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**COURSE TITLE: THESIS WORK**

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# DECLARATION

I, Tahsina Tasmin, Student ID. 110525 declare that the thesis is based on my own work except for quotation and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Khulna University or any other institutions.

I, hereby, give consent for my thesis, if accepted, to be available for any kind of photocopying and for inter- library loans.

Signature. Tahsina Tasmin ..................................

Name of the candidate: Tahsina Tasmin

**Dedicated To**

**My Parents and beloved Sister**

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**Tahsina Tasmin**

# ABSTRACT

The study was conducted to manufacture the cement- bonded fiber board from Bagasse (*Saccharum officinarum L.*) fiber and to evaluate the properties of cement- bonded board from Bagasse (*Saccharum officinarum L.*) fiber. The fibers used to make the board was isolated by three different processes, these are grinded fibers that were isolated by grinding pith fiber, boiled fibers that were isolated by hot water treatment of pith fiber, pulped fibers that were isolated by chemical pulping of pith fiber. The ratio used for this work was fixed for three types of fiber and it was fiber: cement: water = 1: 2.2: 1.1. The density of grinded fiber board was 1.094 $g/cm^3$, pulped fiber board was 1.14 $g/cm^3$and hot water treated board was 1.13 $g/cm^3$. The MOR of grinded fiber board was 8.92 $N/mm^2$, pulped fiber board was 19.19 $N/mm^2$ and hot water treated fiber board was 14.03 $N/mm^2$, and MOE of grinded fiber board was 2470.60 $N/mm^2$, pulped fiber board was 4539.70 $N/mm^2$ and hot water treated fiber board was 3120.68 $N/mm^2$. From all type of Cement- bonded Bagasse fiber board, cement- bonded pulped fiber board showed the better performance than grinded and hot water treated fiber board. Hence, it can be concluded that cement bonded fiber board from Bagasse fiber can be an alternative material for manufacturing cement bonded board.

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# ABBREVIATION

| | |
|---|---|
| ASTM | American Society for Testing and Material |
| BFRI | Bangladesh Forest Research Institute |
| CBF | Cement- Bonded Fiber board |
| $Cm^3$ | Cubic Centimeter |
| FAO | Food and Agricultural Organization |
| $m^3$ | Cubic Meter |
| Kg | Kilogram |
| mm | millimeter |
| IB | Internal Bonding |
| MOE | Modulus of Elasticity |
| MOR | Modulus of Rupture |
| MPa | Mega Pascal |
| SD | Standard Deviation |
| N | Newton |
| MC | Moisture Content |
| TS | Thickness swelling |
| WA | Water absorption |
| LE | Linear Expansion |
| CBGBF | Cement- Bonded Grinded Bagasse Fiber board |
| CBBBF | Cement- Bonded Boiled Bagasse Fiber board |
| CBPBF | Cement- Bonded Pulped Bagasse Fiber boar |

# CHAPTER ONE

# INTRODUCTION

## 1.1 General Introduction

Fibers of lignocellulosic material bonded together with an inorganic material such as Ordinary Portland Cement (OPC) is referred to as Cement- bonded- Fiber board. Fiber board manufactured using mineral cement as the binding agent is gradually gaining importance in many countries of the world. Cement bonded Fiber board are already used in Europe, Russia, United States S. E. Asia mainly used for roofs, floors and walls. Cement bonded Particle has the required strength as well as the resistance to high humidity in the tropical climate. These composites are strong, stiff and resistance to moisture, fire, fungi, and insects. In panel form, they are being utilized for structural and non-structural application in both interior and exterior situation (Anon, 1985).

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 lignocellulosic 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 1994). Nowadays agricultural residues are getting importance in research works. These are almost waste materials and there is no specific use of these, sometimes used for fuel wood purpose. It has already showed good performance for making composites. Fibers have enough strength properties to bind with cement.

Present world is very concerned about environmental pollution. All formaldehyde based resin binders are more or less toxic and injurious to health and both environment. Considering these aspects manufacture of cement bonded composites from saw dust and agricultural wastes are attempted. (Stillinger and Wentworth, 1977). Uses of Agricultural wastes are not only reduced environmental hazard but also contributed to the economic growth of the country and also reduced pressure on trees from forest.

One of most recent proposals for a research frame work 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 wastes and agricultural wastes in future is to be blend proportionate amounts of materials with inorganic materials. For the inorganic materials, the most apparent and wide used example is cementing (Aoki, 1999).

Bangladesh is a densely populated country. The problem of housing is becoming more and more acute with the increase in its population. Moreover, natural disasters like flood are very frequent, and humid weather prevails in most part of the year. So there is need of making low cost housing materials. For these purpose CBF composites can be used as cheap constructional material. The useless agricultural products like rice- husks, sugarcane – dregs and coconut shell are always thrown away as the wastes. In fact, these agricultural wastes containing some natural fibers are valuable and can utilize to improve mechanical properties of the materials. It can also be reduced the pressure on forests. In this context, the present study was undertaken to evaluate the suitability of Bagasse (*Saccharum officinarum*) fiber in the fabrication of cement bonded fiber composites.

## 1.2 Objectives of the study

1. To develop cement bonded board from Bagasse (*Saccharum officinarum*) fiber.
2. To evaluate the physical and mechanical properties of cement bonded board from Bagasse (*Saccharum officinarum*).

# CHAPTER TWO

# REVIEW OF LITERATURE

## 2.1 General information about Cement bonded Fiber board

### 2.1.1 Definition of Cement bonded Board.

Particles or fibers of lignocellulosic material bonded together with Portland cement matrix are produced in panel form is called Cement bonded particle board or Fiber board. Its production and continuous research are becoming more prevalent in the number of countries around the world. Discovering new methods of manufacturing technologies to replace the traditional ones, expanding base, and 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 cement, when combined with water, immediately reacts in a process called hydration to eventually solidifying into a solid stone- like mass. Successfully marketed Portland cement bonded composites consists of both low density products made with excelsior and high density products made particles or fibers (Anon, 1987).

Cement bonded fiber board is produced from fiber which we can get from either wood or non woody materials. Wood fiber agricultural residue fiber reinforced cement- bonded boards are manufactured from fiber (7- 8.5%), 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 proportions outlined above are combining the cement, sand, fibers and additives and diluted to form slurry with a solids content of 10% (Shakri, 2008)

The low density products may be used as interior ceiling and wall 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 panel is stuccoes, and the interior is plastered. High density panels can be used as flooring, roof sheathing, load bearing walls, and cement forms. Fairly complex molded shapes can be molded or extruded, such as decorative roofing tiles or non-pressure pipes. (Anon, 1987).

### 2.1.2 Brief History about Cement bonded Board

Particleboards are not more than a few decades old production. Before particle board, modern plywood, as an alternative to natural wood, was invented in the 19$^{th}$ 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. The new technologies 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. It was used waste material such as planer shavings, off- cuts or sawdust, hammer- milled into chips, and bound together with a phenolic resin. In the early 1960s, a high density cement- bonded structural flake board was developed leading to expand applications (Deppe, 1974). Today, wood- cement panels have found acceptance in a number of countries as a result of certain desirable characteristics. The majority of research in this field has been carried out on particleboards and flake boards. An excellent review can be found elsewhere (Jorge et al. 2004).

