitutes retain their entitles in the composition in a macro scale, that is, these do not dissolve or otherwise merge into each other completely but do act in concert. Wood composites represent one of the most challenging product groups in the world from a marketing point of view because of their number, versatility, end-use variation, dissimilarities of the producer base and resource richness. Today, composite industries can play an important role in earning a lot of foreign exchange by importing world class panel products and in developing socio-economic condition of rural people involved in collecting, processing and manufacturing of composite products (Salehuddin, 1992).

Especially in warm and humid climates, where high resistance against termites and fungal decay is demanded for constructive materials (Eusibeo, 2003; Wolfe and Gjinolli, 1996) Cement-bonded Composites show a high potential as a building material. Further benefits of CBCs are easy machining with conventional wood working tools and simple fabrication (Wolfe and Gjinolli, 1996), which make these materials interesting for less developed countries. However, the production and use of CBCs in these countries is small because of a lack of information and the limited economic sales potential (Ramirez-coretti *et al*, 1998). Nowadays, these countries show a big interest in these composite materials, whereas industrial countries mainly use CBCs, especially cement-bonded wood wool board, for insulation purposes. The increasing interest of less developed countries in CBCS can be explained by low costs and availability of raw materials (Flybort *et al*, 2008).

Present world is very concerned about environmental pollution. Nowadays, environmental and economic concerns are stimulating research in the development of new materials for construction, furniture, packaging and automobile industries. Particularly, many research studies have conducted on composite panels from non wood lingo-cellulosic materials in which most are based on natural renewable resources. These resources are abundantly available in many countries, including residues from annual growth crops and plants (Markessini *et al,* 1997; Rowell, 1998; Chow, 1974).

The effect of human influence on the forest areas has reduced greatly the available number of valuable and economic tree species. The over-exploitation of tree species from the natural and plantation forests necessitates the need to focus on alternative sources of raw materials at least for use in panel products manufacturing which could substitute for use of sawn wood (lumber) and plywood for some specific end uses notably for production of different grades of furniture (Kollmann *et al.* 1975, Sandermann 1970, Simatupang *et al.* 1978).

One of most recent proposals for a research framework on material science is to utilize bio based resource in the waste stream through the development of technologies that will produce composite products and composites. In this context, it was cited that the major recycling opportunity to utilize wood waste and other post consumer waste in future is to blend proportionate amounts of materials with inorganic materials. For the inorganic materials, the most apparent and wide used example is cementing (Aoki, 1999).

Betel nut is almost hard, long and thin and branchless like coconut tree. It becomes thick as bamboo. Betel nut is found in all over Bangladesh. It grows well in Chittagong, Sylhet and District adjacent to the coastal zone. It has several verities. *A. triandre* is grown in Chittagong and Tekhnaf which is red in color. There is another variety *A. grcilis* which grows well in Sylhet region. Straight stem is used as pillar, joint, scaffoldings pillar of fishing net, water pipe, fencing, handicraft house posts, roofing and fuelwood etc. in Bangladesh. It is imperative to study on alternate utilization of Betel nut to increase its economic value. Cement-bonded particleboard (CBP) manufactured from Betelnut may create an alternative new source of raw material for CBP manufacturing and will add a new economical dimension of Betelnut. So in order to find out the technical performances (physical and mechanical properties) of Betelnut CBP the study was conducted.

Objectives of the study:

- To develop the manufacturing technology of cement bonded board from *Areca catechu.*
- To evaluate the physical and mechanical properties of cement bonded board from *Areca catechu.*

Chapter Two

Review of Literature

CHAPTER TWO

REVIEW OF LITERATURE

2.1 General information about Cement Bonded Particle board

2.1.1 Definition of Cement Bonded board

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, humidify, catalyst etc. (Anon, 1970).It may be classified as a panel products 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).

When, wood particles bonded together with an inorganic material such as ordinary Portland cement (OPC) are referred to as cement bonded particleboard (CPB). Its production and continuous research and becoming more prevalent in the number of countries around the world. Discovering new methods of manufacturing technologies' to replace the traditional one, expanding bases, more modifying the inorganic binders are some of the aspects that are increasing in momentum (Aoki,1991).

The most apparent and widely used inorganic-bonded composites are those bonded with Portland cement. Portland land cement, when combine with water, immediately reacts in a process called hydration to eventually solidify into a solid stone-like mass. Successfully marked Portland cement bonded composites consists of both low density products made with excelsior and high density products made particles or fiber.

The low density products may be used as interior ceiling and panels in commercial buildings. Low density composites bonded with Portland cement offers sound control and can be quite decorative. In some parts of the world, these panels function as complete wall and roof decking systems. The exterior of the panels is stuccoes and the interior is plastered. High density pannls can be used as flooring, roof sheating, fire doors, load bearing walls, and cement forms. Fairly complex melded shapes can be melded or extruded, decorative roofing title or non-pressure pipes (Anon, 1987).

2.1.2 Brief history about cement bonded particle board

Particleboard is not more than a few decades old production. Before particleboard, modern ply wood, an alternative to natural wood, was invented in the 19th century, but by the end of the 1940's there was not enough lumber around to manufacture plywood affordably. By the time particleboard was invented to be a replacement. But before that scarcity in raw materials of plywood, first efforts were made in 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. The first commercial piece was produced during World War 2 at a factory in Bremen, Germany (Anon, 2007 and Moslemi, 1985).

In Indonesia the first mineral-bonded board made of saw dust was established in 1952 in Pontiana, and in 1956 another mineral-bonded board type was established in Palembang. This board used saw dust and shavings as raw materials. In 1970s there were 6 mineral bonded board mills in Indonesia and four of them used excelsior or wood-wool and the rest used wood flakes in the mix. However the development of this board industry was not last long because it was not supported by settlement industry to result in limited production and inadequate sales. This experience will be good consideration for future development of mineral-bonded board industry in Indonesia (Sutigno, 1991).

Cement bonded particle board (CBP) established itself in Switzerland and central Europe in the mid-1970s and has been imported in UK since the late 1970s. The number of plants worldwide is over 40, with one in the UK (Desch and Dinwoodie, 1996). Currently, there are over 38 plants in operation throughout the world (Moslemi, 1989). An extensive development of CBP industry has taken place throughout the world during 1980-90 when 12 plants were established in Soviet Russia, five in Japan, two each in Germany and Turkey, and one each in Malaysia and Thailand. Stillinger and wentworth (1977) pointed out that in tropical and subtropical countries, the problem of building low cost dwelling houses that would withstand extreme climatic conditions and last long can be solved by using high density wood-cement board.

During more recent times, there has been applied to using wood fibers and particle in conjunction with Portland cement and other inorganic materials such as gypsum and magnesites. As shown in the table 1, wood cement composites panel production dates back to mid-1960s. The early magnesite-bonded boards were generally of low quality because the magnesite matrix was extremely sensitive to moisture (Kossatz *et al*, 1983). Cement bonded excelsior boards, which were developed in the 1920s, has better water resistance.

The industrial application of pressure to manufacture wood-cement panels did not occur until the about mid-1930s. With the gradual evaluation of resin-bonded particleboard technology, much was leant that is also applicable to cement-bonded wood particle panels. Early industrial production of wood cement panels was based on Elmendorf Research Inc. (ERI) patents, and such panels were produced in Japan in 1965 (Moslemi, 1989).

Table 2.1 Industrial production of inorganic-bonded wood composites (Kossatz *et al*, 1983).

Year	Product
1900	Magnesite-bonded boards
1905	Gypsum-bonded excelsior board
1915	Gypsum plasterboard
1915	Magnesite-bonded excelsior board
1927	Cement- bonded excelsior board
1937	Molded wood-cement products
1942	Resin-bonded particleboards
1965	Cement-bonded wood composite panels
1972	Gypsum fibreboards
1972	Magnesite-bonded wood composite panels
1982	Gypsum particleboard

2.1.3. Type of Cement Bonded particle board

There are three main types of wood cement board which are Wood Wool Cement Board (WWCB), Cement-bonded particle board (CBP) and Cement -bonded fiber board (CFB). Each type of composites gives different type of characteristics and properties. Moreover, the technology involved in the manufacture of each of these types of composites is different (Maloney, 1977).

2.1.3.1. Wood Wool cement board (WWCB)

WWCB is a panel product consisting of a thin strand of wood that are bonded together with an inorganic bonded such as Portland cement. Panels dimension are mainly 610mm wide (2 ft) and 2440mm long (8ft) and thickness ranging from 15 to 75mm. It is usually produced in densities from 450 to 900 kg/m3.Board density is higher for thinner board. Moreover, WWCB is made from debarked softwood logs that have been stored for varying prior of time to reduce the starch and sugar content of the wood (Akther, 1995)

Using 50 years of European research and technology, WWBC has been produced as a constructing materials that comprising entirely natural and non toxic materials It is an exceptionally versatile building material made from wood fibers that are chemically impregnated and cleverly bonded under pressure with Portland cement to form a closely shed building slab of immerse strength. WWBC has a unique combination of structural thermal fire resistance and acoustic properties making it a highly versatile construction material. It is extremely lightweight, termite and fungus resistance, east to use and environmentally friendly alternatively to conventional building systems use today (Shakir, 2008).

