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FEASIBILITY OF USING THE WASTAGE OF TEA INDUSTRY FOR MANUFACTURING OF FIBERBOARD

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Declaration

I, Biddut Kumar Das, declare that this thesis is the result of my own work and that it has not been submitted or accepted for a degree in any university.

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Date: 02.03.2017

Dedicated to

My Father

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Abstract

The wastage of tea factory is generally incinerated without utilizing their heat performances. The first objective of this study was to manufacture Medium density fiber board (MDF) using wastage of tea factory (*Camellia sinenses* L.) The second objective was to evaluate modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding strength (IB), water absorption (WA) and thickness swelling (TS) properties of the boards produced. The variables were pressing time (10, 13 and 16 minutes) and temperature (80, 85 and 90^0C) and treatment was modified steam explosion and 25% saw dust mixture. All boards were produced by 4 MP. The MOR values ranged from 3.58 to 7.14 N/mm^2 and MOE values ranged from 529.92 to 1130.72 N/mm^2. The mean values of IB ranged from 0.04 to 0.22 N/mm^2. WA and TS after 2 h of water soaking of the fiberboard ranged from 110% to 132.69% and from 33.86% to 44.24% respectively.

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Chapter One
Introduction

1.1 Background of the study

A composite material is a combination of two or more materials that results in better properties than those of the individual components used alone. It made from two or more than two constituents or materials with considerably differ in physical and chemical properties (Piyoosh *et al.*, 2013). In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties (Campbell, 2010). The two constituents are reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part (Piyoosh *et al.*, 2013). In present day several industries such as aeronautical industries, automobile industries, marine industries, chemical industries and transportation industries relay on fibre reinforced composites to manufacture several components such as flaps, doors, gears and other components (Rathnakar and Shivanand, 2014).

Among different types of composite, medium density fiber board is very well known. Newsletter of the Wood working National Interest Group, (1999) reported that MDF is a wood composite material, has been commercially available since the 1960s. Medium density fiberboard has a specific gravity between 0.6 and 0.8 which are frequently used in place of solid wood, plywood, and particle board in furniture manufacturing (Berglund, 2005; Youngquist, 1999). Comparing to particleboard, overlaying with sheet materials and veneering, fiberboard has tight edges that need not be banded and can be routed and molded like solid wood (Seidl, 1966). Wood, primarily softwood is the main raw material of MDF.

Wood is one of the most valuable forest products having diversity of use worldwide. Demand for forestry products continues to grow despite decreases in industrial wood products from natural forests. High demand for wood in the forestry industry due to increasing population and new applications puts great pressure on existing forest resources (Mehmet. 2007). In Bangladesh, as timber harvesting from natural forests are prohibited we are dependent on plantations and home gardens for fulfillment of our demand of wood. But the sources of timber are not sufficient to fulfill our demand. The supply of timber is 44% less than the

demand in Bangladesh (Salehuddin, 1990). As wood supply is not sufficient to the demand, people are searching new raw material for panel products.

Chow (1974), Youngquist *et al.* (1993), and Youngquist *et al.* (1994) provide accounts of worldwide research dealing with the utilization of non-wood plants in the forest industry. Several researchers examined the practicality of using wheat straw (Eroğlu and İstek, 2000), cotton stalk (Gencer *et al.*, 2001; Guler and Ozen, 2004), cotton carpel (Alma *et al.*, 2005), sunflower stalk (Bektas *et al.*, 2005), kiwi prunings (Nemli *et al.*, 2003), hazelnut husk (Copur *et al.*, 2007), and hazelnut shell and husk (Copur *et al.*, 2008) in composite panel production; however, the literature contains only limited data concerning the use of wastage of tea industry in MDF production. Bruno *et al.* (2014) showed the effect of mixture of household waste in composite.

Tea leave contain high phenolic extractive shows good resistance against deteriorating fungi (Mustafa *et al.*,1998; Kalay *et al.*, 1993; Kacar, 1991) . Therefore, the aim of the present study was to investigate the potential utilization of wastage of tea industry as a supplement to wood in MDF production.

1.2 Objective of the Study

In Bangladesh there are 172 tea estates and 357 small growers/holders have devoted an area of 116,264 ha for tea plantation out of which 56,846 ha been brought under tea cultivation in 2011 (Muzafar, 2012). Large amount of wastage are produced from the tea industries every year. Large parts of this quantity of wastage are normally burnt off in the factory or dumped in landfills, while the remaining part is used as fuel. These methods of disposal are certainly wastage of a primary resource. Burning of these materials in the open air is likely to cause environmental pollution as carbon dioxide (CO_2) and carbon-monoxide (CO) would be released into the atmosphere as a result of insufficient oxygen in the heap of the tea residues. In addition, the biodegradation of lignocellulosic wastage in landfills, emits methane, a green house gas which has 72 times heating effect relative to that of CO_2 (Leliveld, 1992). The release of these gases into the atmosphere changes the climate, thereby resulting in global warming, which is now one of the greatest threats to our world. Based on this fact, there is the need to find uses for this wastage. Apart from the fact that the use of these wastes will serve as an environmental management system, it will also contribute positively to the economic growth of the country.

Thus, this study intended to introduce the wastage of tea industries as a raw material of Fiberboard manufacturing. The specific objectives of the study are-

1. To assess the technical feasibility of using wastage of tea industries as a raw material for manufacturing fiberboard.
2. To evaluate the physical and mechanical properties of the fiberboard.

Chapter Two

Review of Literature

2.1 Fiberboard

Fiberboard (cellulosic fiber) – structural and decorative – is a fibrous-felted, homogeneous panel made from ligno-cellulosic fibers – usually wood – which has a density of less than 31 lb/ft^3 (497 kg/m^3), but more than 10 lb/ft^3 (160 kg/m^3). Fiberboard is characterized by an integral bond which is produced by interfelting the fibers, but which has not been consolidated under heat and pressureas a separate stage in manufacture. Other materials may be added to fiberboard during manufacture to improve certain properties.

A fiberboard is a board (or sheet) of material made from fiber of wood or other lingo cellulosic materials bonded with organic binders with the help of one or more agents like heat, pressure, humidity, catalyst etc. Bonding agents and supplementary materials may be added at the felting stage to improve certain properties like mechanical properties, resistance to moisture etc. (Anon, 1970).

Fiberboard is a sheet material generally manufactured from ligno-cellulosic fiber with the primary bond from the felting of the fiber and their inherent adhesive properties. Bonding materials and/or additives may be added to improve certain properties (Salehuddin, 1992).

2.2 Types of Fiberboard

There are different types of fiberboards depending on-

Depending on Density

There are mainly three types of fiberboard depending on density.

1. Soft board: Soft board is a board having density up to 250 kg/m^3 .
2. Medium board: Medium board is a board having density between 250 kg/m^3 and 800 kg/m^3.
3. Hard board: the fiberboard having density above 800 kg/m^3 is classified as hard board (Youngquist, 1999).

According to Anon (1985), fiberboards are classified into three types;

1. Soft board: The board which having the density less than 400 kg/m^3.

2. Wall board: The board having density between 400 kg/m^3 and 481 kg/m^3.
3. Hard board: The board having the density not less than 481 kg/m^3.

There are another three types of fiberboard depending on specific gravety-

Low Density Fiberboard (LDF)

Low density fiberboard has specific gravity between 0.15 and 0.45 and are used for insulation and for light weight core for furniture. They are usually produced by dry process tha uses a ground wood fiber.

Medium Density Fiberboard (MDF)

Medium density fiberboard has a specific gravity between 0.6 and 0.8 and is frequently used in place of solid wood, plywood, and particle board in many furniture manufacturing. It is also used for interior door skins, moldings and interior trim components.

High Density Fiberboard (HDF)

High density fiberboard has a specific gravity of between 0.85 and 1.2 and is used as an overlay on workbenches, floor and for siding. It is produced both with and without wax and sizing agents. The wax is added to give the board water resistance (Berglund and Rowell, 2005; Youngquist, 1999.).

2.3 General Manufacturing Steps of Fiberboard

2.3.1 Method of Fiber Production

Fibers are made by various mechanical pulping methods or by explosion process.