Men developed composite wood products such as particle board, plywood, fiber board but they use mainly chemical resin as a binder. This chemical causes hazardous to human health. Even its load bearing capacity is not so good to use for building construction through it can be used for different types of furniture or decorative purposes. Considering that man is trying to find out the alternative which should not be harmful and bonding quality should be such that man can use it as building materials. All natural material is considered as environment friendly and cement is one of them. Environmental concern about the disposal of waste materials has focused renewed attention on low density cement bonded wood composites (CBWCs) (Moslemi,1989)

In Indonesia the first mineral- bonded board made of saw dust was established in Palembang. This board used saw dust and shavings as raw materials. In 1970s there were six mineral bonded board mills in Indonesia and four of them used excelsior or wood- wool and rest used wood flakes in the mix. 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, 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 (Desch, 2001)

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 particle board technology, much was leant that is also applicable to cement- bonded wood particle panels. Early industrial production of wood cement panels were produced in Japan in 1965(Moslemi, 1989).

Interest in wood fiber-reinforced cement was sparked by the post-World War II shortage of asbestos fibers, which caused some private companies to consider cellulose fiber as a substitute for asbestos in fiber-reinforced cement. This interest faded as asbes- tos supplies recovered in the 1950s, but it regained strength by the mid- 1970s with growing concern over the health risks linked to asbestos. The controversy over asbestos led a number of companies in Australia, Europe, and Scandinavia to develop processes for fabricating fiber-reinforced cement boards using cellulose and other mineral fillers. Over the past 25 years, the American Concrete Institute has also sponsored research to develop high-performance fiber-reinforced cement composites that use discrete fibers, including steel, glass, synthetic polymers, and cellulose (Moslemi, 1989)

Today, cellulose fiber is used in a wide variety of fiber-reinforced cement products, many of which were originally developed using asbestos fiber. These materials use only 5 to 15 percent cellulose fiber by weight, have densities ranging from 1,100 to 1,800 kg/m^3, and have bending strengths ranging up to 30 MPa. The primary function of fibers in these cement composites is to increase the energy of fracture. By bridging gaps, the fibers prevent stress concentrations at crack tips, thus retarding brittle fracture mechanisms and dissipating energy in the form of fiber pullout or rupture.

### 2.1.3 Inorganic Bonded Board

Inorganic binders fall into three main categories: gypsum, magnesia cement and Portland cement. Gypsum and magnesia cement are sensitive to moisture, and their use is generally restricted to interior applications. Composites bonded with Portland cement are more durable than those bonded with gypsum or magnesia cement and are used in both interior and exterior applications. Inorganic bonded composites are made by blending proportionate amounts of lignocellulosic fiber with inorganic materials in the presence of water and allowing the inorganic material to cure or "set up" to make a rigid composite. All inorganic bonded composites are very resistant to deterioration, particularly by insects, vermin and fiber.

Table 2.1: Industrial production of inorganic- bonded wood composites

| 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 fiber boards |
| 1972 | Magnesite- bonded wood composite panels |
| 1982 | Gypsum particleboard |

(Kossatz et al, 1983)

#### 2.1.4 Board performance

Cement bonded board has been found to be a good substitute for concrete hollow blocks, plywood, particle board and other resin bonded boards. It 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).

Cement bonded boards properties offer a variety of advantages. One of these includes excellent machinability 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. The use of special adhesives enables the manufacture to produce panels with flanges. Such components can be used in the construction of building without the use of studs. House construction utilizing these type of technology is taking place in a number of countries where such panels are vertically, bolted together for quick assembly. In addition to home construction, cement bonded particle board is used in nonresidential construction as cladding and as facing. The boards can be used in its natural gray color or can be finished with a variety 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 (Stillingger and Wentworth, 1977).

Table 2.2 General properties of low density cement wood fabricated using excelsior type particles.

| **Property** | **From (MPa)** | **To (MPa)** |
|---|---|---|
| Bending strength | 1.7 | 5.5 |
| Modulus of elasticity | 621 | 124 |
| Tensile Strength | 0.69 | 4.1 |
| Compression strength | 0.69 | 5.5 |

(Eusebio, 2003)

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, fire resistance, nail and screw withdrawal resistance, and finishing qualities with paints and other coating are important practical consideration.

### 2.1.5 Composition of Cement bonded Bard

Cement boards are mainly cement bonded particle boards and cement fiber. Cement bonded particle boards have treated wood flakes as reinforcement, whereas in cement fiber boards have cellulose fiber, which is a plant extract as reinforcement. Cement acts as binder in both the cases. The fire resistance properties of cement bonded blue particle boards and cement fiber boards are the same. In terms of load-bearing capacity, cement-bonded particle boards have higher capacity than cement fiber boards. Cement particle boards can be manufactured from 6 mm to 40 mm thickness making it ideally suitable for high load bearing applications. These boards are made of a homogeneous mixture and hence are formed as single layer for any thickness. Cement fiber boards are more used in decorative applications and can be manufactured from 3 mm to 20 mm thickness. Many manufacturers use additives like mica, aluminium stearate in order to achieve certain board qualities. Typical cement fiber board is made of approximately 40-60% of cement, 20-30% of fillers, 8-10% of cellulose, 10-15% of mica. Other additives like above mentioned aluminium stearate and PVA are normally used in quantities less than 1%. Cenospheres are used only in low density boards with quantities between 10-15%. The actual recipe depends on available raw materials and other local factors.

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 | 5- 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 (Mpa) | 3- 4 | 4- 5 | 2- 3 | 2- 3 | 7- 10 |

### 2.1.6 Application of Cement bonded 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 $A_2$ boards.

### 2.1.7 Advantages of Cement bonded boards

- Cement bonded boards are strong, stiff and resistance to moisture, fungi and insect. Fire resistance is being higher than any other materials. In panel form, they are being utilized for structural and nonstructural 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, isocyanides, wood preservatives, fungicides.
- It can be produced by either labor- incentive or machine incentive operations, which is most economically feasible.
- 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 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)

## 2.1 General information about Bagasse (*Saccharum officinarum*)

### 2.2.1 General description of Sugarcane

**Sugarcane**, or **sugar cane**, is one of the several species of tall perennial true grasses of the genus *Saccharum*, tribe Andropogoneae, native to the warm temperate to tropical regions of South Asia and Melanesia, and used for sugar production. It has stout jointed fibrous stalks that are rich in the sugar sucrose, which accumulates in the stalk internodes. The plant is two to six meters (6 to 19 feet) tall. All sugar cane species interbreed and the major commercial cultivars are complex hybrids. Sugarcane belongs to the grass family Poaceae, an economically important seed plant family that includes maize, wheat, rice, and sorghum and many forage crops. (https://en.Wikipedia.org/wiki/sugarcane).

Fig: 2.1 Sugarcane stem

Sugarcane is a tropical, perennial grass that forms lateral shoots at the base to produce multiple stems, typically three to four meters high and about five cm in diameter. The stems grow into cane stalk, which when mature constitutes approximately 75% of the entire plant. A mature stalk is typically composed of 11–16% fiber, 12–16% soluble sugars, 2–3% non-sugars, and 63–73% water. A sugarcane crop is sensitive to the climate, soil type, irrigation, fertilizers, insects, disease control, varieties, and the harvest period. The average yield of cane stalk is 60–70 tonnes per hectare per year. However, this figure can vary between 30 and 180 tonnes per hectare depending on knowledge and crop management approach used in sugarcane cultivation. Sugarcane is a cash crop, but it is also used as livestock fodder.

### 2.1.2 Sugarcane production in the World

In 2012, The Food and Agriculture Organization of the United Nations (FAO) estimate sugarcane was cultivated on about 26.0 million hectares, in more than 90 countries, with a worldwide harvest of 1.83 billion tons. Brazil was the largest producer of sugar cane in the world. The next five major producers, in decreasing amounts of production, were India, China, Thailand, Pakistan and Mexico. Bagasse production is 422 million tonnes per year in the world.