2.1.3.2. Cement –bonded particle board (CBP)

Cement –bonded particle board were developed in the 1960's. The technology used to produce this material shows a lot of similarities to that used to manufacture resin-bonded particleboard. There is difference in manufacture CBP between WWCB. The difference is in the storage of wood before manufacture and in the forming and pressing of boards. Debarked logs, usually conifers species are kept in store for at least 2-3 months prior to processing to reduce their moisture and suger content. Wood particles are then prepared in the same manner as for conventional particleboard.

CBP is highly resistance to fire and has been attributed to the lower content of organic matter and the crystal water in the binder. Heat evolution and spread the material, and smoke and flame behaviour are strongly correlated with the wood cement ratio used. In recent years, CBP manufacturing band utilization in housing construction has grown for domestic dwelling. Some typical external application suitable to CBP include agricultural buildings, prefabricated and mobile buildings, flat roofing, industrial and exterior domestic cladding, tunnel and lining, highway sound barriers, fire barriers, and paving tiles (Shakri, 2008)

2.1.3.3. Cement bonded fibre board

Cement bonded fibre board is produced from fiber which we can get from either wood or non woody materials. Wood-fiber reinforced cement-bonded boards are manufactured from wood fiber (7-8%), sand (60%), cement (30%), and aluminium tri-hydrate (3-4%). The wood fiber is usually obtained from softwood chemical pulp. They act as a reinforcing agent in the boards, a role previously played by asbestos fibers in an older generation of building materials. The manufacture involves washing the sand and reducing it to a fine powder using a ball mill. Fibers are then refined or beaten twice in conical refiners to make the ability to interact with sand and cement higher. The properties outlined above are combining the cement, sand, fibers and additives and diluted to form slurry with a solids content of 10% (Shakri, 2008).

2.1.4 Board performance

Cement bonded board is very versatile material that can be used as ceiling, partition wall, exterior wall, flooring, eaves, cladding and even roofing provided that proper coating is applied. The properties of cement bonded boards are highly dependent on board type, thickness and density. Cement bonded boards that are not suitable for load bearing elements are often used with framing materials like wood and steel section (Eusebio, 2003).

Property	**From**	**To**
Bending strength	1.7MPa	5.5MPa
Modulus of elasticity	621 MPa	1241MPa
Tensile strength	0.69 MPa	4.1MPa
Compression strength	0.69 MPa	5.5MPa

Table 2:2 General properties of low density cement wood fabricated using excelsior-type particles (Eusebio, 2003).

Cement bonded properties offer a verity of advantages. One of these includes excellent mach inability enabling the manufacture or the user to incorporate intricate cuts or joints. This has facilitated the development of a process by which V shaped grooves can be cut into flat panel surfaces. In addition to home construction, cement bonded particle board is used in non-residential construction as cladding and as facing. The boards can be used in its natural gray color or can be finished with a verity of finishes. Cement bonded particle board offer properties that, in some respects, are unique to this kind of material. Table 2.2 provides a comparison of some of the important strength properties for cement bonded particleboard as compared with some of the other panel products. These boards generally have a lower modulus of rupture than resin bonded particle-board but are superior in modulus of elasticity (Stillinger and Wentworth, 1977).

Table 2.3: Comparison of Some Mechanical properties of cement bonded particle board with a number of other panel products (Moslemi, 1989).

Properties	**Gypsum-bonded particle board**	**Cement-bonded particle board**	**Gypsum fiber board**	**Gypsum plaster board**	**Resin-bonded particle board**
MOR(Mpa)	6-10	9-16	5-8	3-8	12-24
MOE(Gpa)	2-4	3-6	2-4	2-4	2-4
IB(Mpa)	0.3-0.6	0.4-0.7	0.3-0.5	0.2-0.3	0.5-1.0
Tensile strength in board plane (Mpa)	3-4	4-5	2-3	2-3	7-10

A major advantage of cement bonded boards is the ability to withstand outdoor exposure. These panels have performance well in accelerated weathering tests. One important factor responsible for durability to outdoor exposure is the ability of the board to maintain a low level of dimensional change under environmental humidity functions. Commercial cement bonded board's exhibit excellent thickness stability and acceptable linear expansion characteristics (Moslemi, 1989; Kossatz *et al,* 1983; Dinwoodie and Paxton, 1989; Dinwoodie and Paxton, 1991). Fire resistance is particularly important consideration for cement bonded-boards, especially considering the need for a replacement for asbestos boards. High fire resistance can lead to a new market opportunities and expanded production in many countries. Cement bonded boards contribute to the combustion process or to the spread of fire. The afterglow is either nonexistent or negligible (Deppe, 1975; Parameswaran and Broker, 1979) these boards can form fire resistant wall or ceiling linings. Based on German and British sanders cement bonded particle boards are classify as "highly fire resistance" but should not be considered "fire proof" or "incombustible".

Biological deterioration due to insects and fungi is minimal with these boards. The highly alkaline nature of the material coupled with the cement-encased structural of wood particles makes such attacks very difficult. Under microscopic examination, early cement-bonded particleboard samples in use for some 25 years in a building in Switzerland showed no structural change in wood tissues. (Parameswaran and Broker, 1979) the samples were free of insects and fungal damage. Microscopic examination of a sample buried under soil for more than 30 years showed fungal hyphae in the outmost 2 to 3 mm layer. However, the inner parts of these samples were completely free from any type of degradation. Generally, cement bonded boards are considered to be resistant to such biological attacks, making them very suitable for tropical climates (Moslemi, 1989; Parameswaran and Broker, 1979).

Cement bonded boards can be nailed, sawed, and otherwise machined with wood working tools. At higher densities, however, the materials must be screws and nails. The board density, however, can be manipulated without difficulty, which offers a considerable range of properties. Other important properties such as heat and sound insulation, nail and screw withdrawal resistance, and finishing qualities with paints and other coating are important practical consideration. Generally, under equivalent condition, cement bonded particle-board is not a good heat insulator as wood but is better than concrete. It has high usage in the industrial prefabrication of housing and building element for public, agriculture and industrial use (Stillinger and Wentworth, 1977).

2.1.5 Technological consideration

In cement bonded technology, many parameters greatly affect board properties. Some of these are: material (wood/cement, agro-wastes/cement) ratio; water/cement ratio; type of wood/agro-wastes; cement setting accelerators and others (Eusebio, 2003).

Although the entire sphere of inorganic bonded lingo-cellulosic composites is attractive, and cement bonded composites are especially so, the use of cement involves limitations and tradeoffs. In addition, hemi-cellulose, starch, sugar, tennis, and lignin, all to a varying degree, affect the cure rate and ultimate strength of these composites. To make strong and durable composites, measures must be taken to ensure long term stability of the lingo-cellulosic in the cement matrix. To overcome these problems, various schemes have been developed. The most common is leaching, whereby the lingo-cellulosic is socked in water for 1 or 2 days to extract some of the dimensional components. However in some parts of the world, water containing the leach ate is difficult to dispose off. Low water cement ratios are helpful, as is the use of curing accelerators like calcium carbonate. Conversely, low alkali cements have been developed, but they are not readily available throughout the world (Anon, 1996).

2.1.6 Factors that Affect the Properties of Cement Bonded Particleboard

Mechanical and physical properties, dong with other important properties like fire resistance, sound absorption, and motion behaviour, are primarily influenced by the density of the products and the binder wood ratio as well as the ratio of water to cement, proper ratios not only influence panel properties adversely, they can also make processing difficult. The binders are applied as a powder or as a slurry. Water is required as a homogenizer during the mixing process, as a solvent during the hardening reactions, and also as a component in the chemical hydration process. The optimum water cement ratio is approximately 0.4. Currently, commercial cement bonded particleboard, incorporating 2.75 to 3.0 parts of Portland cement to 1.0 part of wood particles (weight basis) are reported to attain acceptable mechanical and physical properties (Bahre and Greten, 1977).

The quantity of water added to the wood-cement mixture was calculated using a relationship developed by Simatupang (1979). In this flotation, the water requirement was determined as follows:

Water (litters) = 0.35C + (0.30 - MC) W

Where C = cement weight (kg)

MC = wood MC (oven-dry basis)

W = oven-dry wood weight (Kg)

Moslemi et al (1987) examined the influence of decreasing cement/wood ratio 3.0 to 1.5 on fled and dimensional stability properties of cement-bonded composite panels. The study indicated that Modulus of Rupture (MOR) increased as the cement wood proportion decreased. A cement/wood ratio of 2.0 was found to demonstrate optimum bending strength. Modulus of Elasticity (MOE), however, increased linearly with greater cement/wood ratios.

Generally wood-cement panels made in this study exhibited high dimensional stability when exposed to a 24-hour water soak.

The geometry of particles can impact on the properties of cement-bonded particleboard. Badejo (1987) studied that laboratory scale of cement-bonded particleboards made from mixed particles of three tropical hardwoods. The study showed that use of longer flakes significantly increased MOR and MOE in static bending and improved dimensional stability relating to water absorption and thickness swelling; MOR and MOE were significantly reduced by the use of thicker flakes and use of thicker flakes also manifestos in significantly increased water absorption and thickness swelling of the experimental boards. The study also demonstrated that the longer and thinner the flakes, the stronger, stiffer and more dimensionally stable the cement-bonded particleboards produced from them.

2.1.7 Application of Cement Bonded Particle Board

Successful new applications in Western Europe, different from that of boards, are amongst others:

- Flooring with tongue and grooved boards;
- Large size prefabricated elements for permanent shuttering of concrete walls and floors
- The production of complete prefabricated houses.