2.3.1.1 Mechanical Pulping

There are broadly two methods for the production of mechanical pulp. One is the grinding of debarked logs and another is the refining of wood chips and agricultural residues.

Wood can be broken down into fiber bundle and single fibers by grinding or refining. In the grinding process, the wood is mechanically broken down into fibers. In the refining process wood chips are placed between one or two rotating plates in a wet environment and broken down into fiber. If the refining is done at high temperature, the fibers tend to slip apart as a result of the softening of lignin between the fibers and consequently the fiber will have a

lignin rich surface. If the refining is done at low temperature, the fibers tend to break apart and the surface is rich in carbohydrate polymers. Fiberboards can be formed using a wet-forming or a dry forming process. In a wet-forming process, water is used to distribute fibers into a mat, which is then pressed into a board. Some cases adhesive is not used and the lignin in the fibers serve as adhesive. In the dry process, fibers from the refiner go through a dryer and a blow line, where the adhesive is applied and then formed into a mat, which pressed into a board (Berglund and Rowell, 2005; Youngquist, 1999.).

The other method involves either treatment of the wood chips or agricultural residues with chemical; or thermal pre-treatment prior to pulping in disk refiners or attrition mills. Solid wood is debarked and then chipped in a chipper and screened. The coarse chips are re-chipped and fines send to the boiler. In the semi-mechanical pulping, neutral sulphite cook, sodium hydroxide cook or a lime cook is used. Thermo-mechanical pulping is based on the softening of the middle lamella or inter-cellular layers between the fibers due to heating at 150 ^{0}c to 180 ^{0}c. This facilitates separation of fiber. The chemical composition of the pulp remains almost identical to that of the original wood or other lingo-cellulosic materials. The original fiber structure is also reserved and very high yield, 90 to 93 percent is obtained (Salehuddin, 1992.)

2.3.1.2 Explosion Process

This process is better known as the Masonite process. Here 100 kg of wood chips or agricultural residues are charged into a high pressure cylinder called a "Gan" and steam is admitted. The pressure is raised to 40 Kp/cm in about 30 second. After a steaming period of another 300 seconds under this pressure, the steam pressure is quickly raised from 70 to 80 kp/cm, raising the temperature to 185^{0} c to 295^{0} c held for only about 5 seconds, before suddenly releasing the pressure by a hydraulically operated quick opening valve. The "Gan" blown first under the influence of high steam pressure, moisture and high temperature, the wood under goes a hydrolytic reaction which breaks down the lingo-cellulosic bond. Secondly, the sudden release of the hydrolyzed chips to atmospheric pressure tears them separate to produce a characteristically blows, fluffy fiber. The fibers are washed with clean hot water to remove hydrolytic products and buffered before mat formation.

2.3.2 Method of Mat Formation

Mat is formed by wet, dry or semi-dry processes. Dry processes are applicable to board with high density (hard board) and medium density fiber (MDF). Wet processes are applicable to both high density fiber board and low density insulation board. The manufacturing of high and medium density dry process fiber board and wet process fiber board are briefly described below:

2.3.2.1 Wet Process

Wet process hard boards differ from dry process fiber boars in several significant ways. First, water is used as the distribution medium for forming the fibers into a mat. As such, this technology is really an extension of paper manufacturing technology. Secondly, some wet process boards are made without additional binders. If the ligno-cellulosic contains sufficient lignin and if the lignin is retained during the refining operation, lignin can serve as the binder. Under heat and pressure, lignin will flow and act as a thermosetting adhesive, enhancing the naturally occurring hydrogen bonds. Refining is an important step for developing strength in wet process hard boards. The refining operation must also yield a fiber of "freeness" that is, it must be easy to remove water from the fibrous mat. The mat is typically formed on a Fourdriner wire, like papermaking or on cylinder formers. The wet process employs a continuously travelling mesh screen, onto which the soupy pulp flows rapidly and smoothly. Water is drawn off through the screen and then through a series of press rolls, which use a wringing action to remove additional water. Wet process fiber boards are pressed in multi-opening presses heated by steam. The press cycle consists of three phases and lasts 6 to 15 min. The first phase in conducted at high pressure and removes most of the water while bringing the board to the desired thickness. The primary purpose of the second phase is to remove water vapour. The final phase is relatively short and results in the final cure. A maximum pressure of about 5 MPa (725 lb/in^2) is used. Heat is essential during pressing to induce fiber to fiber bond. A high temperature of up to 210^0C is used to increase production by causing faster evaporation of the water. Lack of sufficient moisture removal during pressing adversely affects strength and may result in "spring back" or blistering (Suchsland and Woodson, 1986).

Hot Pressing

a) Insulation board

For producing soft or insulation board the partially dry wet-lap, as it is now called, is trimmed in width and cut into the desired sheet length and dried in tunnel-kilns, continuous multi-deck. Roller type dryer or hot presses with stops at a temperature of 120^0C to 190^0C.

b) Hard board

For the production of hard board single or multiple light presses heated by steam or hot water are used. Temperature of 200^0C with a high initial pressure of 50 kp/cm^2, followed by a lower pressure of about one-fifth of the initial pressure, then bringing the pressure up to the original level with a time schedule of 2/1/3 minutes in typical for a 3.2mm thick wet process hard board. In these wet process hard board, a screen is used between the mat and the bottom platens of a day light to prevent blowing up of the wet board, so that steam may escape during the low pressure breathing part of the pressing cycle. These boards have one side smooth (Salehuddin, 1992).

2.3.2.2 Dry and semi-dry processes

Dry process fiber board is made in a similar fashion to particle board. Resin (UF, PF) and other additives may be applied to the fibers by spraying in short-retention blenders or introduced as the wet fibers are fed from the refiner into a blow line dryer. Alternatively, some fiber board plants add the resin in the refiner. The adhesive-coated fibers are then air-laid into a mat for subsequent pressing, much the same as mat formation for particle board. Pressing procedures for dry process fiber board differ somewhat from particle board procedures. After the fiber mat is formed, it is typically pre-pressed in a band press. The mat is then trimmed by disk cutters and transferred to caul plates for the hard board pressing operation; for MDF, the rimmed mat is transferred directly to the pres. All dry formed boards are pressed in multi opening presses at approximately 140^0C to 165^0C (284^0F to 329^0F) for UF-bonded products and 190^0C (410^0F) for PF bonded products. Continuous pressing using large, high pressure ad presses is also gaining in popularity. Board density is a basic property and indicator if board quality. Since density is greatly influenced by moisture content, this is constantly monitored by moisture sensors using infra-red light (Suchsland and Woodson, 1986; Maloney, 1993)

2.3.3 Post Treatment of Wet and Dry Process fiber board

Several treatments are used to increase the dimensional stability and mechanical performance of fiber board. Heat treatment, tempering and humidification may be done singularly or in conjunction with one another.

Heat Treatment

Exposure of pressed fiber board to dry heat improves dimensional stability and mechanical properties, reduces water absorption and improves inter fiber bonding (Maloney, 1993).

Tempering

Tempering is the heat treatment of pressed boards, preceded by the addition of oil. Tempering improves board surface hardness and is sometimes done on various types of wet formed hard boards. It also improves resistance to abrasion, scratching and water. The most common oils used include linseed oil, tung oil and tall oil (Maloney, 1993).

Humidification

Humidification is the addition of water to bring the board moisture content into equilibrium with the air. Initially, a pressed board has almost no moisture content. When the board is exposed to air, it expands linearly by taking 3% to 7% moisture. Continuous or progressive humidifiers are commonly use for this purpose. Air of high humidity is forced through the stack where it provides water vapour to the boards. The entire process is controlled by a dry-bulb, wet-bulb controller. Another method involves spraying water on the back side of the board (Maloney, 1993).

Surface treatment

Surface may be sealed, primed, enamelled and lacquered, pulp-faced, moulded and embossed, laminated, provide with wood-grained effects, perforated or flame-retardant treated (Salehuddin, 1992).

