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UTILIZATION OF WATER HYACINTH (*Eichhornia crassipes*) FOR THE MANUFACTURING OF MEDIUM DENSITY FIBERBOARD (MDF)

SHAH AHMADUL HASAN
STUDENT ID: 090520

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

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DECLARATION

I, Shah Ahmadul Hasan, declare that this thesis is the result of my own works and it has not been submitted or accepted for a degree in any other university. I also declare that this thesis or any information of this paper can not be used industrially or commercially without any prior permition of the author.

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Shah Ahmadul Hasan

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To

Late Hadiul Islam Hadi (11 Batch)

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APPROVAL

This project thesis has been submitted to the Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh, in partial fulfillment of the requirements of Four year professional B. Sc. (Hons.) degree in Forestry. I have approved the style and format of the project thesis.

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ABBREVIATION

Anon	Anonymous
ANOVA	Analysis of Variance
LSD	Least Significant Difference
ASTM	American Society for Testing and Materials
AWPA	Australian Wood Panels Association
BBS	Bangladesh Bureau of Statistics
FAO	Food and Agricultural Organization of United Nations
g/cm^3 or gm/cm^3	Gram per cubic centimeter
Ha	Hectare
kg/m^3	Kilogram per cubic meter
kN	Kilo Newton
lb/ft^3	Pound per cubic feet
cm	Centimeter
m	Meter
mm	Millimeter
µm	Micro meter
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MPa	Mega Pascal
N/mm^2	Newton per square millimeter
PVC	Poly vinyl chloride
PVAC	Poly-vinyl acetate
rpm	Rotor per minute
UTM	Universal Testing Machine
ANSI	American National Standard Institute
APA	American plywood Association
CPA	Composite panel Association
NES	National Evaluation Services
ASTM – D-1037partB	Test Methods for MDF

ABSTRACT

This study investigated the potentiality of using water hyacinth as a raw material for the production of the Medium density Fiberboard (MDF) and its basic physical and mechanical properties. It appears that manufacturing of water hyacinth fiberboard (MDF) is technically feasible for various structural purposes.

The physical and mechanical properties were as: Density (0.78 gm/cm^3); moisture content (10.28%); water absorption (71.03%); thickness swelling (48.41%); Modulus of Rupture (MOR, 31.25 N/mm^2) and Modulus of Elasticity (MOE, 3135 N/mm^2).

The physical and the mechanical properties of 5 mm water hyacinth fiberboards were compared with 5 mm MDF boards available in market. It has been observed that all the properties of the boards meet the requirements of the international standards like ANSI, ISO, and AS/ NZS. Based on the experiment it is also found that the water hyacinth fiberboard shows quite satisfactory results in case of physical and mechanical properties in comparison with the market fiberboard except in case of thickness swelling.

CHAPTER ONE

INTRODUCTION

1.1 Background and justification of the study

Wood is one of the lingo cellulosic materials and valuable forest resources on the earth and it conforms to the most varied requirements (Anon, 1982). Wood is one of the most valuable resources on the earth and it conforms to the most varied requirements. About 70% demand for timber and 90% for fuel wood of the country is met from the trees grown in village groves of Bangladesh Wood from times immemorial has been the most useful of all the readily available materials to mankind (Anon, 1982). But due to heavy and illegal extraction of timber forest resource has becomes too much meager in Bangladesh and occurring of scarcity of timber. In this case fiberboard represent one of the most challenging product groups in the world from a marketing point of view because of their number, versatility, end-use variation, dissimilarities of the producer base and resource richness.

The population of the world is increasing day by day that creates a tremendous pressure on forest and forest products. This extra pressure damages our forest. Its one of the most important solution of threat shortage is to be provision of alternative high growing fibrous agricultural plant production. Thus, people have placed a high emphasis on forest preservation and rational use of forestry and agricultural residues. This trend is mainly motivated and accelerated by dilemma of an ever – increasing consumption of wood fiber based products relative to dwindling wood resources (Li et al; 2010). However some agricultural plants produce higher cellulosic fibrous materials that to be suitable substitute for certain fiber based industries. Among them water hyacinth may serve as an alternative source in fiber based industries.

In the recent year, special attention has been given to agro – agricultural residues and the re – use of residues in the preparation of new materials, as part of the worldwide trends concerning environmental and economic viability (Pereira et al.2010).

The growing demand for wood based panels has led to continuous efforts to find new resources as an alternative to wood. The use of other renewable resources such as an agricultural residues in the production of composite panel (i.e. fiber boards and particleboards) has recently been considered attractive both from the economical and environmental point of view (Ayrilimis and Buyuksari; 2010).

A great interest towards the development of composite materials reinforced with natural fibers has emerged in the last decade (Mwaikambo and Ansell 2006). One of the principal advantages using natural fibers is given by the widespread availability of fibers, their low cost, low weight, biodegradability, co neutral renewable nature, and good mechanical properties (Esmeraldo et al; 2010). Its other advantages are the availability of alternative fibers could reduce the pressure to harvest trees for paper making, composite (fiber board, particle board) production. Second, alternative fibers may be grown or collected after harvesting food crops in parts of the country where there are no forests, thereby helping to decentralized and diversity the pulp and paper industry and to create additional jobs for struggling rural economics. Third, some of these fibers may even offer environmental advantages.