Depending on cultures and building codes, the developments in the market since 1970 for CBPB are very different in various countries, which is also depending on price and quality of the boards. Recently reported the distribution of their standard CBPB Class B1 and high fire resistant boards Class A2 in Western Europe as follows:

Approximate distribution for the following applications:

15% - (raised) Floors

20% - Office containers, influenced by new governmental fire and moisture regulations

15% - Supply to prefabricated house manufacturers

25% - Various supplies to the industry, amongst others for kitchens, bathrooms and furniture.

5% - Facades .

20% - Various, including high fire resistant Class A2 boards.

2.1.8 Advantages of Cement –bonded particle board

- Cement bonded boards are strong, stiff and resistance to moisture, fungi and insect. Fire resistance is being higher than any other materials. In panel from, they are being utilized for structural and non structural application in both exterior and interior purpose.
- It reduces thermal conductivity and increase sound insulation.
- An added advantage over massive concrete panels is their ability to withstand larger deformation before failure.
- Present world is very much concern about environmental pollution. All formaldehyde based resin binders are more or less toxic to the environment; it is free from formaldehyde, isocynates, wood preservatives, fungicides.
- As cement bonded board can be manufactured from environmental process, it saves energy. Every year, greater portion of energy is needed for particle board industries. But cement bonded board can be made by cold pressing method. So, it needs not electrical energy.
- It can be produced by either labour-incentive or machine incentive operations, whichever is most economically feasible. Owing to the binded used.
- It can be used as erection of free standing solid partition, various sound damming partition construction.
- It is easy to cut to size service fabrication prior to site.
- It is easy to fix.
- It is frost resistance.
- It can be calibabarated, paned, sanded, drilled, routed screwed and primed.
- It is biologically safe.
- It can be disposed of on a landfill site.
- It can be decorated with different finishes which is helpful to diversify its uses.
- It is moisture proof and for this it can be used in damp condition.
- It is paintable which is helpful to design with our own requirements.

(Atchison *et al,* 1985; Hofstrand *et al*, 1984; Kimura *el,* 1996; Eusebio and Kawai, 1999; Rowell, 1997; Rowell, 1998; Topf, 1989; Youngquist *et al,* 1996; Zhang *et al,* 1997).

2.2 General information of Betelnut (*Areca catechu*)

2.2.1 Botanical Description

The name betel nut is misleading, Piper betle, commonly known as betel, is a plant that originated in Asia Areca catechu is the botanical name of a species of palm tree that grows in parts of the tropical Pacific, Asia, and Africa. More commonly known as betel palm or betel nut tree, it can grow to a height of 65-90 feet. Areca catechu is part of the Arecaceae family (commonly referred to as the palm family). There are over 200 genera and about 2600 species contained in the family. Most members of the Arecaceae family only grow in tropical or subtropical climates. The leaves from Piper betle are often chewed together with areca nut and edible lime (also called calcium hydroxide, limbux, or slaked lime). By association, the areca nut has become known as the betel nut.

The betel palm is grown primarily for betel nuts. It can be grown in a variety of soil types. Cultivation is preformed using pre-germinated seeds. The saplings need to grow in the shade because they may be killed by strong sun. The palms bear fruit when they are 10-15 years of age. A productive betel palm can provide fruit for 45-75 years (html://www.entheology.org).

2.2.2. Distribution

2.2.2.1. Native range

Unknown in the wild, betel nut is a cultigen that exists only where humans grow it. An origin in the Philippines has been postulated (George and Robert, 2006).

2.2.2.2. Current distribution

From SE Asia, betel nut was distributed by indigenous peoples throughout tropical Asia as far as East Africa and the Pacific well before the arrival of Europeans in the region.The palm was distributed to the Pacific islandsaboard sailing canoes by the prehistoric ancestors of the Micronesians who explored and settled the islands of western Pacific,East Africa,Madagascar, Arabian Peninsula, India, Sri Lanka, Bangladesh, Myanmar, Thailand, Cambodia, Laos, Vietnam, southern China,Malaysia, Indonesia, Taiwan, and the Philippines. In the Pacific Basin it is grown in Papua New Guinea, Solomon Island, Fiji, and Micronesia Vanuatu. It can also be found on some atolls such as Mwoakilloa in Pohnpei State.It is also found on Pagan, Agrigan, Alamagan, and Anatahan. It has also been recorded as being present Marshall Islands. In Hawai'i it is grown mainly as an ornamental (George and Robert, 2006).

2.3.3. Functional uses

2.3.3.1Products

Fibre: The husk fibres are predominantly composed of cellulose with varying proportions of hemi-cellulose, lignin, pectin and protopectin. Based on various tests, it has been proposed that the husk fiber could be used in making such items as thick boards, fluffy cushions and non-woven fabrics. Trial experiments have shown that satisfactory yield and quality of brown wrapping paper could be prepared from blends of areca nut and bamboo or banana pseudostem pulp.

Timber: Betel nut stem forms a useful building material in the villages, and it is widely used throughout Southeast Asia for a variety of construction purposes. The timber can also be used in making a variety of utility articles such as rulers, shelves and waste paper baskets. Nails made from areca stem are widely used in the furniture industry.

Tannin or dyestuff: Long before the nature and properties of tannins were determined, the tannins in Betel nut were being used for dyeing clothes, as adhesives in plywood manufacture, and for tanning leather for home use in Southeast Asia and the Pacific Ocean countries. The tannins are obtained as a byproduct in preparing immature betelnuts for chewing.

Lipids: The nut contains 8-12% fat that has characteristics comparable with hydrogenated coconut oil. It contains both saturated and unsaturated fatty acids. Betel nut t fat can be extracted by using hexane as a solvent, and the fat can be made edible by refining it with an alkali. Simple blending of Betel nut fat with butterfat followed by inter-esterification gives good products, acceptable in confectioneries.

Alcohol: Innoculated with Saccharomyces cerevisiae, the leaves of Betel nut can be used as a fermentation stimulant in industrial alcohol production.

Poison: The Betel nut decoction as well as arecoline and its salts have been found to be effective on various helminth infections such as those caused by Taenia spp.

Medicine: Betel nut is used against anaemia, fits, leucoderma, leprosy, obesity and worms. In combination with other ingredients, it is also a purgative and an ointment for nasal ulcers. Kernels of green and mature fruits are chewed as an astringent and stimulant, often with the leaves or fruit of betel pepper (Piper betle) and lime (html://www.species information).

2.3.3.2Services:

Soil improver: The Betel nut leaves are a good source of organic manure, containing nitrogen, phosphorous and potassium.

Ornamental: In Florida and Hawaii, Betel nut is used as an ornamental tree.

Intercropping: Experimental evidence indicates that intercropping with Betel nut is not harmful to the main crop. When intercropped with black pepper, it acts as a live standard for training the pepper plants. Banana, cardamom, cowpea, paddy, pineapple, sorghum, vegetables and yams are also grown by farmers as intercrops with Betel nut (html://www.species information).

Chapter Three

Materials and Methods

CHAPTER THREE

MATERIALS AND METHODS

3.1 Methods and Procedures

3.1.1 Collection of raw materials

Areca catechu stem was used to manufacture cement bonded particle board. *Areca catechu* was collected from Mohammadnagar, Khulna. The height and diameter was of the tree was 7m and 0.5m respectably. The age of the tree was 7 years approximately. Ordinary Portland cement, Akij was used as a binder, purchased from local market.

3.1.1.1 Manufacturing of Cement bonded particleboard

Three types of single-layer cement bonded particleboards from stem of *Areca catechu* manufactured in the wood Technology Laboratory of Forestry and Wood Technology Discipline of Khulna University, Khulna, Bangladesh.

Manufacturing procedure

3.1.1.2.1Preparation of raw materials

The bark of the sample tree stem was removed by sawing with 36-inch band saw. The stem was cut into narrow sticks and the sticks were cut into small pieces by a circular saw to feed into the chipper and kept under open sun for 30 days for drying.

3.1.1.2.2 Particle preparation

Chipping was done at the Chipper machine to produce particles. The small pieces of stem were inserted into the Chipper machine. The holes in the perforated mesh of the chipper machine were approximately 8 mm in diameter. The particles were collected manually from the chipper machine. The Particles was differentiated into three categories according to treatment such as fine, coarse and coarse fine. They were dried to 12-14% moisture content. This was because, the chips show poor bonding with cement and they could be scratched off the panel.

3.1.1.2.3 Screening of particles

The particles were screened manually by sieve. The fines were under the sieve and the remaining particles on the sieve were separated. Generally less than 5mm particle size was considered as fine and more than 6mm was considered as coarse particle and other was coarse fine particles which were mixed with each other (Eusebio, 2002).

3.1.1.2.4 Final drying of screened particles

After screening the particles of each type were kept under open sun for 20 days for drying.

3.1.1.2.5 Mixing

The ratios of particles and cement which were used to manufacture the cement bonded particles boards were 1:2 and 1:3 for fine, coarse and coarse fine particles. This mixing condition was employed constantly through all experiments. Required amount water mixing was needed for every board. To obtain a uniform distribution of cement, particle and water, the mixing procedure was carried out systematically in a pan by mixing cement and particles with required amount of water into the particles. Mixing continued until the particles were covered completely with cement.

3.1.1.2.6 Assembly

Each mixture would be hand-formed into a square of iron mould on a stainless steel plate lined with a superior quality polythene sheet to prevent the consolidated mat from sticking to the platen during pressing.