2.4 Advantages of Fiberboard

Fiberboards have some advantages over massive wood such as their homogenous structure in every directions and do not contain defects such as knots, fiber distortion and decay encountered in massive wood. It is possible to manufacture larger dimension boards. Nailing, screwing are easily made. Painting, covering, machining, varnishing and carving are also

easily applied. In addition, resistance against fungi, insects and fire can be obtained by using certain chemical substances. Whereas, massive wood is an anisotropic material. It contains heartwood, sapwood, springwood, summerwood, young wood, knots, fissures and other pathological defects. Therefore, it expands differently in the radial, tangential and longitudinal directions. As a result, it may be bended, distorted and undulated. In addition, fiberboards have more uniform structure than other wood based panels such as waferboard, strandboard, flakeboard and particleboard. Besides, a wide range of lower value raw material can be used in the manufacture of MDF (Eroğlu, 1988; Rowell, 1992).

2.5 Classification of Tea (*Camelia sinensis).*

Genus :C. L- camellia

Family: Theaceae- Tea family

Order: Theales

Subclass: Dilleniidae

Class: Magnoliopsida- Dicotyledons

Division: Magnoliophyta- Flowering plants

Superdivision: Spermatophyta- Seed plants

(Tariq, 2010)

2.6 Plant Morphology of *Camelia sinensis*

C. sinensis, a member of theaceae family is an evergreen tree or shrub that attains a height of 10 - 15 m in the wild and 0.6 - 1.5 m when cultivated. The leaves are light green, short stalked, coriaceous, alternate, lanceolate, serrate margin, glabrous or pubescent beneath, varying in length from 5 - 30 cm and about 4 cm width. Mature leaves are bright green colored, smooth and leathery while young leaves are pubescent. Flowers are white fragrant, 2.5 - 4 cm in diameter, found in solitary or in clusters of two or four. Flowers bear numerous stamens with yellow anther and produce brownish red capsules (Ross, 2005). Fruit is a flattened, smooth, rounded trigonous three celled capsule, seed solitary in each, size of a small nut (Biswas, 2006).

2.7 Tea Composition

Tea is reported to contain nearly 4000 bioactive compounds of which one third is contributed by polyphenols. Polyphenols are bonded benzene rings with multiple hydroxyl groups. Polyphenols are either flavonoids or non-flavonoids but chemicals found in tea are mostly

flavonoids (Sumpio et al., 2006). They are secondary plant metabolites derived from the condensation reaction of cinnamic acid with three malonyl-CoA groups. A number of flavonoids are present but dietary flavonoids are usually categorized into six major groups (Yilmaz, 2006)

Classes of flavonoids

Flavonoid	**Examples**
Flavanols	EGCG, EG, ECG and catechin
Flavonols	Kaempferol and Quercetin
Anthocyanidins	Malvidin, Cyanidin and Delphinidin
Flavones	Apigenin and Rutin
Flavonones	Myricetin
Isoflavonoids	Genistein and Biochanin A

2.8 History of Tea Industry in Bangladesh

Tea Industry developed during the nineteenth century in Assam and especially in Sylhet. Primarily, the British planters initiated the cultivation of tea on the slopes of the hillocks of Sylhet and the highlands of Assam. In 1839, Assam Tea Company was formed at a meeting of some British capitalists and Indian entrepreneurs. The Company formally launched on 12 February 1839 in London and was later merged with the Bengal Tea Association of Kolkata.

Robert Bruce first discovered tea plant in Assam in 1834. In 1855, an indigenous tea plant was discovered in Chandkhani hillock of Sylhet. At about the same time, wild tea plant was found along the Khasi and Jaintia hills. Tea cultivation also started in Chittagong in 1840 with few plants imported from China and some plants of China origin developed in the Calcutta Botanical Garden. The first tea garden of Bangladesh was established in 1854 at Malnichhara in Sylhet. Two other tea gardens, Lalchand and Matiranga were established in 1860.

Initially, the tea plantation was the outcome of individual venture. But following the depression and slump of the 1860s the development of new plantation came to a stand still, and the tea industry turned to be a monopoly of the big companies. For example, James Finlay dominated the plantation venture in Sylhet after the depression. However, in the closing years of the nineteenth century, a small group of local entrepreneurs were involved in tea plantation. Eventually, the European planters and companies faced new competitors, but

the local planters could not stand in their way because of their dependence on the European planters for technological know-how. There developed an interaction of the Europeans and local entrepreneurs. The partition of India in 1947 and the subsequent dislocation of the Hindu entrepreneurs, paved the way for the dominance of some capitalists of West Pakistan and a group of Urdu speaking north Indian Muslims migrating to Pakistan.

Tea estates in Bangladesh were owned and managed by Bangladeshi Companies, Sterling Companies and Proprietorship Concerns. The term Bangladeshi Companies refers to the companies formed and registered in the country under the Companies Act, 1913 and also under earlier Acts. Sterling Companies are foreign companies, mainly originating in the United Kingdom and multinational in nature. The average size of the tea estate of the Sterling Companies was 1648 acres, and that of Bangladeshi Companies 669 acres, while that of proprietorship concern 343 acres.

At first emphasis was given to the introduction of Chinese seeds. Forty two thousand Chinese plants were reared in the Calcutta Botanical Gardens and distributed in the Himalayas and Assam. Most of them died in transport, and the rest were planted, but did not survive. This proved to be fortunate, because the experts thereafter paid no further attention to China, and the enthusiasts on the spot had to continue their efforts with the indigenous plants. Thus the idea of 'hybrid tea' was abandoned in favour of an indigenous variety. Assam Brand Tea obtained the seal of imperial approbation in 1851. In Sylhet 'wild' or 'indigenous' tea was discovered on 4 January 1856. This discovery created enthusiasm at the local level and particularly the European planters and officials envisaged an extension of the tea frontier with Sylhet. In his report to the Lieutenant Governor of Bengal, the Magistrate of Sylhet, TP Larkins mentioned, 'Tea Plants in great abundance are growing in Chandkhanee Hills85I have sent specimens this day to the Agricultural Society of India for analysing. Larkins also suggested that in consequence of the importance of this discovery, the Lieutenant Governor of Bengal might sanction reward of Rupees 50 to the lucky discoverer, Mohammad Warish. Thus an ordinary native was rewarded for his contribution (Banglapedia).

Table 2.1: Tea Area since 1947

Year	No.of Tea Estates	Area Under Tea (ha)
1947	103	28,734
1960	127	31,418
1970	153	42,685
1980	153	43,528
1990	158	47,385
2000	160	50,470
2005	163	52,317
2006	163	52,407

Source: http://www.teaboard.gov.bd

Chapter Three

Materials and Method

3.1 Collection and Preparation of Raw Materials

3.1.1 Wastage of Tea Industry

The wastage of tea industry was collected from a tea state of Sylhet. It was already in fiber form. Impurities were removed manually from the raw material. Moisture content of the material was measured by oven dry method. The moisture content was found 13.33%

3.1.2 Saw Dust

Saw dust was obtained from the local saw plant of the Khulna District. The dust was composed of different types of wood particles. After collection it was screened to remove impurities. Moisture content of saw dust was found 26.7% by oven dry method.

3.2 Manufacturing of Fiberboard

The materials were formed into mat on a steel sheet. The mat was formed manually. The dimension of the mat was 34cm×17cm × 3.4cm. Press was applied in two phases. In first phase pressure was applied manually to reduce the mat height which facilitates the easy insertion of the mat into the hot press. In second phase pressure was applied with electrically heated improvised hot press. Pressing temperature and time was variable. On other hand pressure and pressure holding time was 5 MP and 10 minutes respectively. After hot pressing, the fiber boards were removed from the press for cooling. Finally the boards were trimmed to remove rough edge and prepared for test.

At first three categories of board was manufactured. Temperature was fixed at 80^0 C and time was variable at 10 minute, 13 minute and 16 minutes. (Table 3.1).From the three type best one was selected by considering physical appearance and cost. Then the time of this type was fixed and temperature was variable at 80^0 C, 85^0C and 90^0C. From the second stage best one was

selected by considering physical appearance cost. Then raw materials treated with modified steam explosion for two hours with autoclave. Then board was manufactured with selected time and temperature. Another category of board was manufactured where 25% saw dust was mixed with the raw material. Three boards of each category were manufactured. Total 3×8=24 board were manufactured (Table-3.1).