What is the prospect to use water hyacinth fiber as a composite? It answer is to be the good mechanical properties of water hyacinth fiber. It has generally no commercial use. Farmer uses it as compost manure or as fodder. So it can place a vital role for a large amount of biomass. So it is a vast resource of cellulosic material. Moreover, the water hyacinth fiber shows satisfactory physical properties, such as relatively high tensile strength and stiffness, which indicate its prospect as a promising fiber material.

The application of natural fibers including water hyacinth fiber has been proved promising in various technical fields, such as replacing synthetic fibers as reinforcement in various composites.

The potentiality in use of water hyacinth fiber is not only for food production but also for other application. We are solicitous on water hyacinth fiber. So it can be a prominent source for fiber board manufacture considering its mechanical and physical properties. Further study on the chemical composition and microstructure of water hyacinth fiber can be conducted. It will be beneficial to the novel applications of these valuable resources.

If these are studied for finding out the technical feasibility to convert them into particleboard, a new avenue can be opened to the fiberboard manufacturing industries at the present situation of raw material crisis as well as the economic values of these materials will be increased.

1.2 Objectives of the study

The overall objectives of this study are to evaluate the physical and mechanical properties of the water hyacinth fiberboards. This study also aims at to evaluate density, moisture content, water absorption, thickness swelling, modulus of rupture and modulus of elasticity and compare the result with physical and mechanical properties of the standard fiberboards. The study consisted of the following specific objectives –

1. To show the potentiality of water hyacinth fibers as an alternative raw material for fiber board manufacturing.

2. To asses the physical and mechanical properties of water hyacinth fiberboards and compare with the standard board quality.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Detail information about Fiberboard:

2.1.1 Fiber

A fiber is tabular or cylindrical element, obtained from plant matter, containing cellulose as the principal constituent. Woo fibers are elongated cells which are similar to trachieds except they are smaller, only 0.7 to 3 mm long and less than 20×10^{-6} m in diameter, and they do not serve for fluid transport in the living tree.

2.1.2 Pulping

Pulping refers to any process by which wood or other fibrous materials is reduced to a fibrous mass. Basically it is the means by which the bonds are systematically ruptured with the wood structure. The task can be accomplished mechanically, thermally, chemically or by combinations of these treatments (Smook, G. A., 2002).

Mechanical pulping separates fibers by such methods as disk abrasion and billeting. In the chemical pulping, the chips are cooked with appropriate chemicals in an aqueous solution at elevated temperature and pressure. Chemi-mechanical processes involve mechanical abrasion and the use of chemicals. Thermo- mechanical pulps, which are used for making products such as newsprint, are manufacture from raw materials by the application of heat, in addition to mechanical operations. Semi chemical pulping combines chemical and mechanical methods. Essentially the chips are partially soften or digested with chemicals; the remainder of the pulping action is then supplied mechanically, most often in disc refiners (Smook, G. A., 2002).

2.1.3 Fiber board and its importance:

Fiberboard is a generic name for construction panels made of wood or vegetable fibers. Some are homogeneous materials, while others are laminated sheets with fiber cores and surfaces of ground wood. The earliest fiberboard panels were made with fibers from an array of materials including jute, straw, sugar cane stalks, flax, hemp, grass, newspaper and peanut shells. They were manufactured under name such as fire – tex, homosate, beaver board, Feltex, Nu – wood, and upson Board. Wood has always been the most common fiber used in fiberboard.

Natural fibers are lignocellulosic in nature and the most abundant renewable biomaterial of photosynthesis on earth. Unutilized natural fiber residues are readily available rich resources of lignocellulosic materials. Since last decade, there is considerable worldwide interest in the potential in substituting natural fibers (agrofibers) for either wood or man made fiber (e.g., fiber glass) in composite materials. Composites consisting lignocellulosic fibers and synthetic thermoplastics have received substantial attention in scientific literature as well as industry primarily due to improvements in process technology and economic factor (Sanadi, 1992; Yam, 1990).

Fiber board is a sheet material generally manufactured from lingo – 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). A fiberboard is a board (or sheet) of material made from fibers 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 oyster, etc (Anon, 1970).

The production of fiberboard has been increasing consistently due to its numerous advantages over solid wood and other composite materials. Fiberboards with uniform fiber distribution in their structure meet most end use requirements. With fiberboards, smooth and solid edges can easily be machined and finished for various purposes, especially furniture production. Smooth and uniform surfaces also provide an excellent substrate for paint and decorative overlays. The surface smoothness of MDF makes it the best material for cabinet manufacturing (Couper et al. 2008). Fiber board does not contain knots or rings, making it more uniform than natural woods during cutting and in service. However, fiberboard is not entirely isotropic, since the fibers are pressed together primarily through the sheet. Like natural wood, fiberboard may split when wood screws are installed without pilot holes, and fiber board may be glued, dwelled or laminated, but smooth – shank nails do not hold well.