**Top ten sugarcane producers — 2015**

| Country | Production (thousand metric tons, TMT) |
|---|---|
| Brazil | 739 267 |
| India | 341 200 |
| China | *125 536 |
| Thailand | 100 096 |
| Pakistan | 63 750 |
| Mexico | 61 182 |
| Colombia | 34 876 |
| Indonesia | *33 700 |
| Philippines | 31 874 |
| United States | 27 906 |

(Food and Agricultural Organization of United Nations: Economic and Social Department: The Static Division)

In Bangladesh total sugarcane cultivation area is 0.17 million hectares, and average sugarcane production is 7.0- 7.5 million tonnes. Sugarcane crushed in mills is 2.6 million tonnes. Average bagasse production in Bangladesh is 0.8 million tonnes. Contribution of sugarcane to national GDP in Bangladesh is about 0.78%. Five million people depend on sugarcane production in Bangladesh.

### 2.1.3 General Description of Bagasse

**Bagasse** is the fibrous matter that remains after sugarcane or sorghum stalks are crushed to extract their juice. It is used as a biofuel and in the manufacture of pulp and building materials.

Table 2.4: The constituents of bagasse are,

| Constituents | % |
|---|---|
| Moisture | 49 |
| Fiber | 48.7 |
| Soluble solids | 2.3 |

For each 10 tonnes of sugarcane crushed, a sugar factory produces nearly 3 tonnes of wet bagasse. Since bagasse is a by-product of the cane sugar industry, the quantity of production in each country is in line with the quantity of sugarcane produced.

Fig: 2.2 Crushed Sugarcane (Bagasse)

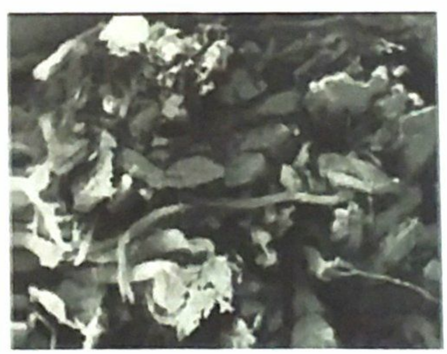

Fig: 2.3 Bagasse Fiber Bundle Cross-Section

Bagasse contains bundles of fibers and the fibers are randomly dispersed. Bagasse fibers are consisting with **pith fibers, rind fibers** and **dermax**. Juices containing internal fibers are the **pith fibers**. Pith fibers are mainly parenchyma material. Outer tough fibrous materials are **rind fibers**. Higher hemicellulose content and Lower lignin content present in rind fibers. Fiber contains parenchyma cells and vascular bundles. Thin wax laden skin is called **dermax**.

That is composed of epithelial cell. Waxy layer is hydrophobic and indirectly helps for bonding.

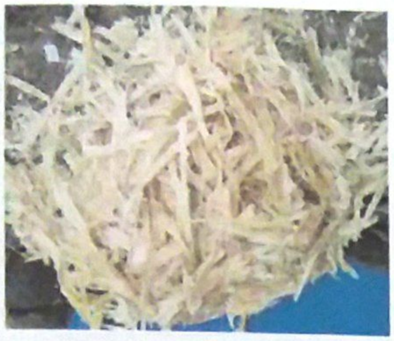

Fig: 2.2 Pith Fibers

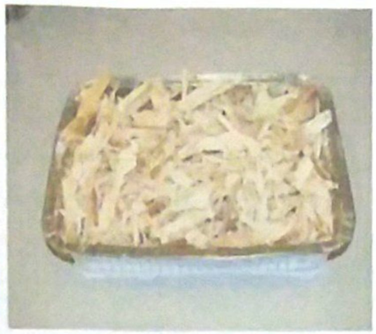

Fig: 2.3 Rind fibers

Fig: 2.4 Dermax

**2.1.3 Bagasse Fiber Chemical Composition**

Fibers in bagasse consist mainly of cellulose, hemicelluloses, and lignin. The cellulose is present in three types: α, β and γ. The cellulose is known as pure cellulose, whereas β and γ cellulose combined are called hemicellulose. The hemicelluloses are chemically linked with cellulose molecules. The other main compound in sugar cane fiber bundles is lignin which is a high molecular weight substance. Because it is not possible to isolate lignin quantitatively from plant materials without chemical or mechanical degradation, its true molecular weight is not known. The amount of lignin that naturally occurs in sugar cane depends to a great extent on the variety and age of the cane. The amounts of sugar, lignin, and lignin-like compounds are increased as the plant advances in age until the flowering time, when the plant is considered to be fully mature. Beyond the flowering time, the sugar cane plant tends to consume its stock of sucrose and lignin as a result of physiological changes due to flowering. The depletion of the organic compounds makes the rind and the fiber bundles softer and spongy.

Table 2.5: Percentage of chemical constituent of Bagasse,

| **Chemical Constituents** | **Percentage (%)** |
|---|---|
| Cellulose | 45–55% |
| Hemicellulose | 20–25% |
| Lignin | 18–24% |
| Ash | 1–4% |
| Waxes | <1% |

(https://en. Wikipedia.org/wiki/Bagasse)

Table 2.6 Comparison of bagasse fiber with other vegetable fibers (G. Duraisamy & Karthic.T;)

| Fiber | Cellulose% | Hemicellulose% | Lignin% |
|---|---|---|---|
| Sugar cane | 50 | 30 | 18 |
| Kenaf | 65.7 | 13.2 | 21.6 |
| Ramie | 68.6 | 13.1 | 0.6 |
| Jute | 64.4 | 12.1 | 18.8 |
| Flax (un retted) | 56.5 | 15.4 | 2.5 |
| Flax (retted) | 64.1 | 16.7 | 2.0 |

### 2.2.5 Bagasse Fiber Length and Linear Density

The length of the fiber should be several hundred times the width, which enables fibers to be twisted together to form a yarn. The actual length of the fiber is also important. It can be infinitely long, but should not be shorter than 6 to 12 mm, or it may not hold together after sinning. The apparent limitation on length of the sugar cane rind is the internode length, and this varies from 5 to 25 cm. The length of the ultimate fiber cells is from 2 to 4 mm. The length of extracted fiber bundles depends on extraction conditions and the extraction process. The width of the fiber bundles can vary between considerable limits, and eventually determines the fineness. The resultant sugar cane fiber bundles consist of several to hundreds of ultimate fiber cells, with the width of the fiber bundles being dependent on extraction conditions and extraction processes. The amount of lignin removed from the rind affects the size of the fiber bundles as well as their tensile and bending properties.

Table 2.7 Comparison of Bagasse fiber length and linear density with other vegetable fibers (Duraisamy & Karthic).

| Fiber | Length (mm) | Linear density (tex) | Cell Length (mm) |
|---|---|---|---|
| Cotton | 1.5- 5.6 | 0.11- 0.37 | 15- 56 |
| Sugarcane | 2.5- 20 | 6.5- 14 | 2- 4 |
| Kenaf | 7- 15 | 1.5- 4.5 | 1- 7 |
| Flax | 20- 140 | 0.19- 1.98 | 4- 77 |
| Jute | 150- 360 | 1.44- 3.0 | 0.8- 6 |

# CHAPTER THREE

# MATERIALS AND METHOD

## 3.1 Materials

- Main raw material for manufacturing cement bonded fiber board is bagasse pith part.
- The important raw material is Portland cement (Elephant Brand Cement).
- For mixing of Portland land cement and bagasse water is an essential material for this work.