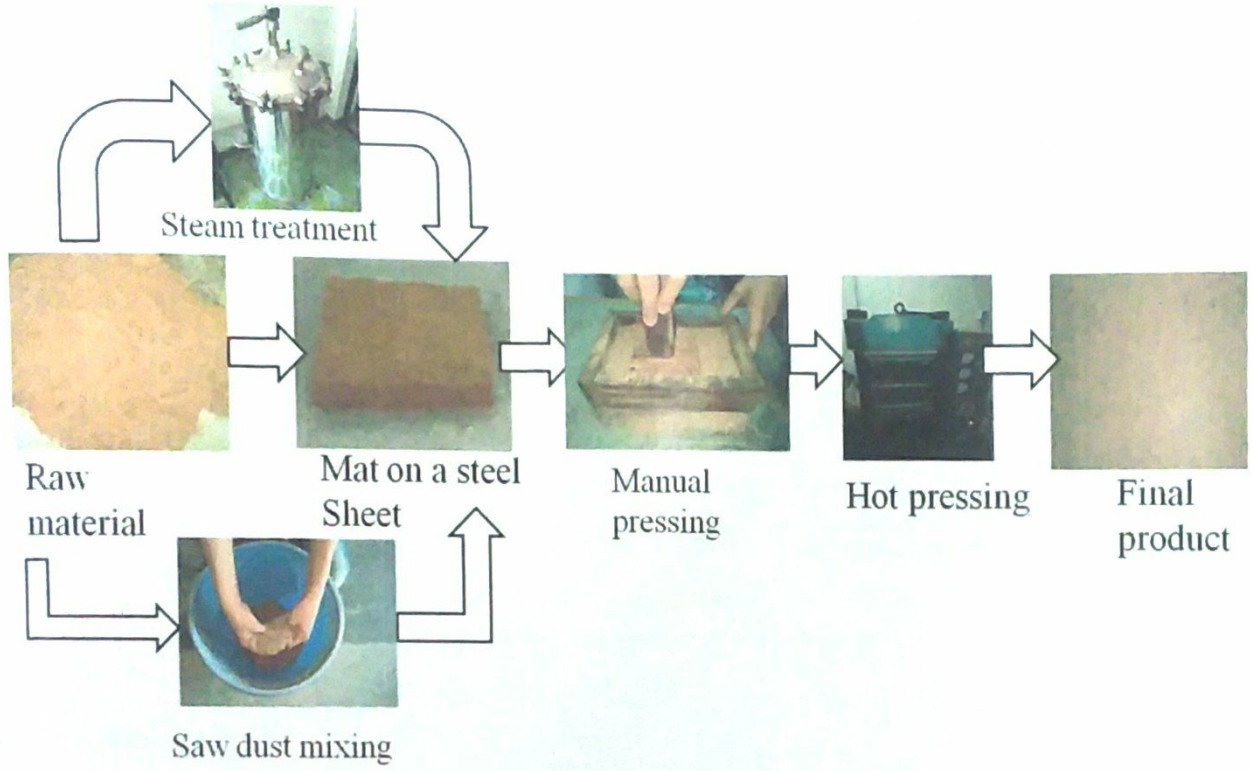

Figure 2.1: Manufacturing process of fiberboard

Table 3.1: Detail Experimental Condition

Experiment no.	Board type	Time (minute)	Temperature (^{0}c)	Treatment
1	A1	10	80	
	A2	13	80	
	A3	16	80	
2	B1	Best from experiment 1	80	
	B2	Best from experiment 1	85	
	B3	Best from experiment 1	90	
3	C	Best from experiment 1	Best from experiment 2	Modified steam explosion
4	D	Best from experiment 1	Best from experiment 2	25% saw dust

3.4 Laboratory Test

Physical and mechanical properties of the fiberboards were tested in the laboratory of Forestry and Wood Technology Discipline, Khulna University, Khulna and Akij Particle Board Mills Ltd respectively.

3.4.1 Preparation of Test Sample

Test samples of the fiber board were randomly selected from the boards of each category. For physical and mechanical test 43 mm × 39 mm and 200 mm × 50 mm samples were prepared from the fiber boards.

3.4.2 Physical Properties

3.4.2.1 Density

Density was calculated with the following formula-

$$d = \frac{m}{v} \quad \text{..... Equation 1}$$

Where, d= Density in gm/cm^3

m= mass of the sample in gm

V= volume in cm^3

M2=Oven-dry mass of the sample (gm)

Electric weight balance was used for measuring mass of the samples and a slide calipers was used to measure the dimension (length, width and thickness) of the sample.

3.4.2.2 Water Absorption

The samples size was 43 mm × 39 mm. It was measured from the differences in weight of the sample before and after 1 hour immersion in water at room temperature. Weight was measured with digital weight balance.

Water absorption was calculated with the following formula-

$$Aw = \frac{M2-M1}{M1} \times 100 \quad \text{..... Equation 2}$$

Where Aw= water absorption

M2= the weight of the sample after (2 hr.) immersion in water (gm)

M1= the weight of the sample before immersion in water (gm)

3.4.2.3 Thickness Swelling

It was measured from the difference of thickness of before and after 1 hour immersion into water at room temperature. Thickness was measured with digital Slide Calipers.

Thickness swelling was calculated with the following formula-

$$Gt(\%) = \frac{T2-T1}{T1} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3}$$

Where Gt=Thickness swelling (%)

T2= Thickness of the sample after (24 hr.) immersion in water (mm)

T1= Thickness of the sample before immersion in water (mm)

3.4.3 Mechanical Properties

3.4.3.1 Modulus of Elasticity

Modulus of elasticity was measured with IMAL machine in Akij Particle Mills Ltd. It was calculated with the following formula-

$$MOE = \frac{P' L^3}{4 \Delta b d^3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 4}$$

Where MOE= modulus of elasticity

P' = load in N at the limit proportionality

L=span length in mm

Δ=deflection in mm at the limit of proportionality

b= width of sample in mm

d= thickness of sample in mm

3.4.3.2 Modulus of Rupture

Modulus of rupture was measured with IMAL machine in Akij Particle Mills Ltd. It was calculated with the following formula-

$$MOR = \frac{3PL}{2bd^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 5}$$

Where MOR= modulus of rupture in N

P= Load in N

L= Span length in mm

b= Width of test sample in mm

d= Thickness of test sample in mm

3.4.3.3 Internal Bonding

Internal bond strength tests were performed in accordance with ASTM D1037–12, section 11. Samples were cut from the originally pressed boards to be 50× 50 mm samples as specified in ASTMD1037. IMAL machine was used to measured the internal bonding of the samples. The maximum load achieved during the test before specimen failure occurred was recorded and used to calculate the internal bond strength, where the internal bond strength is given by Eq. (6):

$$I = Pmax/ ab \quad \text{..... Equation 6}$$

where I represents the internal bond strength in N/mm^2, Pmax represents the maximum load applied to the sample before failure in N, "a" represents the sample width in mm, and "b" represents the sample length in mm. Three (3) internal bond samples were tested for each fiberboard type.

Chapter Four

Result and Discussion

4.1 Physical Properties

4.1.1 Density

It was found that, the mean density of fiber board manufactured with wastage of tea industry ranges from 773 kg/m^3 to 910 kg/m^3 (Fig. 4.1). From the variance analysis (Table A-1) it was observed that there was significance difference (F= 3.16, df=7,8 and $p<0.05$) of density among the fiber boards.