3.1.1.2.7 Cold pressing

Hand formed mats measuring 320×250 mm were cold pressed. It was kept in pressing condition for 24 hrs (Eusebio *et al,* 1994)

3.1.1.2.8. Curing

The cement bonded particle board was cured in the conventional process. After pressing they were kept at room temperature for 14 to 30 days. Water sprayed frequently for proper curing of the cement bonded particle board (Nagadomi *et al,* 1996).

3.1.1.2.9 Trimming

After the boards of each type were produced separately, these were trimmed at edges with the fixed type circular saw. The dimensions of each type of boards were 30cm×20cm.

3.2. Flow diagram of cement bonded Particle board production

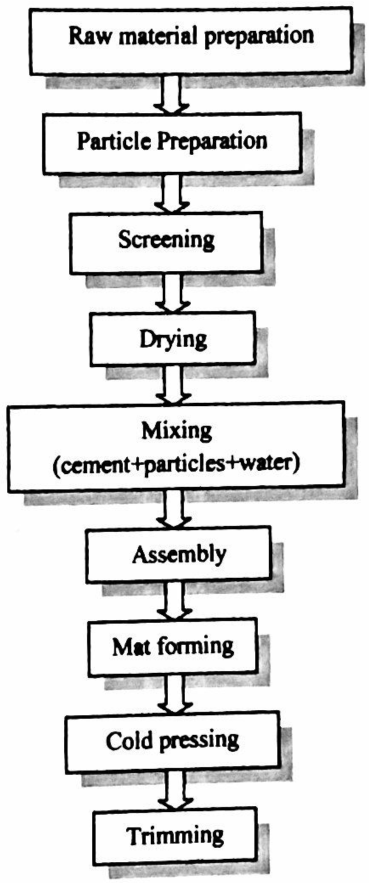

Fig. 3.1: Flow diagrams of cement bonded particleboard production

3.3. Specifications of manufactured Cement Bonded Particleboards

Table: Specifications of manufactured Cement Bonded Particleboards

Dimensions (mm)	320×250
Thickness (mm)	17
Layer	Single
Board types according to texture (fine, coarse and coarse fine)	3
Number of boards	6
Ratios used to made boards (particle: cement)	1:2 and 1:3
Total board manufactured	18 (3×2×3)
Bonding agent	cement

3.4. Laboratory tests

The laboratory tests for characterization of physical properties and mechanical properties for each type of particleboards was carried out respectively in the Wood Technology laboratory of Forestry and Wood Technology Discipline of Khulna University, Bangladesh and in the Laboratory of Civil Engineering Department of Khulna University of Engineering and Technology, Khulna, Bangladesh. The tests were analyzed by the statistical analysis system of ANOVA and Duncan's multiple ranges T-test.

3.5 Preparation of samples for testing

For testing physical properties, three samples were collected from each board of each type. So the total number of sample was nine. The density, moisture content, water absorption, thickness swelling and linear expansion were determined on the same nine samples. For testing mechanical properties, three samples were collected from each board of each type. So the total number of sample was nine. The dimension of samples for testing the physical properties is approximately 5.5cm×5.5cm and for testing the mechanical properties is approximately 32cm×5cm.

3.6 Materials and Equipment

3.6.1 Chipper

A locally made small lab scale chipper was used to chip the raw materials.

3.6.2 Cold press

A single daylight hydraulic cold press was used to press the mat into particleboard. The cold press had two platens. The lower platen was fixed with the body of the cold press and upper platen was moveable. The moveable upper platen was used to measure the load given by the manual hydraulic jack. The cross-sectional area of the platens was 35×35 cm^2.

3.6.3 Hydraulic Universal Testing Machine (UTM)

An analogue Hydraulic University Testing Machine (UTM), model: WE-100, made by Time Group Inc. was used to determine the mechanical properties of the particleboards. A meter was attached with the working unit to measure the deflection. The length of the span, on which the samples were laid, was 200mm. Another part of the working unit was used to determine the tensile strength, which works vertically.

3.6.4 Electric Oven

A lab scale ventilated oven (Name: Gallennkamp, size1, made in UK) was used to determine the moisture content (%) of raw materials as well as the particle boards. A digital indicator outside the oven indicates the inside temperature

3.6.5 Moisture Meter

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

3.6.6 Electric Balance

An air tight digital balance (Model: AB 204, made in Switzerland) was used to measure the weight of the raw materials samples as well as particleboard's samples and also used to measure the weight of cement

3.7 Board Evaluation

3.7.1 Density:

For density study, the weight measurement was taken in an electric balance. Density was determined in green wood and oven dried wood. The following formula was used to calculate the density of wood (ASTM 1983).

$D = M / V$

Where, D = Density in gm/cm^3

M= Mass or weight in gm

V= Volume in cm

3.7.2 Moisture content:

The moisture content of the samples was determined by the following formula (Shivastava, 1997).

$MC (\%) = [(W_w - W_o) \times 100] / W_o$

Where, MC = Moisture content

W_w = Weight of samples in green condition

W_o = Weight of samples in oven dry condition.

3.7.3 Water absorption:

The water absorption is calculated by the following formula-

$A_w = (M_2 - M_1) / M_1 \times 100$ (http://www.imal.it.)

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).

3.7.4 Thickness swelling

Thickness swelling is calculated by the following formula-

$G_t = (T_2-T_1) / T_1 \times 100$ (http://www.imal.it.)

Where, G_t = Thickness swelling (%)

T_2 = Thickness of sample after (24 hr.) immersion in water (mm)

T_1 = Thickness of sample before immersion in water (mm)

3.7.5 Linear expansion

The linear Expansion is calculated by the following formula-

$LX (\%) = (L_A-L_B) / L_B \times 100$ (http://www.imal.it.)

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

L_B = Length of sample before immersion in water (mm).

3.7.6 Modulus of Elasticity:

The modulus of elasticity is calculated from the following equation –

$MOE = P'L^3 / 4\delta bd^3$ (Desch and Dinwoodie, 1996)

Where, *MOE* = Modulus of elasticity in MPa

P'= Load in N at the limit of proportionality.

L= Span in mm.

δ = deflection in mm at the limit of proportionality

b= width in mm, d= depth in mm

3.7.7 Modulus of Rupture:

The MOR in the point of bending is calculated from the following equation,

MOR= 3PL/ bd^2 (Desch and Dinwoodie, 1996)

Where, MOR = Modulus of Rupture

P = Load in N, L = Span in mm, b = Width in mm, d = Depth in mm.

3.8 Analysis of Data

CRD design will be used in the experiment and all the data produced during the laboratory tests for characterization of physical and mechanical properties of each type of boards. ANOVA and LSD were done to analysis the data.

Chapter Four

Results and Discussion

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Results

The results of different physical and mechanical properties that were found during different laboratory tests are delineated (with standard error bar) here.

4.1.1 Physical Properties

4.1.1.1 Density

The density of CBP for fine, coarse and coarse fine were 1 gm/cm^3, 1.05 gm/cm^3 and 1.03 gm/cm^3 respectively for wood : cement ratio 1:2 and 1.02 gm/cm^3, 1.07 gm/cm^3 and 1.04 gm/cm^3 respectively for wood : cement ratio 1:3 (Figure- 4.1). The variation in density among the different types of cement bonded particleboards might be due to the variation in density of the different raw materials used. Coarse particles of betelnut mainly consist of rigid fibers. Moreover the weight of the raw materials for different types of board was different.

Wood: cement ratio of 1:3 for coarse particles showed highest value which is1.07 gm/cm^3. wood: cement ratio 1:2 for fine particles showed lowest value which is 1.02 gm/cm^3. The same amount of Betelnut coarse particles gave higher weight than the fine particles. The variation of a density of the different types of cement board was different because the different ratio used in manufacturing cement bonded board.

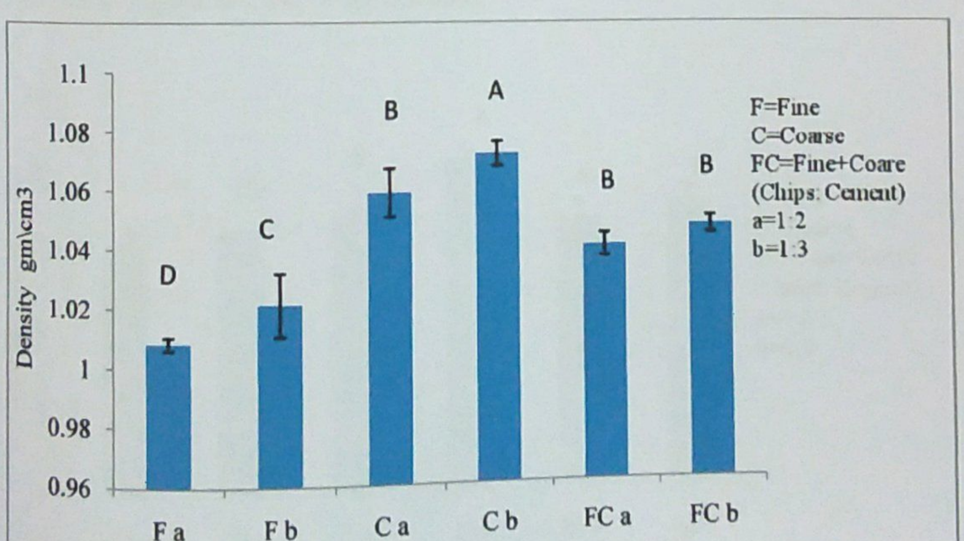

Fig.4.1: Density of cement bonded board made from *Areca catech*

From the analysis of data it had been found that there is significant difference for density between fine, coarse and fine coarse particles and ratios. From the analysis of the date it also had been found that density of course and fine particles were different grouping and fine course particles was same grouping B. Some similarity had been found course fine particles of both ratios and course particles of 1:2 ratios. Course particles of 1:3 ratios were given the height density (Figure- 4.1).