Fig: 3.1 Bagasse

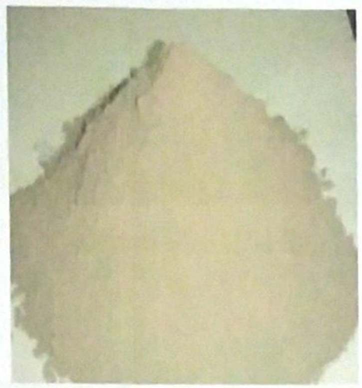

Fig: 3.2 Portland Cement

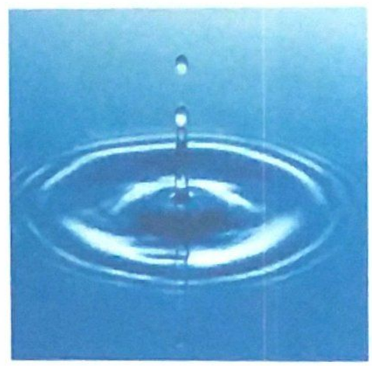

Fig: 3.3 Water

## 3.2 1. Methods and Procedures

**Collection of Raw Material:**

Bagasse pith was collected from Gollamari Bazar just beside Khulna University Campus. Port land cement (Elephant brand) was purchased from the local market. Water was available in the laboratory.

**Preparation of Raw Material:**

After collection of raw material it was air dried for seven days. Then the pith part of bagasse was cut into 1-3 cm size by using conventional hand tool.

**Fiber Isolation Process**

1-3 cm sized pith part was used for fiber isolation. Fiber was isolated in three different processes, *1. Grinding*

1-3 cm sized pith part was inserted into the laboratory grinding machine manually. After grinding pith fibers were separated. Then the grinded fibers were collected from the grinding machine manually. Then the grinded fibers were oven dried at 104 degree centigrade to 12- 14 % moisture content. Then the raw material was ready to make cement bonded fiber board.

Fig: 3.4 (1-3) cm Pith Part

Fig: 3.5 Grinded by Grinding Machine

Fig: 3.6 Grinded Fiber

*2. Hot Water Treatment*

1-3 cm sized pith fiber was grinded by grinding machine as before. Then grinded fiber was boiled with water in a digester at 180 degree centigrate temperature for 2 hours. Then it was kept in the digester for 2 hour for cooling. Then boiled fiber was washed for 20 minutes to remove reamining suger from the fiber. Then it was air dried for 2 days. Then it was oven dried at 104 dergee centigrade to 12-14% moisture content. After hot water teatment fiber was more properly isolated than grinding process.

Fig: 3.7 Hot Water Treatment

Fig: 3.8 Hot Water Treated Fiber

Fig: 3.9 Oven Drying of Fiber

### 3. *Pulping Process:*

1-3 cm sized pith part was cooked with chemicals for fiber isolation. The chemicals used for pulping are Sodium Hydroxide (NaOH) and Sodium Sulfide ($Na_2S$).

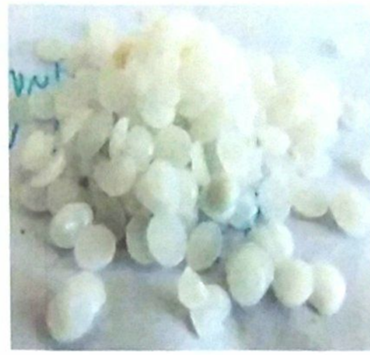

Fig: 3.10 NaOH and $Na_2S$ Fig: 3.11 Sodium Sulfide Fig: 3.12 Sodium Hydroxide

1-3 cm pith part, 40% NaOH, 50% $Na_2S$ with water was cooked in a digester at 180 dergree centigrade temperature for two hour. After cooking it was kept in the digester for 2 hours. Then these material was filtered to separate black liquor. Then the pith fiber was wsahed in a continuous water flow for 2 hours to remove chemicals. Black liquor is very hazardous for environment so it was thrown in proper place. After washing fiber was isolated properly than other two process. Then it was airdried for 2 days in room temperature. After air drying it was oven dried at 104 degree centigrade temperature to 12-14% moisture content.

Fig: 3.13 Cooking Digester Fig: 3.14 Pith part during cooking Fig: 3.15 Isolated Fiber

**Mixing**

Three types of isolated fiber was used for making cement bonded fiber board. Two boards were made by each type of isolated fiber. So six boards were made from three types of fiber which was isolated in three different processess. The cement bonded fiber board was manufactured at cement / oven dried fiber wight ratios of cement: fiber: water = 2.2: 1: 1.1. This ratio was employed for making each type of board. The total procedure was carried out in a pan. At first oven dried fiber was mixed with cement and then requied amount of water was added into it. Mixing continued until the fiber was covered completely with cement.

Fig: 3.16 Mixing of fiber, cement and water

**Mat Forming**

Each mixture was hand formed into a rectangular 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.

Fig: 3.17 Mat formation process of cement bonded fiber board

**Cold Pressing**

Hand formed mats measuring 170×130×32 mm was cold pressed at 5 Mpa pressure. It was kept in pressing condition for 24 hrs.


Fig: 3.18 Hand Formed Mat


Fig: 3.19 Cold Pressing


Fig: 3.20 CBF after pressing

**Curing**

The cement bonded fiber boards were cured in the conventional process. After pressing the boards were kept at room temperature for 14 to 30 days. Water was sprayed frequently for proper curing of the CBF.

**Trimming**

After the boards of each type were produced separately, these were trimmed at edges with the fixed type circular saw. The dimentions of each type of boards were then 160×125 mm.


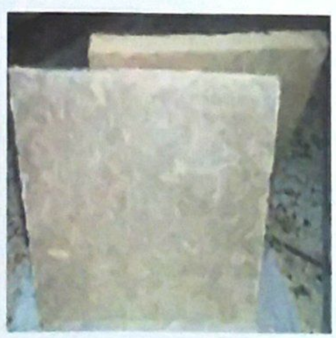
Fig: 3.21 Curing of CBF


Fig : 3.22 Trimmed CBF

### 3.2.2. Flow diagrams of Cement bonded Fiberboard Production

Raw material collection

⇩

Air Drying (7days)

⇩

Chipping (1-3 cm)

⇩

Fiber isolation

- Grinding
- Hot water treatment (2 hrs / 180°C )
- Pulping (40% NaOH, 50% $Na_2S$/ 2hr/ 180°C)

⇩

Mixing (cement: fiber: water= 2.2: 1.0: 1.1)

⇩

Mat forming (170×130×32)mm

⇩

Cold Pressing (24hrs)

⇩

Curing (14-30 days)

⇩

Conditioning

⇩

Trimming

**Fig:** Flow Diagrams of Cement bonded Fiber Board

### 3.2.3 Specifications of manufactured Cement bonded Fiber Boards

Table 3.1: Specifications of manufactured Cement bonded Fiberboards

| | |
|---|---|
| Target Dimensions (mm) | 170 × 130 |
| Target Density ($g/cm^3$) | 1.0 – 1.1 |
| Fiber Isolation Process | Grinding, Hot water Treatment, Chemical Pulping |
| Ratios (Fiber: Cement: Water) | 1: 2.2: 1.1 |
| Pressing | Cold |
| Pressure | 5 MPa |
| Total number of Board manufactured | 18 |

## 3.3 Board Evaluation

### 3.3.1 Preparation of samples for testing

Two replications of each type of boards were used for testing physical and mechanical properties; three samples were collected from each board of each type. The dimension of samples for testing the physical properties was approximately (5 cm × 4 cm) and for testing the mechanical properties was approximately (15cm × 4 cm).

Fig: 3.21 Samples for mechanical test


Fig: 3.22 Samples for physical test

### 3.3.2 Determination of Mechanical Properties

All the samples are cut into required dimension for testing mechanical properties. The laboratory test for characterization of mechanical properties is carried out in the laboratory of Civil Engineering Department of Khulna University of Engineering and Technology, Khulna, Bangladesh.