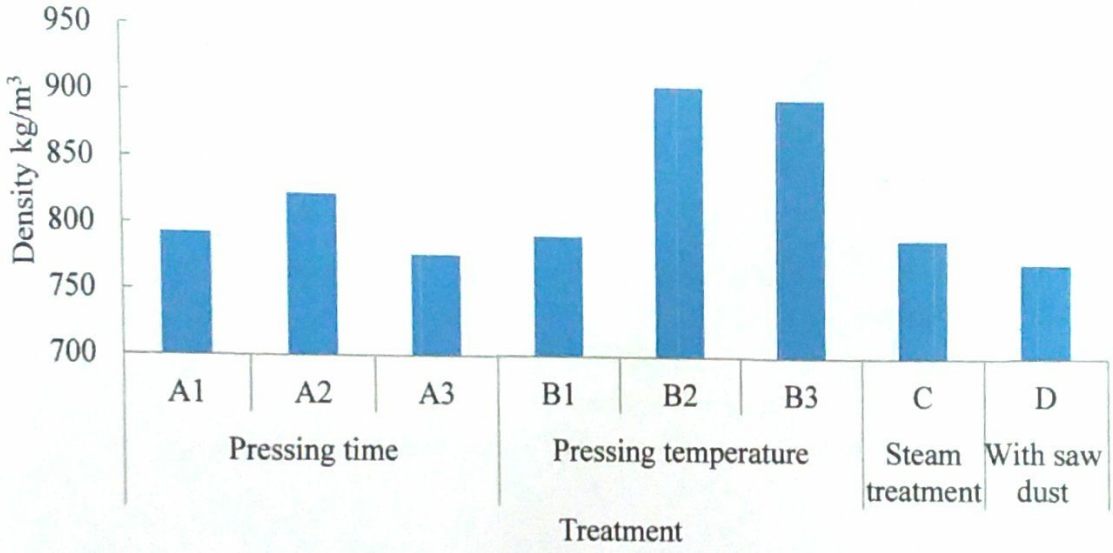

Figure 4.1: Density of fiber board manufactured with wastage of tea industry

All properties of a fiber board affected by density of the board, thus density is very important properties. Density of the fiber board manufactured with wastage of tea industry increased with pressing temperature. Camilo, (2009) also reported that pressing temperature has significant effect on density of binderlessn fiberboard. According to ANSI (1999) standard the density of medium density fiber board ranges from 600 kg/m^3 to 800 Kg/m^3. Hence, the density of board type B2 and B3 were higher than the medium density fiber board. The density found in this study is higher than the density of fiber board manufactured with soybean straw and wheat straw (Evan and Dilpreet, 2015). This might be due to their using of binder which absent in present study. Another cause might be high compaction ratio as Chen *et al.* (2006) reported that the smaller particles make a thinner mat and the compaction.

4.1.2 Water Absorption (WA)

It was found that the mean water absorption of fiberboard category A_1, A_2, A_3, B_1, B_2, B_3, C and D were 125%, 111.29%, 125%, 125%, 116.07%, 132.69%, 110%, 115% respectively (Fig. 4.2). From the variance analysis (Table A-2) it was observed that there was no significance difference ($F=0.5734$, $df=7,16$ and $p<0.05$) among A_1, A_2, A_3, B_1, B_2, B_3, C and D.

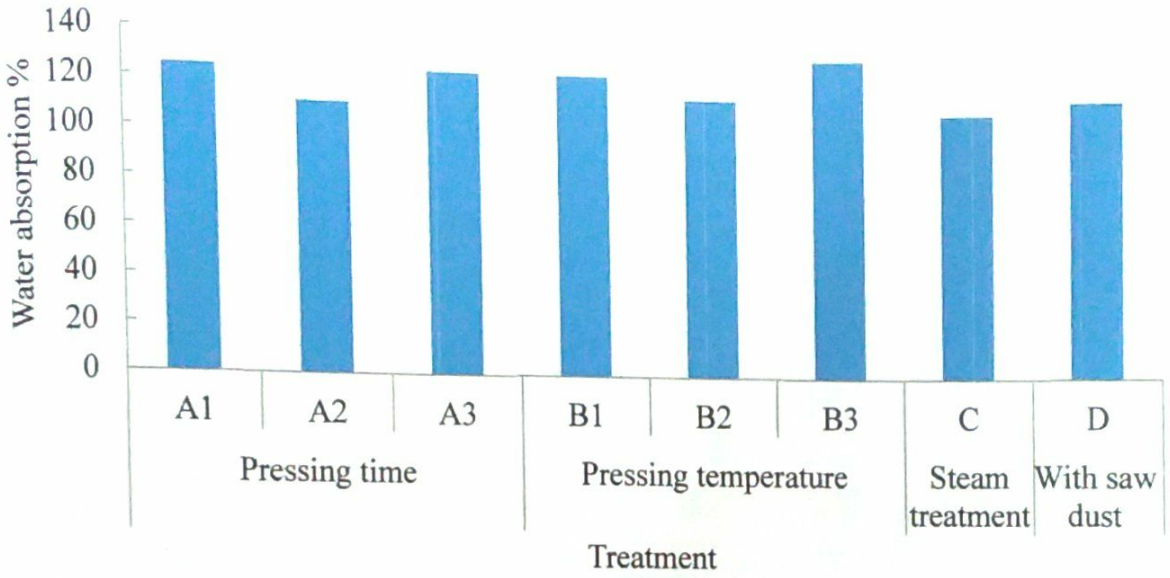

Figure 4.2: Water absorption (%) by the fiberboards after 2 hour

The result showed that percentage of water absorption was very high that means water rersistency power of the fiber board manufactured with wastage of tea industry is very low. This high water absorption may be due to not using any binder. Mustafa *et al.* (1998) reported comparatively good result from particle board manufactured from waste tea leaves using UF resin. Because, if the board is compressed so that there is greater contact between the particles in the mat, the resin is cured more effectively in the void spaces of the board and there is less water absorption. No hydrophobic substance was used during manufacturing the panel that is another reason behind high water absorption (Alireza *et al.*, 2009). In present study 100% fibrous material was used and hydroxyl groups of fibrous materials are responsible for moisture absorption (Naik and Mishra, 2006). Another reason behind the higher water absorption is high porosity. . Hüsnü *et al.*, (2011) reported that higher water absorption value found due to mainly high porosity and high cellulose content.

4.1.3 Thickness Swelling (TS)

It was found that the mean thickness swelling of fiberboard category A_1, A_2, A_3, B_1, B_2, B_3, C and D were 40.72%, 44.04%, 44.24%, 40.72%, 44.21%, 41.04%, 33.865%, and 42.5% respectively (Fig. 4.3). From the variance analysis (Table A-3) it was observed that there is no significance difference ($F=2.654911$, $df=7,16$ and $p<0.05$) among A_1, A_2, A_3, B_1, B_2, B_3, C and D. Kargarfarda, and Jahan-Latibarib, (2014) also found that pressing temperature variation of 10^0C and pressing time variation of one minute has no significant effect on thickness of medium density fiberboard produced from *Eucalyptus camaldulensis* fibers.

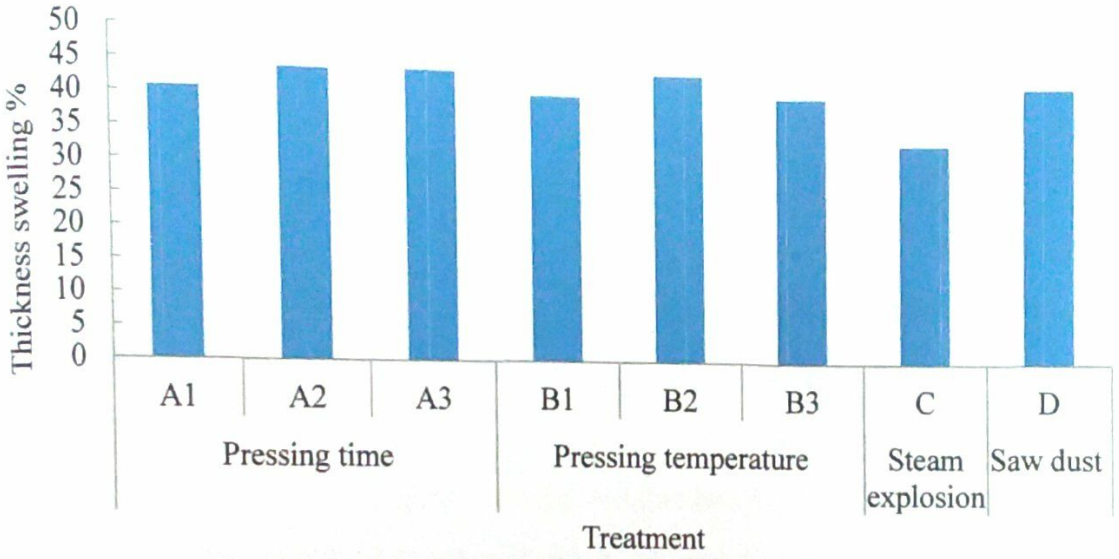

Figure 4.3: Thickness Swelling (%) of the fiberboards after 2 hour

Tendency of the thickness swelling is very similar to the water absorption. Based on EN standard, MDF panel should have a maximum TS value of 8% and 15% for 2 and 24 h immersion, respectively. Whereas present study showed the TS ranges from 33.865% to 44.24% in 2 h. This high thickness swelling take place may be due to not using any binder. Hüdaverdi et al. (2001) found decrease of thickness swelling with increase of percentage of adhesive.