The density of a board depends on the density of particles as well as amount of cement used. This study reveals that the average density of cement bonded particle board is 1.05 gm/ cm^3. In Nigeria, Erakhrumen *et al.*, (2008) found that Cement bonded particle board from only pine (*Pinus caribaea* M.) saw dust 1.79 gm/cm^3. He also found that cement: sawdust-coir ratio of 2:1 had 1.54 gm/$cm^3$and cement: sawdust-coir ratio of 2:2 had 1.13 gm/cm^3dnsities lower than sawdust. In Bangladesh, Study on *Albizia falcataria* wood for cement bonded particleboard (Biswas *et al.,* 1997) shows that the board density is about 976 Kg/m^3. The average density in bison factory (Anon, 1975) found that the cement bonded particle board from saw dust was 1250 Kg/m^3. The target density of cement bonded particle board is 1.2 gm/cm^3 (Anon, 2001).

4.1.1.2 Moisture content

The moisture content of CBP for fine, coarse and coarse fine were 15.56%, 17.86% and 17.12% respectively for wood: cement ratio1:2 and 16.50%; 20.80% and 17.90% respectively for wood: cement ratio 1:3 (Figure- 4.2). Coarse particles of wood: cement ratio of 1:3 had the higher percentage of moisture content (20.80%). The causes behind lower amount of cement were used. Fine particles of wood: cement ratio of 1:3 showed 15.56 %, the lowest amount of moisture content, which might due to the use of highest amount of cement used.

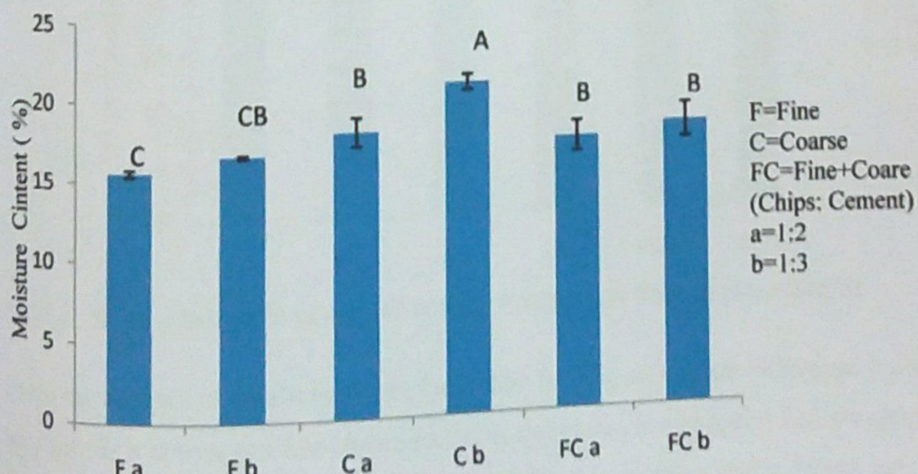

Fig.4.2: Moisture content of cement bonded board made from *Areca catechu*

From the analysis of data it has been found that there is significant difference for moisture content between fine, coarse and fine coarse particles and ratios. From the analysis of the date it also had been found that moisture content of course and fine particles were different grouping and fine course particles was same grouping B. Some similarity had been found course fine particles of both ratios and course particles of 1:2 ratios. In case of fine particles of 1:3 ratios there were same properties of group B and C. Course particles of 1:3 ratios were given the height moisture content (Figure- 4.2).

This study, It had been found that the moisture content of cement bonded particle board was ranges from (16-20) %. In bison factory (Anon, 1975) in china found that the cement bonded particle board from saw dust, Moisture content ranges from 3% to 9% at Factory Point.

4.1.1.3 Water absorption

It was found that the absorption of water by CBP for fine, coarse and coarse fine were 32.50%, 24.59% and 27.93% respectively for wood: cement ratio1:2 and 29.38%; 22.56% and 25.73% respectively for wood: cement ratio 1:3 (Fig.4.3). Fine particles of wood: cement ratio of 1:2 had the higher percentage of water (32.5%) absorption. The causes behind this might be spongy materials and lower amount of cement was used. It had hydrophilic nature. Coarse particles of wood: cement ratio of 1:3 shows 22.5%, the lowest amount of water absorption, which may due to the use of highest amount of cement was used.

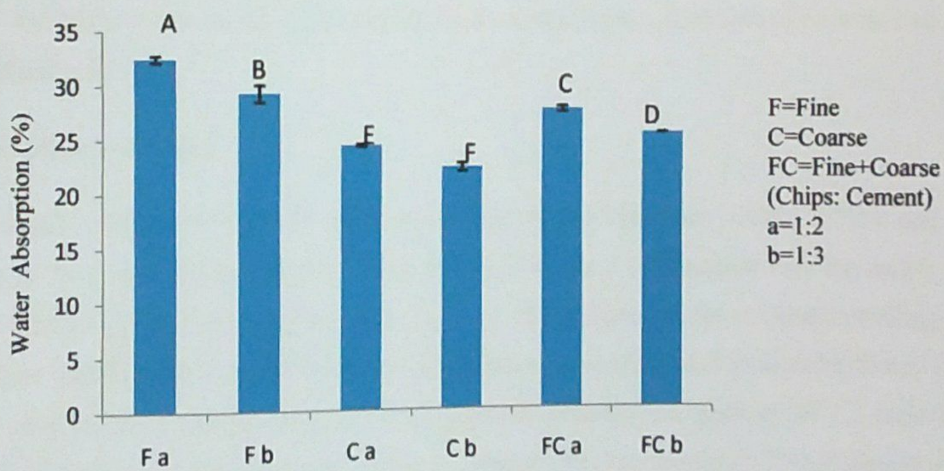

Fig.4.3: Water Absorption of cement bonded board made from *Areca catechu.*

From the analysis of data it has been found that there is significant difference for absorption of water between fine, coarse and fine coarse particles and ratios. It was found that the absorption of water by CBP for fine, coarse and coarse fine were different grouping that's means the variation of water absorption capacity for different particles were different. Fine particles of 1:2 ratios were shown the height absorption of water ability (Fig.4.3).

In this study water absorption of cement bonded particle board ranges from (23-31%). Water absorption (WA) is lower in chip: cement ratio of 1:3 for coarse particles. In bison factory (Anon, 1975) in china found that the cement bonded particle board from saw dust, water absorption of the board is 27%. The WA of the various board specifications was higher where there was reduced proportion of cement inclusion. This pattern of WA variations is in conformity with the observation of many researchers (Badejo, 1987; Oyagade, 1995; Ajayi, 2003, 2004; Del Meneéis *et al.*, 2007). Lowering the cement proportion in composite manufacture might lead to large quantity of exposed particles and free internal spaces which are almost always associated with low density boards, a possible contributory factor to this WA pattern and likely instability of board. Compared to low density particleboards, high density particleboards have lower porosity so that particles and cement can interact with each other more easily to form stronger crosslink (Zheng *et al.*, 2007).

Study on *Albizia falcataria* wood for cement bonded particleboard in BFRI (Biswas *et al.*, 1997) shows that water absorption of the board was 27.8% after 24 hrs submersing into water. Erakhrumen *et al.*, (2008) observed 23.4%, 30.6% and 54.0% water absorption for only pine (*Pinus caribaea* M.) sawdust, sawdust: coir ratio (2:1) and sawdust: coir ratio (2:2) for cement bonded particle board. This result is at variance with some studies that have identified coconut husk as a material with high lignin content with low affinity for moisture which thus, act as a barrier for cellulose microfibril, for moisture absorption but consistent with outcome of studies such as Rahman and Khan (2007) which identified coconut husks fibres as being hydrophilic due to the presence of hydroxyl groups from cellulose and lignin components. Aggarwal (1992) found that water absorption of coconut coir cement bonded board is 14-16%.

4.1.1.4 Thickness swelling

The thickness swelling of CBP for fine, coarse and coarse fine were 2.92%, 2.52% and 2.54% respectively for wood: cement ratio1:2 and 2.60%; 2.13% and 2.24% respectively for wood: cement ratio 1:3 after 24 hours immersion in water (Fig.4.4). The variation in the thickness swelling among the different types of CBP's might be due to the variation in wood: cement ratio and different types of particles. Among the different ratio's of wood: cement particles fine particles of 1:2 ratio had the highest (2.9%) and coarse particles of 1:3(wood: cement) ratio had lowest (2.1%) thickness swelling than others. This might be due to the reason stated above as well as the lower pressure.

From the analysis of data it has been found that there is no significant difference for thickness swelling between fine, coarse and fine coarse particles and ratios. It was found that the thickness swelling by CBP for fine, coarse and coarse fine were same grouping A that's means the variation of thickness swelling capacity for different particles were same (Fig.4.4).