Fig: 3.23 Mechanical testing of CBF

***Modulus of Rupture (MOR)***

Modulus of Rupture (MOR) is measured by the Compression Testing Machine (CTM), maximum capacity- 2 kN. MOR was calculated by the following formula-

$$\text{MOR} = \frac{3pl}{2bd^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

***Modulus of Elasticity (MOE)***

Modulus of Elasticity (MOE) is measured by the Compression Testing Machine (CTM), maximum capacity- 2 kN MOE is calculated by the following formula-

$$\text{MOE} = \frac{pl^3}{4\Delta bd^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where, p = load in N, l = span length in mm, b = width of the test specimen in mm, d = thickness of test specimen in mm and $\Delta$ = deformation of the board in mm.

### 3.3.3 Determination of Physical Properties

All the samples are cut into 5cm × 4cm dimension for testing physical properties. The laboratory test for characterization of physical properties was carried out in the laboratory of Forestry and Bamboo Technology Discipline, Khulna University, Bangladesh. At first all the specimens were weighted and green dimension were taken at room temperature. Then all the samples were kept into oven for 24 hours. After drying oven dry weight and dry dimension were also measured. Then, the samples were submerged into water for 2 hour. Then wet dimension was taken and all the physical properties were calculated by using formula. Then the samples were again submerged into water for 24 hour.

Fig: 3.24 Samples are submersed in water

Then finally, the wet dimension was taken and all the physical properties were calculated by using following formula-

***Density:***

$$\textbf{Density} = \frac{Weight\ of\ Wood}{Standard\ Volume}$$

***Moisture Content:***

$$\textbf{Moisture Content} = \frac{Green\ Weight - Oven\ Dry\ Weight}{Oven\ Dry\ Weight} \times 100$$

***Water absorption:***

Water absorption was calculated by the following formula-

$Aw = (m_2 - m_1)/m_1 \times 100$

Where,

Aw=Water absorption (%)

$m_1$=Weight of the sample before immersion in water (gm.)

$m_2$= Weight of the sample after (24 hr.) immersion in water (gm.)

***Thickness swelling:***

Thickness swelling was calculated by the following formula-

$Gt = (t_2 - t_1)/t_1 \times 100$

Where,

Gt=Thickness swelling (%)

$t_1$= Thickness of the sample before immersion in water (gm.)

$t_2$= Thickness of the sample after (24 hr.) immersion in water (gm.)

***Linear Expansion:***

Linear Expansion was calculated by the following formula-

$$LX\,(\%) = \frac{LA - LB}{LB} \times 100$$

Where,

LX=Linear Expansion (%)

LB= length of the sample before immersion in water (gm.)

LA= length of the sample after (24 hr.) immersion in water (gm.)

**3.3.4 Analysis of Data**

All the data produced during the laboratory tests for characterization of physical and mechanical properties of each type of boards were analyzed by using SAS (Statistical Analysis System) software. ANOVA (Analysis of Variance) and LSD (Least Significant Difference) were done to analyze the data.

# CHAPTER FOUR

# RESULT AND DISCUSSION

## 4.1 Physical Properties

### 4.1.1 Density

Figure 4.1 showed that the density of cement bonded board in ratio of fiber: cement: water = 1:2.2: 1.1 for grinded fiber was 1.094 $g/cm^3$, for pulped fiber was 1.14 $g/cm^3$, for hot water treated fiber is 1.13 $g/cm^3$. Board manufactured from pulped fiber shows greater density than grinded fibered board and hot water treated board. It might be due to the fiber isolation process. Due to chemical pulping lignin portion was almost removed from the fibers. That's why pulped fibers were isolated more uniformly than grinded or hot water treated board. Uniformly isolated fibers showed higher compaction ratio. In other word uniformly isolated fibers showed the lower bulk density and lower bulk density showed the higher compaction ration. And higher compaction ratio increased the density of boards. The lower bulk density fibers result in a higher compaction ratio, which will subsequently produce a higher strength panel than will higher bulk density fibers (Suschsland and Woodson, 1990). Increased density imparts greater strength, stiffness, and moisture resistance for much improved in service performance (Doggett, 2014). From the analysis of data it had been found that there was no significant difference between the density of cement bonded pulped fiber board and cement boiled fiber board but there was significant difference between density of pulped fiber board and grinded fiber board and also significant difference between density of boiled fiber board and grinded fiber board.

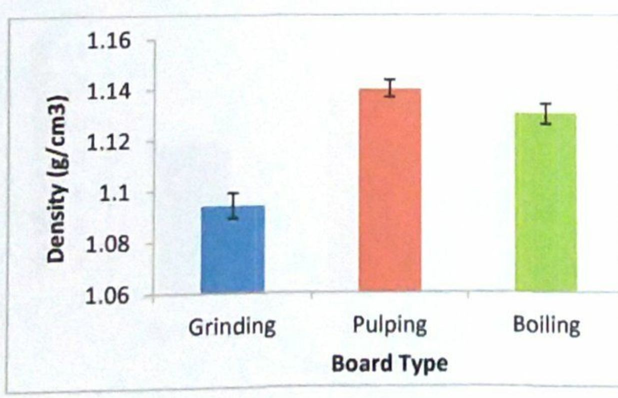


Fig: 4.1 Density of cement bonded board from Bagasse fiber

The density of cement bonded board depends on the compaction ratio. According to Erakhrumen (2008), cement bonded particle board from only pine (*Pinus caribaea*) saw dust was 1.79 g/cm$^3$. It was also found that cement: sawdust- coir ratio of 2: 1 showed 1.54 g/cm$^3$ (Erakhrumen, 2008). In Bangladesh, feasibility study on Betel Nut (*Areca catechu*) for Cement bonded fiber board ratio of Fiber: Cement (1:2) showed that the board density was about 1.07 g/cm$^3$ (Ghosh, 2013). The cement bonded fiber board from Coconut fiber in ratio fiber: cement (1: 2.5) showed that the density was about 0.98 g/cm$^3$. Bison factory was found that the average density of cement bonded particle board from saw dust was 1250 kg/m$^3$. (Anon, 1975).The target density of cement bonded particle board was 1.2 g/cm$^3$ (Anon, 2001). The density obtained from this study satisfied the target density.

### 4.1.2 Moisture Content

Figure 4.2 showed that the moisture content of cement bonded bagasse fiber board for grinded fiber was 14.13%, for pulped fiber was 11.43%, and for hot water treated fiber was 13.38%. Compare to grinded fiber board and hot water treated fiber board moisture content percentage was lower in pulped fiber board. It may be due to the fiber cement bonding. Chemical treated natural fibers can helped in hydration of cement (Liu and Pan, 2010). That's why pulped fibers were uniformly bonded with cement. So the moisture content percentage was lower in pulped fiber board. From the analysis of data it had been found that there was no significant difference between the MC of cement bonded pulped fiber board and cement boiled fiber board but there was significant difference between MC of pulped fiber board and grinded fiber board and also significant difference between MC of boiled fiber board and grinded fiber board.

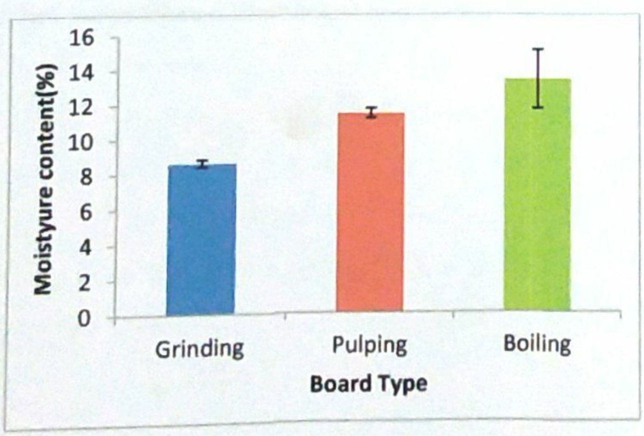


Fig: 4.2 Moisture content of Cement bonded Bagasse fiber board

Feasibility study on Betel Nut (*Areca catechu*) for Cement bonded fiber board ratio of Fiber: Cement (1:2) showed that the moisture content ranges from 16- 20 % (Ghosh, 2013). The cement bonded fiber board from Coconut fiber in ratio fiber: cement (1: 2.5) showed that the moisture content ranges from 11- 20 %. In properties of natural fiber cement boards for building partitions showed that the natural fiber cement board moisture content ranges from 11.2- 13.1% (Liu and Pan, 2010). Compared to above cement bonded bagasse fiber board from pulped fiber was showed lower moisture content.