4.2 Mechanical Properties

4.2.1 Modulus of Elasticity (MOE)

It was found that the mean modulus of Elasticity (MOE) of fiberboard type A_1, A_2, A_3, B_1, B_2, B_3, C and D were 622.72, 685.23, 529.92, 635.63, 1059.84, 1072.26, 1130.72, 585.55 N/mm^2 respectively (Fig. 4.4). From the variance analysis (Table A-4) it was observed that there is significance difference ($F=1280.068$, $df=7,16$ and $p<0.05$) among A_1, A_2, A_3, B_1, B_2, B_3, C and D.

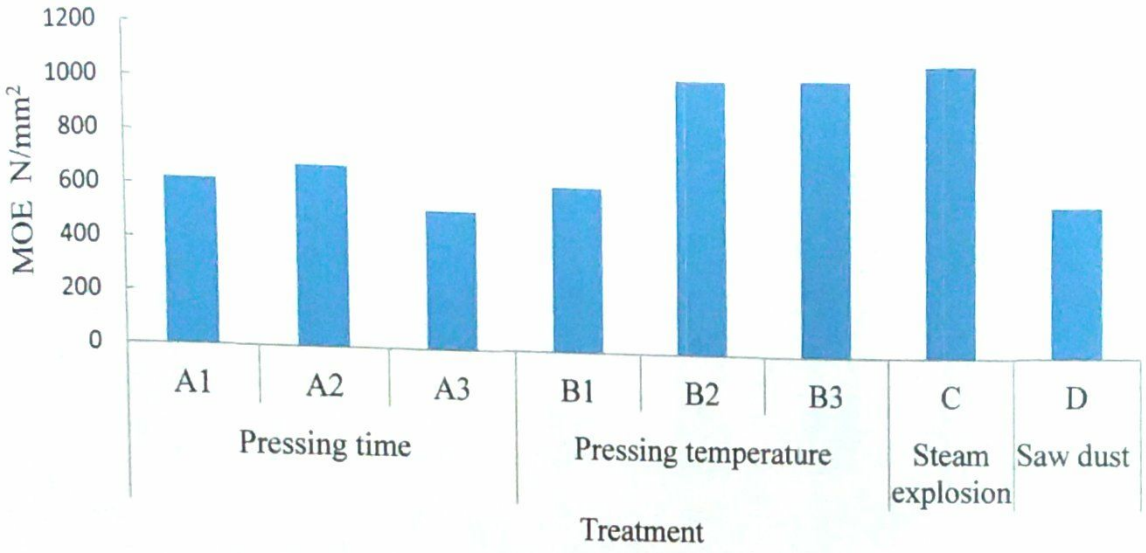

Figure: 4.4 MOE of Fiber board

The result showed that MOE of fiber board type A_1, A_2 and A_3 is very close. Therefore MOE was not affect significantly by the pressing time. Result of present study support the result found by Hüdaverdi *et al.* (2001). Again MOE of fiber board type B_3 is higher than that of B_1 and B_2 which indicate that MOE of the fiber board increased with increase of pressing temperature. The result support the result reported by Kargarfarda, and Jahan-Latibarib, (2014). Finally board type C gave the highest value of MOE but board type D gave very low value. From this result it is clear that steam explosion of fiber has positive effect on MOE of fiber board. Based on EN standard (312-3) 1600N/mm^2 is the minimum requirements for MOE of panels for general purpose and interior fitments. But this study gave highest MOE 1130.72 N/mm^2 that means none of this fiber board fulfills the minimum requirement.

4.2.2 Modulus of Rupture (MOR)

It was found that the mean modulus of rupture (MOR) of fiberboard type A_1, A_2, A_3, B_1, B_2, B_3, C and D were 4.2, 4.48, 3.58, 4.2, 7.04, 6.46, 7.14, 3.96 N/mm^2 respectively (Fig. 4.5). From the variance analysis (Table A-5) it was observed that there is significance difference ($F= 14.6175$, df =7, 16 and $p<0.05$) among A_1, A_2, A_3, B_1, B_2, B_3, C and D. Mustafa *et al.* (1998) found better results from particleboard manufactured from waste tea leaves by using adhesive.

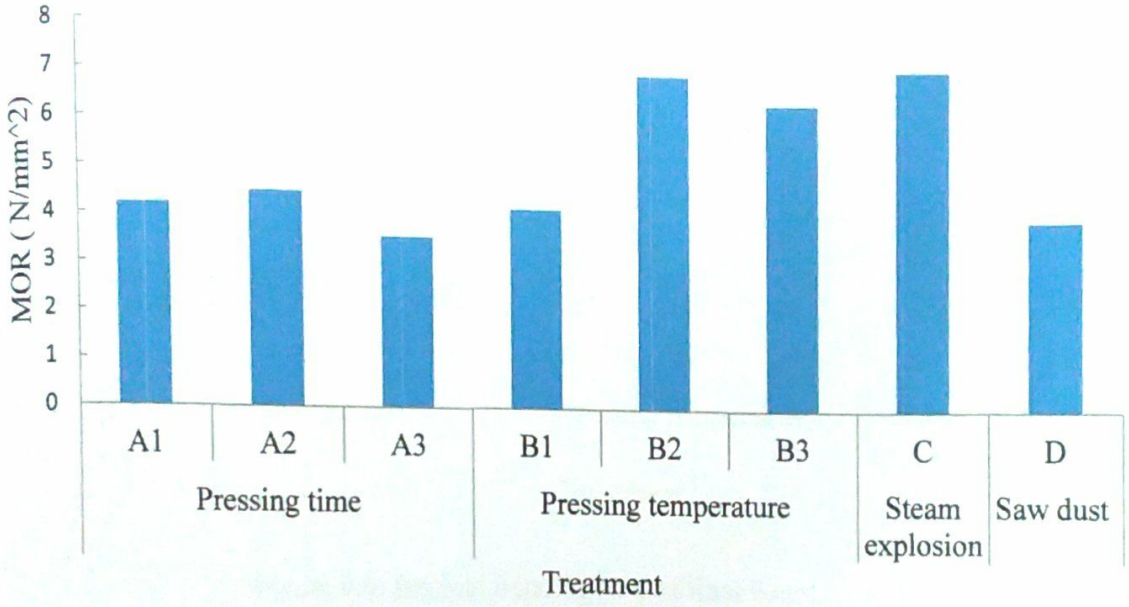

Figure 4.5: MOR of fiberboards

The result showed that board type A_1 and A_2 gave very close result of MOR and A_3 gave comparatively lower value of MOR than the A_1 and A_2. Therefore increasing of pressing time did not affect the MOR positively. Again B_2 gave the higher value of MOR than that of B_1 and B3. 85^0 C is the suitable pressing temperature in this study. Finally figure 4.5 showed that board type C gave the highest value of MOR but board type D gave comparatively low value. Therefore it is clear that steam explosion of fiber positively affects the MOR but mixing of saw dust has no positive effect on MOR in this study. Based on EN standard (312-3) 13 N/mm^2 is the minimum requirements for MOR of panels for general purpose and interior fitments. Whereas MOR in this study was ranges from 3.58 to 7.14 N/mm^2 meaning that fiber boars of this study did not fulfill the minimum requirement.

4.2.3 Internal Bonding

It was found that the mean internal bonding (IB) of fiberboard type A_1, A_2, A_3, B_1, B_2, B_3, C and D were 0.21, 0.16, 0.1, 0.22, 0.04, 0.14, 0.1, 0.04 N/mm^2 respectively (Fig. 4.6). From the variance analysis (Table A-6) it was observed that there is significance difference (F= 14.6175, df =7, 16 and $p<0.05$) among A_1, A_2, A_3, B_1, B_2, B_3, C and D. Mustafa *et al.* (1998) found better results from particleboard manufactured from waste tea leaves by using adhesive.