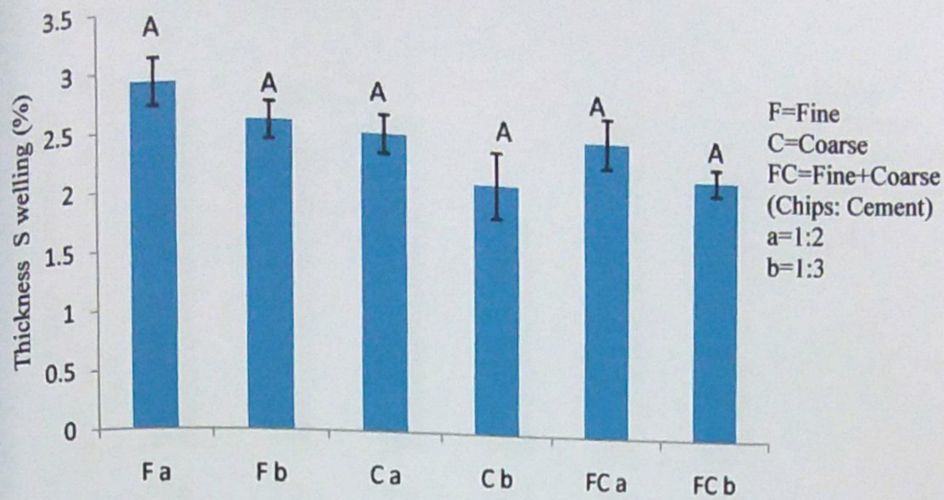

Fig.4.4: Thickness Swelling of cement bonded board made from *Areca catechu*.

Thickness swelling in this study ranges 2.2% to 2.7% and linear expansion 3.4 % to 4.6%. Medium density particle board of this species (bonded with urea formaldehyde glue) showed higher thickness swelling (about 8.69 %) and linear expansion was 0.63 % after 24 socking hrs. Given the same socking period, a particle (bonded with same Portland cement) was found to swell only 2.1% and with no tendency to delaminate after 24 hrs. This implies that cement bonded particleboard made from this species would be a resistant and dimensionally stable product against humidity. Study on *Albizia falcataria* wood for cement bonded particleboard (Biswas *et al.*, 1997) shows that Thickness swelling of the board was 2.87% after 24 hrs submersing into water. Erakhrumen *et al.*, (2008) observed 12.3%, 4.6% and 2.9% thickness swelling for only pine (*Pinus caribaea* M.) sawdust, sawdust: coir ratio (2:1) and sawdust: coir ratio (2:2) for cement bonded particle board. Aggarwal (1992) found that thickness swelling of coconut coir cement bonded board is less than 1.2%. In bison factory (Anon, 1975) China found that the thickness swelling of cement bonded particle board was 1.0%.

4.1.1.5 Linear expansion

The linear expansion of CBP for fine, coarse and coarse were 4.87%, 3.66% and 4.04% respectively for wood: cement ratio1:2 and 4.20%; 3.27% and 3.89% respectively for wood: cement ratio 1:3 after 24 hours immersion in water (Figure-4.5). The variation in the linear expansion among the different types of CBP's may be due to the variation in wood: cement ratio and different types of particles. Among the different ratios of wood: cement particles fine particles of 1:2 ratio had the highest (4.8%) and coarse particles of 1:3 (wood: cement) ratio had lowest (3.2%) linear expansion than others. This may be due to the reason stated above as well the lower pressure.

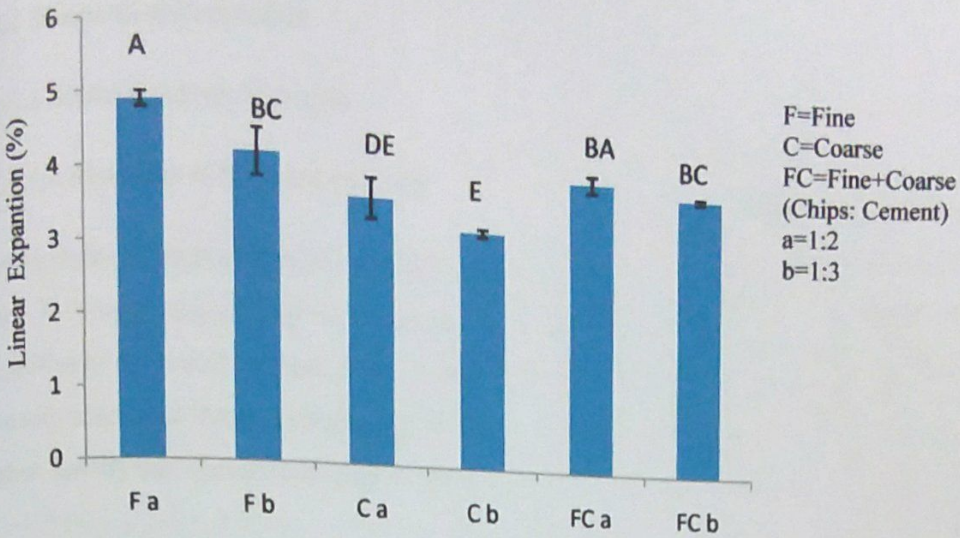

Fig.4.5: Linear Expansion of cement bonded board made from *Areca catechu*

From the analysis of data it has been found that there is significant difference for linear expansion between fine, coarse and fine coarse particles and ratios. It was found that linear expansion of CBP for fine, coarse and coarse fine were different grouping that's means the variation of linear expansion for different particles were different. In case of fine particles of 1:3 ratios, course particles of 1:3 ratio fine courses of both ratios had some same properties. Fine particles of 1:2 ratios were shown the height linear expansion ability (Figure-4.5).

4.1.2 Mechanical Properties

4.1.2.1 Static Bending Strength

4.1.2.1.1 Modulus of Rupture (MOR)

The modulus of rupture (MOR) of CBP for fine, coarse and coarse fine were 3.65N/mm², 4 N/mm² and 3.74 N/mm² respectively for wood: cement ratio1:2 and 3.68 N/mm², 4.05 N/mm² and 3.82N/mm² respectively for wood: cement ratio1:3 (Fig. 4.6). The MOR of CBP coarse particles of 1:3 (wood: cement) ratio was found to higher (4.06 N/mm²) than other types of boards which may due to the higher density and slenderness ratio of the coarse particles than other types of particles.

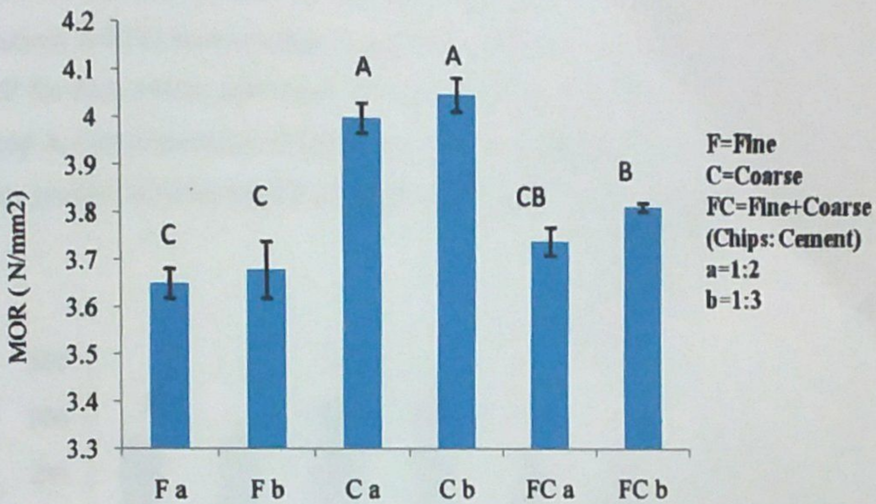

Fig.4.6: Modulus of Rupture of cement bonded board made from *Areca catechu*

From the analysis of data it has been found that there is significant difference for Modulus of Rupture (MOR) between fine, coarse and fine coarse particles and ratios. It was found that MOR of CBP for fine, coarse and coarse fine was different grouping. Fine particles of both ratios had same group A and course particles of both ratio had same group B. In case of fine course particles of 1:2 ratio had some same properties of group B and C. Course particles of both ratios were shown the height MOR values (Fig. 4.6).

Study on *Albizia falcataria* wood for cement bonded particleboard (Biswas *et al*, 1997) shows that the average bending strength value was observed to be 59 Kg/cm^2 with the maximum being 66 Kg/cm^2 and the minimum 51 Kg/cm^2. Erakhrumen *et al*, (2008) observed 46.9 Nmm^2, 51.0 Nmm^2 and 28.1 Nmm^2 MOR for only pine (*Pinus caribaea* M.) sawdust, sawdust: coir ratio (2:1) and sawdust: coir ratio (2:2) for cement bonded particle board. Aggarwal, (1992) found that MOR of coconut coir cement bonded board is 9-11 MPa. In bison factory (Anon, 1975) China found that the MOR of cement bonded particle board was 9 Nmm^2.

4.1.2.1.2 Modulus of Elasticity (MOE)

The modulus of elasticity (MOE) of CBP for fine, coarse and, coarse fine were 280.46 N/mm², 316.47 N/mm² and 264.58 N/mm² respectively for wood: cement ratio1:2 and 286.32 N/mm², 319.59 N/mm² and 265.11N/mm² respectively for wood: cement ratio1:3 (Fig. 4.7). The MOR of CBP coarse particles of 1:3 (wood: cement) ratio was found to higher (319.9N/mm²) than other types of CBP boards. The variation that was found in MOE among the different types of CBP particleboards may be due to the same reasons for variation in MOR among the different types of particleboards.