### 4.1.3 Water Absorption

Figure 4.3 showed that Water absorption of cement bonded bagasse fiber board after two hour submersion in water, for grinded fiber was 13.02 %, for pulped fiber was 7.8 %, and for hot water treated fiber was 9.002%. After 24 hour submersion water absorption for grinded fiber board was 19.14%, for pulped fiber board was 13.76 %, and for hot water treated board was 15.76%. Water absorption of pulped fiber board was lower than grinded and hot water treated fiber board. It may be due to the density of these boards. 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 so there is low possibility of water absorption in high density boards (Zheng *et al.*, 2007). The density of pulped fiber board was 1.14 g/cm$^3$, grinded fiber board was 1.094 g/cm$^3$ and hot water treated fiber board was 1.13 g/cm$^3$. So density of pulped fiber board and hot water treated fiber board were higher than grinded fiber board. That's why water absorption is less in pulped fiber board and hot water treated fiber board than grinded fiber board. From the analysis of data it had been found that there was significant difference exist among the water absorption of cement bonded pulped fiber board, cement bonded hot water treated fiber board and cement bonded grinded fiber board.

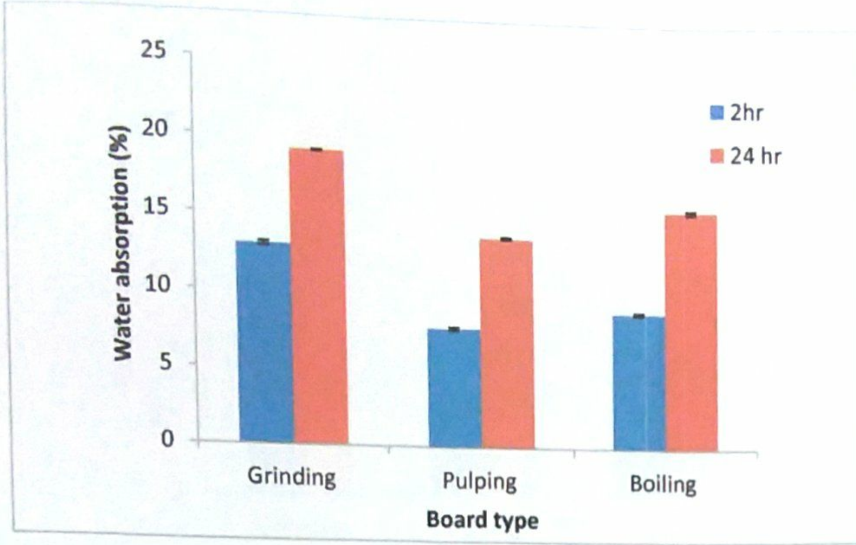


Fig: 4.3 Water absorption of Cement bonded Bagasse fiber board

Study on Betel nut (*Areca catechu*) for cement bonded fiber board showed that, the water absorption of the board was ranges from 23-31 % in 1: 2 fiber cement ratio (Ghosh, 2013). Another study on *Albizia falcataria* wood for cement bonded particle board in BFRI showed that the water absorption was 27.8 % after 24 hour submersion in water. (Biswas *et al*., 1997). It was found that the water absorption of coconut coir cement bonded board was 14- 16 % (Aggarwal, 1992). Compare to above this study showed lower water absorption.

### 4.1.4 Thickness swelling

Figure 4.4 showed that the thickness swelling of cement bonded bagasse fiber after 2 hour submersion in water for grinded fiber board was 1.5 %, for pulped fiber was 0.66 %, and for hot water treated fiber board was 1.1 %. After 24 hour submersion the thickness swelling for grinded fiber board was 2.56 %, for pulped fiber board was 1.42 %, for hot water treated fiber board was 1.62 %. Thickness swelling was lower in pulped fiber board and hot water treated fiber board. It may be due to the density. Higher the density lower the water absorption, lower the water absorption lower the thickness swelling. From the analysis of data it had been found that there was significant difference exist among the thickness swelling of cement bonded pulped fiber board, cement bonded hot water treated fiber board and cement bonded grinded fiber board.

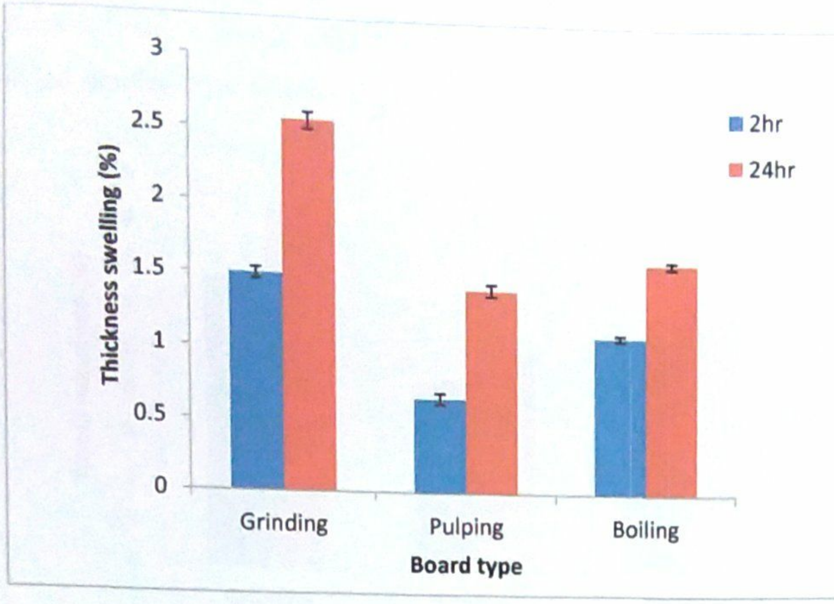


Fig: 4.4 Thickness swelling of Cement bonded Bagasse fiber board

Study on Betel nut for cement bonded fiber board showed that the thickness swelling ranges from 2.2 % to 2.7 % (Ghosh, 2013). Study on *Albizia falcataria* wood for cement bonded particle board showed the thickness swelling of the board was 2.87 % after 24 hour submersion into water (Biswas *et al*., 1997). Study on thickness swelling of coconut coir cement bonded board was less than 1.2% (Aggarwal, 1992). Accept coconut coir cement bonded board the thickness swelling of bagasse pulped and hot water treated board was lower than above studies. This implies that cement bonded fiber board made from bagasse pulped fiber and hot water treated fiber would be a resistant and dimensionally stable product against humidity.

### 4.1.5 Linear expansion

Figure 4.5 showed that the linear expansion of cement bonded bagasse fiber board after 2 hour submersion into water, for grinded fiber board was 3.36 %, for pulped fiber board was 2.21 %, and for hot water treated fiber board was 2.73 %. After 24 hour submersion into water the linear expansion of grinded fiber board was 4.17 %, for pulped fiber board was 2.58%, and for hot water treated fiber was 3.25 %. Linear expansion of pulped fiber board was lower than hot water treated fiber board and grinded fiber board. It may be due to the density of the boards. Higher the density lower the water absorption, lower the water absorption lower the linear expansion. From the analysis of data it had been found that there was significant difference exist among the linear expansion of cement bonded pulped fiber board, cement bonded hot water treated fiber board and cement bonded grinded fiber board.