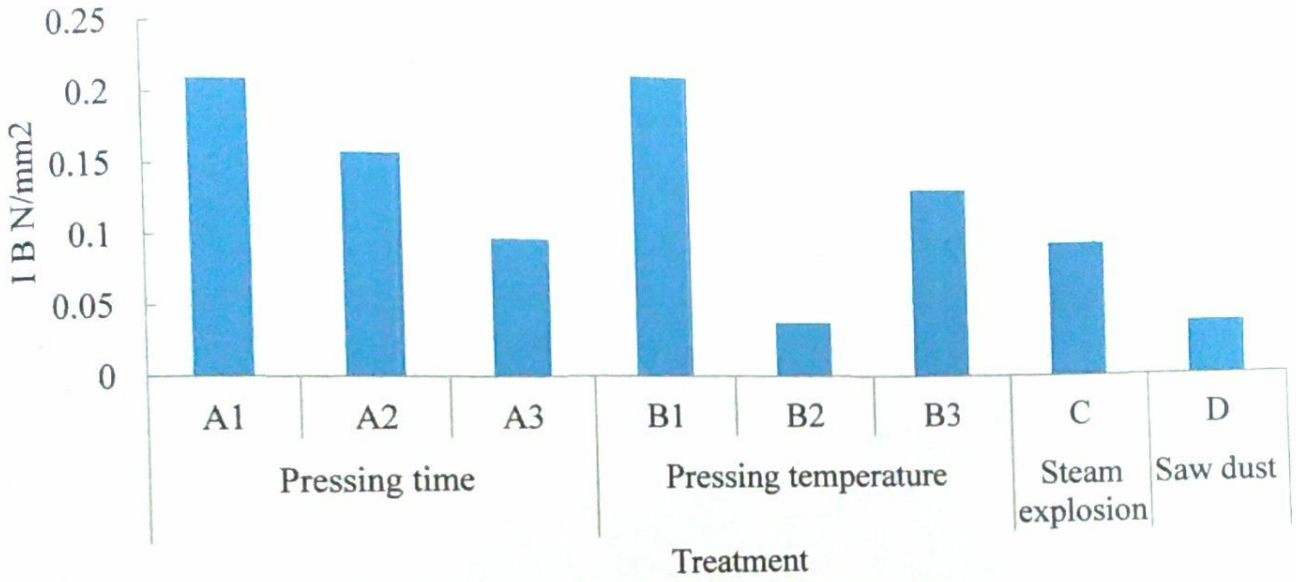

Figure 4.6: Internal bonding (IB) of fiber board

Figure 4.6 showed IB was decrease from A_1 to A_3. There IB was decrease with increase of pressing time. Result of present study shows that IB decrease because of high pressing temperature which supports the report of Alireza *et al.*, (2009). The result also indicates that steam explosion of fiber and mixing of saw dust did not improve the IB of fiber board. IB data ranged from 0.04 to 0.22 N/mm^2. The minimal requirement of IB strength for general purpose (EN 312-2) is 0.24 N/mm^2. Type A_1 and type B_1 gave very close value to minimum requirement.

Chapter Five

Conclusion

5.1 Conclusion

The present study examined the suitability of using wastage of tea industry for fiberboard production. There was no significance difference in physical properties among the fiber board with pressing time and pressing temperature variation. But the mechanical properties vary significantly with the pressing time and pressing temperature. From the study it was observed that modified steam explosion gives better results. But mixing of saw dust decreased the quality of the board. From the tested result of the fiberboard it is clear that manufacturing of fiberboard with wastage of tea industry is feasible but the quality of the board is not up to standard. Quality of the fiber board could be improved and to do that little amount of adhesive may added with the fiber.

References

A. Kargarfarda & A. Jahan-Latibarib, (2014). The effect of press temperature on properties of medium density fiberboard produced from *Eucalyptus camaldulensis* fibers. *International Journal of Lignocellulosic Products*. 2014, 1 (2): 142-150.

Alireza Ashori, Amir Nourbakhsh & Abolfazl Karegarfard, (2009). Properties of Medium Density Fiberboard Based on Bagasse Fibers. *Journal of Composite Materials*. DOI: 10.1177/0021998309341099.

Alma, M. H. Kalaycıoğlu, H. Bektaş, İ. Tutuş, A. (2005). Properties of cotton carpel-based particleboards. *Industrial Crops and Products* 22: 141-149.

Anon, (1970). Indian Forest Utilization. Vol. 1. Forest Research Institute and College, Dehradun, India.

Anon, (1985). Specification for Wood Particleboards (medium density) for General Purposes (first revision). IS:3087-1985, Indian Standard Institution, New Delhi. 19pp.

Bektaş, İ. Guler, C. Kalaycıoğlu, H. (2005). The manufacture of particleboards using sunflower stalks (*Helianhus annuus* I.) and poplar wood (*Populus alba* L.). *J of Composite Materials*. 39: 467-473.

Biswas, K.P. (2006). Description of tea plant. In Encyclopaedia of Medicinal Plants. New Dehli: Dominant Publishers and Distributors. 964-966 pp.

Bruno D. Mattos , Andre L. Misso, Pedro, H.G. de Cademartori, Edson A. de Lima, Washington L.E. Magalhaes, Darci A. Gatto, (2014). Properties of polypropylene composites filled with a mixture of household waste of mate-tea and wood particles. *Construction and Building Materials*. 61 (2014) 60–68pp.

Campbell F.C. (2010). Structural Composite Materials. ASM International.

Camilo Mancera Arias, (2009). Binderless Fiberboard Production from *Cynara candunculus* and *Vttis vinifera*. *Universitat Rovirai Virgili*. ISBN:978-84-692-1537-1/DL:T-300-2009.

Chen, H.C. Chen, T.Y. & Hsu, C.H. (2006). Effects of Wood Particle Size and Mixing Ratios of HDPE on the Properties of the Composite. *Holz als Roh-und Werkstoff*. 64: 172-177

Chow, P. (1974). Dry formed composite board from selected agricultural residues world consultation on wood based panels. Food and Agriculture Organization of the United Nations. New Delhi, India.

Copur, Y. Guler, C. Akgul, M. Tascioglu, C. (2007). Some chemical properties of hazelnut husk and its suitability for particleboard production. *Building and Environment*. 42: 2568-2572.

Copur, Y. Guler, C. Taşcıoğlu, C. Tozluoğlu, A. (2008). Incorporation of hazelnut shell and husk in MDF production. *Bioresource Technology*. 99: 7402-7406.

Dr. Kazi Muzafar Ahammed, (2012). "Investment for Sustainable Development of Bangladesh Tea Industry – An Empirical Study".

Eroğlu, H. (1988). Lif Levha Endüstrisi. *Ders Notları*, No:304, K.T.Ü., Trabzon, 209 s.

Eroğlu, H. İstek, A. (2000). Medium density fiberboard (MDF) manufacturing from wheat straw (Triticum aestivum L.). *Inpaper International*. 4: 11-14.

Evan D. Sitz, Dilpreet S. Bajwa, (2015). The mechanical properties of soybean straw and wheat straw blendedmedium density fiberboards made with methylene diphenyldiisocyanate binder. *Industrial Crops and Products*. INDCRO-8059; No. of Pages 6

Gencer, A. Eroğlu, H. Ozen, R. (2001). Medium density fiberboard manufacturing from cotton stalks (Gossipium hirsutum L.). *Inpaper International*. 5: 26-28.

Guler, C. Ozen, R. (2004). Some properties of particleboards made from cotton stalks (*Gossypium hirsitum* L.). *Holz als Roh-und Werkstoff*. 62: 40-43.

Hüsnü YEL, Ayfer DÖNMEZ ÇAVDAR & Hülya KALAYCIOĞLU, (2011). Mechanical and Physical Properties of Cement-bonded Perticleboard Made from Tea Residues and Hardboards. *Key Engineering Materials*, Vols. 471-472 (2011) pp 572-577.

Hüdaverdi EROĞLU, Abdullah İSTEK & Mustafa USTA, (2001). Medium Density Fiberboard (MDF) Manufacturing from Wheat Straw (*Triticum aestivum* L.) and Wood Straw Mixture. Journal of Engineering Science. 7 (20: 305-311.

Leliveld J., P.J. Crutzen, (1992). Nature, 41, 355-339.