From the analysis of data it has been found that there is significant difference for Modulus of Elasticity (MOE) between fine, coarse and fine coarse particles and ratios. It was found that MOR of CBP for fine, coarse and coarse fine was different grouping. Fine particles of both ratios had same group A, course particles of both ratio had same group B and course fine particles of both ratios had same group C. Course particles of both ratios were shown the height MOE values (Fig. 4.7).

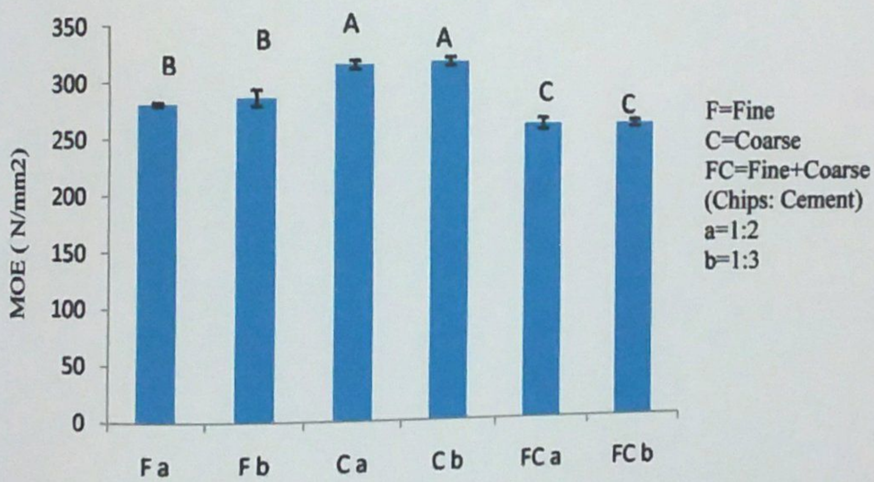

Fig.4.7: Modulus of Elasticity of cement bonded board made from *Areca catechu.*

For MOE, Erakhrumen *et al.*, (2008) observed 7813 Nmm², 11185 Nmm² and 4171 Nmm² MOE for only pine (*Pinus caribaea* M.) sawdust, sawdust: coir ratio (2:1) and sawdust: coir ratio (2:2) for cement bonded particle board. Aggarwal (1992) found that MOE of coconut coir cement bonded board is 2500-2400 MPa. In bison factory (Anon, 1975) China found that the MOE of cement bonded particle board was 3000 Nmm².

The strength properties were also influenced by board density, with higher density boards possessing higher strength properties (MOR and MOE). These findings are in agreement with studies by Kwon and Geimer (1998), Ajayi (2002) and Zheng *et al,* (2007). It was also reported by Wang and Sun (2002) and Papadopoulos *et al,* (2002, 2004) that the density of particleboards made from wheat straw, coconut chips, and bamboo chips significantly affected the particleboard properties. The increase in water resistant properties as density increased was also in conformity with results from the experiment by Zheng *et al,* (2007).

The reduction in the values of MOR and MOE obtained as a result of reduction in the cement component in the mixing ratios is in conformity with similar studies on cement-reinforced lingo-cellulosic composites. The result also showed that boards with higher cement content had higher density values (Eusebio *et al.*, 1998; Latorraca and Iwakiri, 2000; Zhou and Kamdem, 2002). Irrespective of this, ways by which stable low-density cement-bonded composites, with reduced cement to particle ratio, can be made should be of priority as high density boards are difficult to handle, cut, nail and transport (Zhou and Kamdem, 2002) coupled with the cost implication associated with higher content of cement component for its production. It has also been noted that higher cement contents do not always result in continuous further property increase in composite boards (Del Meneéis *et al*, 2007).

Chapter Five

Conclusion

CHAPTER FIVE

CONCLUSION

1. The result showed that higher cement content had higher density values as well as higher mechanical properties. It also founded that course particles had higher density and low water absorption capacity and higher mechanical properties.
2. Cement bonded particle board from *Areca catechu* is a cheap constructional material and it can be manufactured from conventional process. It may create an alternative new source of raw material of CBP manufacturing.
3. Further study is necessary to improve the mechanical and physical properties of Betelnut cement-bonded board.
4. Govt and other wood based industries should take some necessary steps for introducing and popularizing cement bonded particle board in Bangladesh.

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CHAPTER SIX

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Appendix

APPENDIX ONE

Sample No.	Density(gm/cm3)	STDEV	Average	STDEV	Final	Total Density
Fa1	1.015817	0.014654	Fa Avg 1	0.002149	FINE 1.01	1.06 gm/cm3
Fa2	1.0145	0.010524				
Fa3	1.014797	0.011557				
Fb1	1.037496	0.030117	Fb Avg 1.02	0.01072		
Fb2	1.039736	0.035801				
Fb3	1.046704	0.015056				
Ca1	1.083793	0.007774	C a Avg 1.05	0.008231	Coarse 1.06	
Ca2	1.105361	0.009353				
Ca3	1.077433	0.022754				
Cb1	1.089108	0.012656	C b Avg 1.07	0.004233		
Cb2	1.130503	0.00728				
Cb3	1.107908	0.015632				
FCa1	1.059231	0.018896	FC a Avg 1.03	0.016928	Fine+Coarse 1.04	
FCa2	1.066361	0.014854				
FCa3	1.084067	0.045985				
FCb1	1.081801	0.018435	FC Avg 1.04	0.003003		
FCb2	1.093217	0.015339				
FCb3	1.084784	0.012431				

Sample No.	MC (%)	STDEV	Average	STDEV	Final	Total MC (%)
Fa1	15.13482	0.430285	Fa Avg 15.56638	0.224679	Fine 16.04	17.62%
Fa2	15.74273	0.021457				
Fa3	15.82159	0.06436				
Fb1	16.38803	0.035675	Fb Avg 16.50782	0.044355		
Fb2	16.54094	0.036071				
Fb3	16.5945	0.112697				
Ca1	19.45742	0.036216	Ca Avg 17.86679	0.898154	Coarse 19.33	
Ca2	17.41148	1.616905				
Ca3	16.73148	0.087569				
Cb1	20.17492	1.392477	Cb Avg 20.80094	0.502948		
Cb2	20.92966	0.538				
Cb3	21.29824	1.424881				
FCa1	18.58959	3.703608	FC a Avg 17.12863	0.955606	Fine Coarse 17.52	
FCa2	17.11262	1.984138				
FCa3	15.68367	2.121298				
FCb1	19.2391	0.150274	FC b Avg 17.90667	1.089169		
FCb2	17.81181	2.059929				
FCb3	16.66911	2.012728				

Sample No.	WA (%)	STDEV	Average	STDEV	Final	Total WA (%)
Fa1	32.31832	0.368053	Fa Avg 32.50851	0.315902	FINE 30.95	27%
Fa2	32.69871	0.260748				
Fa3	33.00668	0.318905				
Fb1	29.65843	0.154617	F b Avg 29.38236	0.788526		
Fb2	29.71798	0.178338				
Fb3	28.77067	1.532091				
Ca1	24.31109	1.035357	C a Avg 24.59069	0.123484	Coarse 23.58	
Ca2	25.27558	1.079136				
Ca3	24.18539	1.26774				
Cb1	22.88496	0.412891	C b Avg 22.56375	0.377641		
Cb2	22.33245	1.153766				
Cb3	22.47383	0.910476				
FCa1	27.66743	0.057585	FC a Avg 27.93021	0.256289	Fine+Coarse 26.83	
FCa2	28.17648	0.420031				
FCa3	27.94673	0.15407				
FCb1	25.43096	0.306464	FC b Avg 25.73723	0.01142		
FCb2	25.95622	0.31722				
FCb3	25.8245	0.294392				

Sample No.	TS (%)	STDEV	Average	STDEV	Final	Total TS (%)
Fa1	2.619176	0.847509	F a Avg 2.921746	0.203335	Fine 2.76	2.40%
Fa2	2.94209	0.517783				
Fa3	3.203972	0.476499				
Fb1	2.897784	0.483433	F b Avg 2.607464	0.65619		
Fb2	2.295214	0.923329				
Fb3	2.629393	1.774187				
Ca1	2.011494	0.406383	C a Avg 2.526767	0.363133	Coarse 2.33	
Ca2	4.119443	1.030939				
Ca3	1.449363	1.039664				
Cb1	1.44682	0.493369	C b Avg 2.135923	0.28222		
Cb2	2.647104	0.013446				
Cb3	2.313843	0.5107				
FCa1	2.631847	0.907843	FC a Avg 2.54024	0.508675	Fine+Coarse 2.39	
FCa2	2.352119	0.504341				
FCa3	2.636754	1.514881				
FCb1	2.339449	1.039664	FC b Avg 2.243664	0.313584		
FCb2	2.354707	0.519893				
FCb3	2.036835	0.475834				