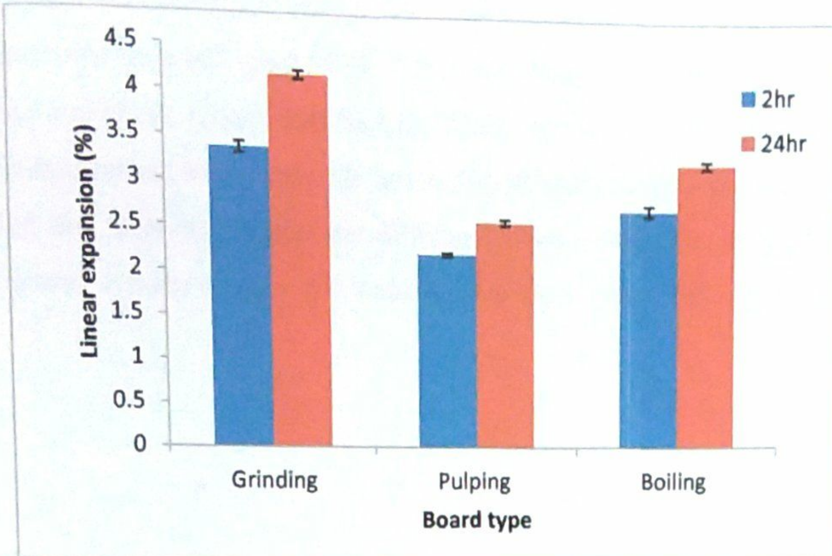


Fig 4.5 Linear expansion of Cement bonded Bagasse fiber board

Study on Betel nut for cement bonded fiber board showed that the linear expansion ranges from 3.2 % to 4.8 % after 24 hour submersion into water; (Ghosh, 2013). Study on cement bonded board from coconut palm showed the linear expansion ranges from 3.4% to 4.6 % after 24 hour submersion into water. Compared to above studies cement bonded pulped fiber board and hot water treated fiber board showed lower linear expansion.

## 4.2 Mechanical Properties

### 4.2.1 Modulus of Rupture (MOR)

Figure 4.6 showed that the modulus of rupture of cement bonded bagasse fiber board for grinded fiber was 8.92 N/mm$^2$, for hot water treated fiber board was 14.03 N/mm$^2$, and for pulped fiber board was 19.19 N/mm$^2$. Pulped fiber board showed the higher MOR than grinded fiber board and hot water treated fiber board. It may be due to the slenderness ratio and compaction ratio. Literature showed that higher the fiber length and lower the fiber thickness showed higher the slenderness ration and higher compaction ratio. It was found that the fibers must be sufficiently long to allow adequate overlap for transfer of applied stress from one fiber to the next; (Barnes, 2001; Yadama, 2002). Due to chemical pulping fibers were properly isolated and length of pulped fiber was higher than grinded or hot water treated fiber, and due to removal of lignin fibers were isolated properly and the thickness of pulped fiber was lower than grinded fiber and hot water treated fiber. So the slenderness ratio and compaction ratio of pulped fiber board was higher than grinded and hot water treated fiber board. So cement bonded bagasse fiber board from pulped fiber was showed higher MOR. It was also found that there is a positive relationship between density and MOR; (Ayayi and Badejo, 2005). Due to the higher density of pulped fiber board than grinded and hot water treated board the MOR also higher. From the analysis of data it had been found that there was significant difference exist among the MOR of cement bonded pulped fiber board, cement bonded hot water treated fiber board and cement bonded grinded fiber board.

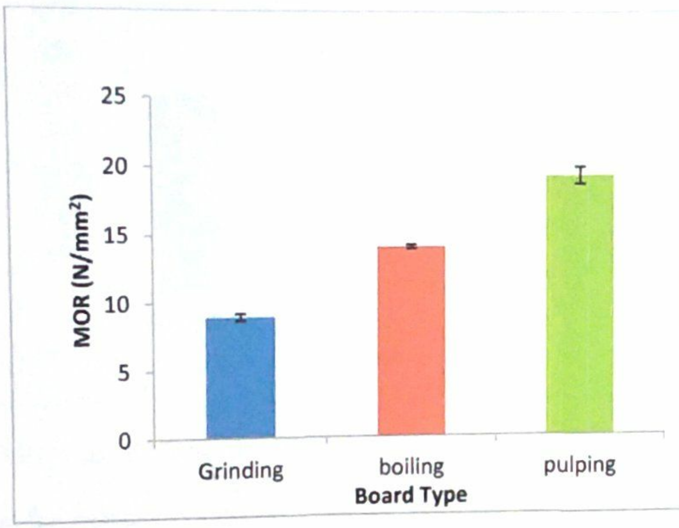


Fig: 4.6 Modulus of rupture (MOR) of Cement bonded Bagasse fiber board

Study on Betel nut for cement bonded fiber board showed that the MOR ranges from 3.68 $N/mm^2$ to 4.05 $N/mm^2$ in fiber cement ratio of 1: 2 (Ghosh .2013). It was also found that MOR of coconut coir cement bonded board was 9- 11 $N/mm^2$ (Aggarwal, 1992). In bison factory china found that the MOR of cement bonded particle board was 9 $N/mm^2$. Compare to above study cement bonded bagasse fiber board showed the higher MOR value. Higher MOR showed the higher Strength properties; (Ayayi and Badejo, 2005). So cement bonded bagasse fiber board showed higher strength properties than above studies.

#### 4.2.2 Modulus of Elasticity (MOE)

Figure 4.7 showed that the modulus of elasticity of cement bonded bagasse fiber board for grinded fiber was 2470.60 $N/mm^2$, for hot water treated fiber board was 3120.68 $N/mm^2$, and for pulped fiber board was 4539.70 N/mm$^2$. Pulped fiber board showed the higher MOE than grinded fiber board and hot water treated fiber board. It may be due to the same reasons for variation in MOR among three different fiber isolation processes. Higher slenderness ratio and higher compaction ratio increase the MOE of the boards. From the analysis of data it had been found that there was significant difference exist among the MOE of cement bonded pulped fiber board, cement bonded hot water treated fiber board and cement bonded grinded fiber board.

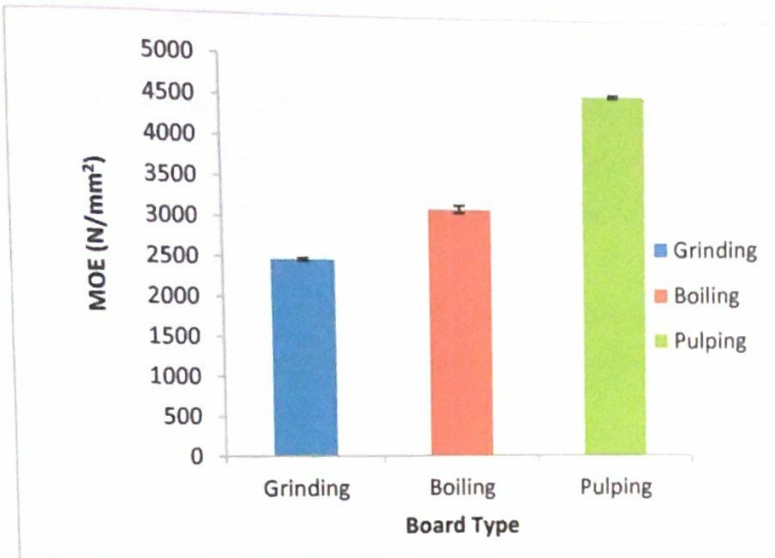


Fig: 4.7 Modulus of elasticity (MOE) of Cement bonded Bagasse fiber board

Study on Betel nut for cement bonded fiber board showed that the MOE ranges from 265.11 N/mm$^2$ to 319.59 N/mm$^2$ in fiber cement ratio of 1: 2 (Ghosh, 2013). It was also found that MOE of coconut coir cement bonded board was 2400- 2500 N/mm$^2$ (Aggarwal, 1992). In bison factory china found that the MOR of cement boned particle board was 3000 N/mm$^2$ (Anon, 1975). Compare to above study cement bonded bagasse fiber board showed the higher MOE value.