Kacar, B. (1991). Tea Analysis. Ankara University, Fat. of Agric. Ankara, Turkey, ISBN 975-7717-02-9,289 pp.

Kalay, H.Z. Yalinkilic, M.K. Altun, L. (1993). Mushroom production from waste tea leaves substrate and utilization of waste compost as organic fertilizer. Res. Project of Black Sea Tech. Univ., Code 89.113.001.1, Trabzon,Turkey, 127pp.

Maloney, T. M. (1993). Modern Particleboard and Dry-process Fiberboard Manufacturing. San Francisco, CA: Miller Freeman Publication.

Medium density fibreboard *(MDF)* Hazard Assessment Document EH75/1 HSE Books 1999 ISBN 0 7176 1735 1.

Mehmet Akgu¨l, Ayhan Tozluog˘lu, (2007). Utilizing peanut husk (Arachis hypogaea L.) in the manufacture of medium-density fiberboards, *Bioresource Technology*. 99 (2008) 5590–5594.

Mustafa Kemal Yalinkilicy, Yuji Imamuraa, Munezoh Takahashi, Hulya Kalaycioglub, Gokay Nemlib, Zafer Demircib, Turgay Ozdemirb, (1998). Biological, physical and

mechanical properties of particleboard manufactured from waste tea leaves. *International Biodeterioration & Biodegradation.* 41 (1998) 75-84pp.

Naik, J.B. & Mishra, S. (2006). The Compatibilizing Effect of Maleic Anhydride on Swelling Properties of Plant-fiber-reinforced Polystyrene Composites. *Polymer-plastics Technology and Engineering*, 45(8): 923_927.

Nemli, G. Kırcı, H. Serdar, B. Ay, N. (2003). Suitability of kiwi (*Actinidia sinensis* P.) prunings for particleboard production. *Industrial Crops and Products*. 1: 39-46.

Piyoosh Thori, Pawan Sharma & Manish Bhargava, (2013). An Approach of Composite Materials in Industrial Machinary: Advantages, Disadvantages, and Applications. *IJRET: International Journal of Research in Engineering and Technology*. Volume: 02 Issue: 12.

Rathnakar, G. & Shivanand, H. K. (2014). Experimental Evaluation of Inter Laminar Shear strength of Fibre Reinforced Composites. *International Journal of Mechanical Engineering and Robotics Research.* Vol. 3, No. 4.

Ross, I.A. (2005). Tea common names and its uses. In Medicinal Plants of the World. 3rd Vol. New Jersey: Humana Press, 1-19 pp.

Rowell, R. M. (1992). Opportunities for Lignocellulosic Materials and Copposites; (In) Emerging Technologies for Materials and Chemicals from Biomass: Proceedings of Symposium; 1990 August 26-31 Washington, DC: American Chemical Society ; Chapter 2 ACS Symposium series 476.

Salehuddin, A.B.M. (1990). A multidimensional approach to forestry in Bangladesh. Bangladesh Forest Research Institute, Chittagong. 5pp.

Salehuddin, A.B.M. (1992). Wood and Fiber Composite Materials. Gen. Tech. Rep.

Seidl, R.J., (1966). Product development—the key to expanding markets for wood-based panel products. Plywood and Other Wood-based Panels, Report of an International Consultation on Plywood and other Woodbased Panel Products. Food and Agriculture Organization of the United Nations, Rome.

Suchsland, O, Woodson, G.E. (1986). Fiberboard Manufacturing Practices in the United State, Agric. Handb. 640. Washington DC: U. S. Department of Agriculture.

Sumpio, B.E. Cordova, A.C. Berke-Schlessel, D.W. Qin, F. Chen, Q.H. (2006). Green tea, the "Asian Paradox", and cardiovascular disease. *J. Am. Coll. Surg.* 202: 813-820.

Tariq Mahmood, Naveed Akhtar, Barkat Ali Khan, (2010). The morphology, characteristics, and medicinal properties of *Camellia sinensis*' tea. *Journal of medicinal plant research.*

Yilmaz, Y. (2006). Novel uses of catechins in food. Trends. *Food. Sci. Technol.* 17: 64-71.

Youngquist, J. English, B. Scharmer, S. Chow, P. Shook, S. (1994). Literature review on use of non-wood plant fibers for building materials and panels. Gen Tech Rep FPL-GTR-80. USDA Forest Serv., Forest Products Lab., Madison, Wis.

Youngquist, J. English, B.E. Spelter, H. Chow, S. (1993). Agricultural Fibers In Composition Panels. In: Maloney, Thomas M, ed. Proceedings of the 27th International Particleboard /Composite Materials Symposium; March 30-31; April 1; Pullman, WA: Washington State University.

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

Appendices-1:

Table-A1.1 Result for Density

Board type	Pressing time (minute)	Pressing temperature (°C)	Result (kg/m^3)
A1	10	80	793± 92.45
A2	13	80	824± 87.13
A3	16	80	778±75.34
B1	10	80	793± 92.45
B2	10	85	910± 35.07
B3	10	90	901± 50.42
C	10	85	792± 55.22
D	10	85	773± 89.52

Table A -1.2 Result for Water Absorption

Board type	Pressing time (minute)	Pressing temperature (°C)	Result (%)
A1	10	80	125±27.22
A2	13	80	111.29±17.69
A3	16	80	125±11.09
B1	10	80	125±26.22
B2	10	85	116.07±10.88
B3	10	90	132.69±32.22
C	10	85	110±20.72
D	10	85	115±9.50

Table A -1.3 Result for Thickness Swelling

Board type	Pressing time (minute)	Pressing temperature (°C)	Result (%)
A1	10	80	40.72±12.22
A2	13	80	44.04±7.69
A3	16	80	44.04±10.09
B1	10	80	40.72±8.22
B2	10	85	44.21±9.88
B3	10	90	41.04±7.22
C	10	85	33.865±11.72
D	10	85	42.5±6.50

Table A -1.4 Result for MOE

Board type	Pressing time (minute)	Pressing temperature (°C)	Result
A1	10	80	622.7± 19.94
A2	13	80	685.23± 14.78
A3	16	80	529.92± 10.11
B1	10	80	635.63±4.91
B2	10	85	1059.84±10.80
B3	10	90	1072.26±9.92
C	10	85	1130.72± 10.87
D	10	85	585.55±10.30

Table A -1.5 Result for MOR

Board type	Pressing time (minute)	Pressing temperature (°C)	Result
A1	10	80	4.2±0.45
A2	13	80	4.48±1.05
A3	16	80	3.58±0.58
B1	10	80	4.2±0.45
B2	10	85	7.04±0.18
B3	10	90	6.46±0.96
C	10	85	7.14±0.41
D	10	85	3.96±0.85

Table A -1.6 Result for IB

Board type	Pressing time (minute)	Pressing temperature (°C)	Result
A1	10	80	0.22±0.05
A2	13	80	0.16±0.03
A3	16	80	0.1±0.04
B1	10	80	0.22±0.09
B2	10	85	0.04±0.06
B3	10	90	0.14±0.08
C	10	85	0.1±0.04
D	10	85	0.04±.01

Appendices-2:

Table A-2.1: ANOVA for Density

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	62588	7	8941.143	3.156069	0.02697	2.657197
Within Groups	45328	16	2833			
Total	107916	23				

Table A-2.2: ANOVA for Water Absorption

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6837.114	7	976.7306	0.5734	0.767296	2.657197
Within Groups	27254.44	16	1703.403			
Total	34091.55	23				

Table A-2.3: ANOVA for Thickness Swelling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1013.857	7	144.8367	2.654911	0.050146	2.657197
Within Groups	872.8679	16	54.55424			
Total	1886.725	23				

Table A-2.4: ANOVA for MOE

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1324346	7	189192.3	1280.068	9.01E-21	2.657197
Within Groups	2364.777	16	147.7986			
Total	1326711	23				

Table A-2.5: ANOVA for MOR

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	44.62156	7	6.374509	14.6175	7.21E-06	2.657197
Within Groups	6.9774	16	0.436088			
Total	51.59896	23				

Table A-2.6: ANOVA for IB

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	44.62156	7	4.364509	14.6175	7.21E-06	2.657197
Within Groups	6.9774	16	0.336088			
Total	51.59896	23				