Sample No.	LE (%)	STDEV	Average	STDEV	Final	Total LE (%)
Fa1	4.916695	0.411104	F a Avg 4.877264	0.102893	FINE 4.54	3.90%
Fa2	4.914104	0.375997				
Fa3	4.800992	0.217947				
Fb1	4.221846	0.192271	F b Avg 4.203206	0.319649		
Fb2	4.337099	0.769986				
Fb3	4.050673	0.718216				
Ca1	3.704428	0.409547	C a Avg 3.664333	0.278846	Coarse 3.46	
Ca2	3.761682	0.105852				
Ca3	3.526889	0.662782				
Cb1	2.331429	0.433126	C b Avg 3.275197	0.052366		
Cb2	3.684918	0.365456				
Cb3	3.809242	0.468517				
FCa1	4.569672	0.410397	FC a Avg 4.048588	0.112405	Fine+Coarse 3.97	
FCa2	4.50981	0.474259				
FCa3	3.066282	0.628999				
FCb1	4.164477	0.469233	FC b Avg 3.894395	0.032291		
FCb2	3.816163	0.471762				
FCb3	3.702546	0.414611				

Sample No.	MOE(N/mm2)	STDEV	Average	STDEV	Final	Total MOE(N/mm2)
Fa1	278.5539	11.3740	F a Avg 280.4681	1.635941	FINE 283.40	288.80N/mm2
Fa2	285.9043	8.57122				
Fa3	276.9461	11.4345				
Fb1	280.0055	25.8099	F b Avg 286.3297	7.565198		
Fb2	285.7507	25.0818				
Fb3	293.2329	12.3577				
Ca1	311.7751	3.78340	Ca Avg 316.4747	3.657874	Coarse 318.22	
Ca2	328.2537	10.2776				
Ca3	309.3954	6.7367				
Cb1	317.1358	7.2411	C b Avg 319.9593	0.670275		
Cb2	331.5616	5.91327				
Cb3	311.1805	7.6475				
FCa1	261.9099	9.94750	FC a Avg 264.5825	5.070753	Fine+Coarse 264.85	
FCa2	269.0933	10.3147				
FCa3	262.7442	2.9023				
FCb1	264.1651	12.6027	FC b Avg 265.1149	2.981149		
FCb2	272.3674	10.4384				
FCb3	258.8122	8.39311				

Sample No.	MOR(N/mm2)	STDEV	Average	STDEV	Final	Total MOR(N/mm2)
Fa1	3.641092	0.17097	F a Avg 3.650071	0.031132	FINE 3.67	3.85 N/mm2
Fa2	3.670599	0.15298				
Fa3	3.63852	0.11035				
Fb1	3.68846	0.29116	F b Avg 3.680047	0.060022		
Fb2	3.640492	0.21379				
Fb3	3.711188	0.17299				
Ca1	3.951164	0.10053	C a Avg 4.00446	0.031543	Coarse 4.04	
Ca2	4.140219	0.04178				
Ca3	3.921998	0.09103				
Cb1	4.014514	0.13732	C b Avg 4.057782	0.035943		
Cb2	4.16058	0.09215				
Cb3	3.998251	0.06623				
FCa1	3.750578	0.07088	FC a Avg 3.747883	0.029613	Fine+Coarse 3.79	
FCa2	3.836084	0.11981				
FCa3	3.656987	0.06644				
FCb1	3.86901	0.07590	FC b Avg 3.824041	0.008708		
FCb2	3.846496	0.06637				
FCb3	3.756619	0.05851				

APPENDIX TWO

Analysis of Variance Procedure (Density)

Class Level Information

Class	Levels	Values
TRTMENT	6	t1, t2, t3, t4, t5, t6.

Number of observations in data set = 54
Dependent Variable: Density

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.05083967	0.01016793	24.16	0.0001
Error	48	0.02020268	0.00042089		
Corrected Total	53	0.07104235			

R-Square	C.V.	Root MSE	Density Mean
0.715625	1.919077	0.02051559	1.06903426

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRTMENT	5	0.05083967	0.01016793	24.16	0.0001

T tests (LSD) for variable: Density

Alpha= 0.05; df= 48; MSE= 0.000421
Critical Value of T= 2.01
Least Significant Difference= 0.0194

Grouping	Mean	N	TREATMENT
A	1.08	9	T4
B	1.05	9	T3
B	1.04	9	T6
B	1.03	9	T5
C	1.02	9	T2
D	1.00	9	T1

Analysis of Variance Procedure (Moisture Content)

Class Level Information

Class	Levels	Values
TRTMENT	6	t1, t2, t3, t4, t5, t6.

Number of observations in data set = 54
Dependent Variable: Moisture Content

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	143.60994045	28.72198809	12.23	0.0001
Error	48	112.69314556	2.34777387		
Corrected Total	53	256.30308601			

R-Square	C.V.	Root MSE	MC Mean
0.560313	8.691349	1.53224471	17.62953860

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRTMENT	5	143.60994045	28.72198809	12.23	0.0001

T tests (LSD) for variable: Moisture Content

Alpha= 0.05; df= 48; MSE= 0.000421
Critical Value of T= 2.01
Least Significant Difference= 1.4523

Grouping	Mean	N	TREATMENT
A	20.8009	9	T4
B	17.9067	9	T6
B	17.8668	9	T3
B	17.1286	9	T5
CB	16.5078	9	T2
C	15.5664	9	T1

Analysis of Variance Procedure (Water Absorption)

Class Level Information

Class	Levels	Values
TRTMENT	6	t1, t2, t3, t4, t5, t6.

Number of observations in data set = 54

Dependent Variable: Water Absorption

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	15.40520439	3.08104088	11.92	0.0001
Error	48	12.40365989	0.25840958		
Corrected Total	53	27.80886429			

R-Square	C.V.	Root MSE	WA Mean
0.553967	12.45775	0.50834003	27.14646704

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRTMENT	5	591.23404664	118.24680933	230.69	0.0001

T tests (LSD) for variable: Water Absorption

Alpha= 0.05; df= 48; MSE= 0.512576
Critical Value of T= 2.01
Least Significant Difference= 0.6786

Grouping	Mean	N	TREATMENT
A	32.67	9	T1
B	29.38	9	T2
C	27.93	9	T5
D	25.73	9	T6
E	24.60	9	T3
F	22.56	9	T4

Analysis of Variance Procedure (Thickness Swelling)

Class Level Information

Class	Levels	Values
TRTMENT	6	t1, t2, t3, t4, t5, t6.

Number of observations in data set = 54
Dependent Variable: Thickness Swelling

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	3.50925180	0.01016793	24.16	0.0001
Error	48	0.02020268	0.00042089		
Corrected Total	53	0.07104235			

R-Square	C.V.	Root MSE	Thickness Swelling Mean
0.715625	1.919077	0.02051559	1.06903426

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRTMENT	5	3.050	0.01016793	24.16	0.0001

T tests (LSD) for variable: Thickness Swelling

Alpha= 0.05; df= 48; MSE= 0.845
Critical Value of T= 2.01
Least Significant Difference= 0.871

Grouping	Mean	N	TREATMENT
A	2.92	9	T1
A	2.60	9	T2
A	2.54	9	T5
A	2.52	9	T3
A	2.20	9	T6
A	2.13	9	T4

Analysis of Variance Procedure (Linear Expansion)

Class Level Information

Class	Levels	Values
TRTMENT	6	t1, t2, t3, t4, t5, t6.

Number of observations in data set = 54
Dependent Variable: Linear Expansion

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	15.40	3.08	11.92	0.0001
Error	48	12.40	0.258		
Corrected Total	53	27.80			

R-Square	C.V.	Root MSE	LE Mean
0.554	12.45	0.51	4.08

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRTMENT	5	15.40	3.08	11.92	0.0001

T tests (LSD) for variable: Linear Expansion

Alpha= 0.05; df= 48; MSE= 0.258
Critical Value of T= 2.01
Least Significant Difference= 0.482

Grouping	Mean	N	TREATMENT
A	4.87	9	T4
BA	4.55	9	T5
BC	4.20	9	T2
DC	3.49	9	T6
DE	3.68	9	T3
E	3.27	9	T4

Analysis of Variance Procedure (MOR)

Class Level Information

Class	Levels	Values
TRTMENT	6	t1, t2, t3, t4, t5, t6.

Number of observations in data set = 54

Dependent Variable: MOR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1.29	0.259	14.80	0.0001
Error	48	0.84	0.0175		
Corrected Total	53	2.13			

R-Square	C.V.	Root MSE	MOR Mean
0.6065	3.45	0.1323	3.82

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRTMENT	5	1.295	0.256	14.80	0.0001

T tests (LSD) for variable: MOR

Alpha= 0.05; df= 48; MSE= 0.0175
Critical Value of T= 2.01
Least Significant Difference= 0.1254

Grouping	Mean	N	TREATMENT
A	4.05	9	T4
B	4.00	9	T3
B	3.82	9	T6
B	3.74	9	T5
CB	3.68	9	T2
B	3.65	9	T1

Analysis of Variance Procedure (MOE)

Class Level Information

Class	Levels	Values
TRTMENT	6	t1, t2, t3, t4, t5, t6.

Number of observations in data set = 54
Dependent Variable: MOE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	26638.38	5327.61	35.13	0.0001
Error	48	7279.15	151.64		
Corrected Total	53	33917.23			

R-Square	C.V.	Root MSE	MOE Mean
0.785	4.26	12.31	288.82

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRTMENT	5	26638.07	5327.61	35.13	0.0001

T tests (LSD) for variable: MOE

Alpha= 0.05; df= 48; MSE= 151.64
Critical Value of T= 2.01
Least Significant Difference= 11.67

Grouping	Mean	N	TREATMENT
A	319.95	9	T4
A	316.45	9	T3
B	286.33	9	T2
B	280.46	9	T1
C	265.11	9	T6
C	263.58	9	T5