# CHAPTER FIVE

## CONCLUSION

From the detailed analysis of data and on the basis of outcome following specific conclusion can be made:

- Bagasse fiber can be a potential candidate for producing used Cement bonded Fiber board.
- Cement bonded Bagasse fiber board from pulping process showed good mechanical and physical properties than grinded or hot water treated fiber board and satisfy the standard physical and mechanical properties.
- Further study is needed to improve the physical and mechanical properties of cement bonded Bagasse fiber board by using some chemical additives.

# CHAPTER SIX

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# CHAPTER SEVEN

## Appendix 1

Analysis of Variance (Density)

Class Level Information

| Class | Levels | Values |
| --- | --- | --- |
| TRTMENT | 3 | T1 T2 T3 |

Number of observations in data set = 12

Dependent Variable: DENSITY

| Source | DF | Sum of Squares | F Value | Pr > F |
| --- | --- | --- | --- | --- |
| Model | 2 | 0.00526373 | 26.87 | 0.0002 |
| Error | 9 | 0.00088154 | | |
| Corrected Total | 11 | 0.00614527 | | |

T tests (LSD) for variable: DENSITY

Alpha= 0.05 df= 9 MSE= 0.000098

Critical Value of T= 2.26

Least Significant Difference= 0.0158

Means with the same letter are not significantly different.

| T Grouping | Mean | N | TRTMENT |
| --- | --- | --- | --- |
| A | 1.142292 | 4 | T2 |
| | A | | |
| A | 1.132025 | 4 | T3 |
| B | 1.093628 | 4 | T1 |

# Appendix 2

Analysis of Variance (Moisture content %)

Class Level Information

| Class | Levels | Values |
|---|---|---|
| TRTMENT | 3 | T1 T2 T3 |

Number of observations in data set = 12

Dependent Variable: MC

| Source | DF | Sum of Squares | F Value | Pr > F |
|---|---|---|---|---|
| Model | 2 | 30.95463754 | 36.20 | 0.0001 |
| Error | 9 | 3.84755218 | | |
| Corrected Total | 11 | 34.80218972 | | |

T tests (LSD) for variable:MC

Alpha= 0.05 df= 9 MSE= 0.427506

Critical Value of T= 2.26

Least Significant Difference= 1.0459

Means with the same letter are not significantly different.

| T Grouping | Mean | N | TRTMENT |
|---|---|---|---|
| A | 12.3740 | 4 | T3 |
| | A | | |
| A | 11.4327 | 4 | T2 |
| B | 8.5952 | 4 | T1 |

# APPENDIX 3

Analysis of variance (Water Absorption %)

Class Level Information

| Class | Levels | Values |
|---|---|---|
| TRTMENT | 3 | T1 T2 T3 |

Number of observations in data set = 18

Dependent Variable: WA

| Source | DF | Sum of Squares | F Value | Pr > F |
|---|---|---|---|---|
| Model | 2 | 88.64300152 | 1195.95 | 0.0001 |
| Error | 15 | 0.55589713 | | |
| Corrected Total | 17 | 89.19889865 | | |

T tests (LSD) for variable: WA

Alpha= 0.05 df= 15 MSE= 0.03706

Critical Value of T= 2.13

Least Significant Difference= 0.2369

Means with the same letter are not significantly different.

| T Grouping | Mean | N | TRTMENT |
|---|---|---|---|
| A | 19.1396 | 6 | T1 |
| B | 15.7567 | 6 | T3 |
| C | 13.7634 | 6 | T2 |

# APPENDIX 4

Analysis of Variance (Thickness Swelling%)

Class Level Information

| Class | Levels | Values |
|---|---|---|
| TRTMENT | 3 | T1 T2 T3 |

Number of observations in data set = 12

Dependent Variable: TS

| Source | DF | Sum of Squares | F Value | Pr > F |
|---|---|---|---|---|
| Model | 2 | 3.31008404 | 61.79 | 0.0001 |
| Error | 9 | 0.24105832 | | |
| Corrected Total | 11 | 3.55114236 | | |

T tests (LSD) for variable: TS

Alpha= 0.05 df= 9 MSE= 0.026784

Critical Value of T= 2.26

Least Significant Difference= 0.2618

Means with the same letter are not significantly different.

| T Grouping | Mean | N | TRTMENT |
|---|---|---|---|
| A | 2.5635 | 4 | T1 |
| B | 1.6236 | 4 | T3 |
| C | 1.3329 | 4 | T2 |

# APPENDIX 5

Analysis of Variance (Linear Expansion%)

Class Level Information

| Class | Levels | Values |
|---|---|---|
| TRTMENT | 3 | T1 T2 T3 |

Number of observations in data set = 12

Dependent Variable: LE

| Source | DF | Sum of Squares | F Value | Pr > F |
|---|---|---|---|---|
| Model | 2 | 5.09947722 | 259.70 | 0.0001 |
| Error | 9 | 0.08836120 | | |
| Corrected Total | 11 | 5.18783841 | | |

T tests (LSD) for variable: LE

Alpha= 0.05 df= 9 MSE= 0.009818

Critical Value of T= 2.26

Least Significant Difference= 0.1585

Means with the same letter are not significantly different.

| T Grouping | Mean | N | TRTMENT |
|---|---|---|---|
| A | 4.16691 | 4 | T1 |
| B | 3.24528 | 4 | T3 |
| C | 2.57683 | 4 | T2 |

# APPENDIX 6

Analysis of Variance (MOE)

Class Level Information

| Class | Levels | Values |
|---|---|---|
| TRTMENT | 3 | T1 T2 T3 |

Number of observations in data set = 12

Dependent Variable: MOE

| Source | DF | Sum of Squares | F Value | Pr > F |
|---|---|---|---|---|
| Model | 2 | 8956528.20331 | 785.06 | 0.0001 |
| Error | 9 | 51339.30895 | | |
| Corrected Total | 11 | 9007867.51226 | | |

T tests (LSD) for variable: MOE

Alpha= 0.05 df= 9 MSE= 5704.368

Critical Value of T= 2.26

Least Significant Difference= 120.81

Means with the same letter are not significantly different.

| T Grouping | Mean | N | TRTMENT |
|---|---|---|---|
| A | 4539.69 | 4 | T3 |
| B | 3120.68 | 4 | T2 |
| C | 2470.59 | 4 | T1 |

# APPENDIX 7

Analysis of Variance (MOR)

Class Level Information

| Class | Levels | Values |
|---|---|---|
| TRTMENT | 3 | T1 T2 T3 |

Number of observations in data set = 12

Dependent Variable: MOR

| Source | DF | Sum of Squares | F Value | Pr > F |
|---|---|---|---|---|
| Model | 2 | 210.67795293 | 110.76 | 0.0001 |
| Error | 9 | 8.55945704 | | |
| Corrected Total | 11 | 219.23740996 | | |

T tests (LSD) for variable: MOR

Alpha= 0.05 df= 9 MSE= 0.951051

Critical Value of T= 2.26

Least Significant Difference= 1.5599

Means with the same letter are not significantly different.

| T Grouping | Mean | N | TRTMENT |
|---|---|---|---|
| A | 19.1857 | 4 | T3 |
| B | 14.0368 | 4 | T2 |
| C | 8.9223 | 4 | T1 |