2.1.4. Utilization of Medium-density and High- density fiberboard:

Medium-density fiberboard is frequently used in place of solid wood, plywood, and particleboard in many furniture applications. It is also used for interior door skins, mouldings, and interior trim components (Youngquist and others 1997). The uses for hardboard can generally be grouped as construction, furniture and furnishings, cabinet and store work, appliances, and automotive and rolling stock. Typical hardboard products are prefinished paneling (ANSI/AHA A135.5–1995 (AHA 1995b)), house siding (ANSI/AHA A135.6–1990 (AHA 1990)), floor underlayment, and concrete form board. Some of the sample pictures are given here –

Fig: Decorative floor

Fig: Side cabinet

Fig: Flush door

Fig 2.1: sample pictures of medium density fiberboard furniture

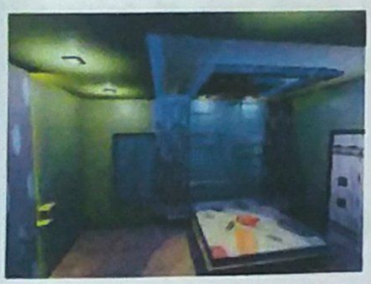


Fig: Room decoration

Fig: house siding

Fig: Decorative Wall

Fig: Shelves siding

2.1.5. History and development of fiberboards

As early as 1933, acceptable wall and ceiling products included fiberboard (Sometimes referred to as rigid board, or wall board) and plywood. The Washington office's improvement Handbook (1937) and principles of Architectural planning for forest service Administrative improvements (1938) noted that certain fiberboards were acceptable for use as insulation and or interior walls and ceilings. These included Masonite, Nu – wood, Du – X and Fire – tex. To support the forest services goal of using wood, fiberboards were favored as a finish material, although they were also deemed suitable as a lath or base for plaster finishes. Although the first American patent for fiber board was issued in 1858, fiber board was not used widely until the 1910s. During World War II, production increased because could be installed easily and quickly in temporary military structures. The fiber board industries also grew with the demand for housing after the war, particularly as an interior finish. Some fiberboard materials were manufactured for exterior application, but they often performed poorly (Wilson. R. 2007). MDF was first developed in the United States during the 1960 s, with production starting in the Deposti, New York. A similar product, hardboard (compressed fiberboard), was accidentally invented by wiliam Manson in 1952, while he was trying to find use for the huge quantities of wood chips that were being discarded by lumber mills. He was attempting to press wood fiber into insulation board but produced a durable thin sheet forgetting to shut down his equipment. This equipment consisted of a blow torch, an eighteenth – century letter press, and old automobile boiler (Anon, 2011)

2.1.6. Types of fiber board

There are di8fferent types of fiber boards. They are classified according to their density. This are –

2.1.6.1. Wilson (2007) categorized fiberboards according to density as low – density (insulation) board, medium – density board and hardboard.

Low density fiberboard: Low density fiberboard was known as insulation board because of its sound – deadening and thermal qualities. This light weight, rigid product made of fibrous pulp was available in sheets, planks and tiles. Insulation board was best suited for interior application because of its susceptibility to water damage. While the thickness of insulation board ranged from 3/8 to 1 inch. Forest service guide books often recommended ½ inch insulation board for facilities. Sheets were 4 to 8 feet wide and could be up to 16 feet long. Insulation board was secured to the building frame with adhesives, nails, screws or patented methods such as dropped metal grids for ceilings, the forerunner of the suspended ceilings found in many offices today.

Medium – Density fiberboard:

Homasote, Beaver Board, and Upson Board were medium – Density fiberboards promoted for use in a variety of applications. Homasote (3/16 – inch – thick) introduced in 1916, was a homogeneous material made of recycled newspapers (the source of its gray color) and petroleum wax.

Hardboard: Most historic hardboard was 1/8 to 5/16 inch thick, although two boards could be glued together to maker a panel that was more rigid. Masonite corp. introduced its first hardboard in the early 1930s. The pressed wood hardboard, from 1/10 to 5/16 inch thick, was used for interior finishes and as battens over other masonite products. Panels could be nailed or glued vertically or horizontally, then painted or wall papered.

2.1.6.2. Various types of hardboards are generally classified into three types according to their method of manufacture, density, mechanical and physical properties (Anon, 2011).

Medium Hardboard: It is homogeneous fiber building board having a density between 480 kgm-3 and 800 kgm-3

Normal Hardboard: It is homogeneous fiber building board having a density between 800 kgm-3 and 1200 kgm-3

Tempered hardboard: Hardboard is further treated in the course of manufacture to increase its density, strength and water resistance.

2.1.6.3. There are another three types of fiberboards depending on their specific gravity, this are –

1. Low density Fiberboard (LDF): Low-density Fiberboards have a specific gravity of between 0.15 and 0.45 and are used for insulation and light weight cores for furniture. They are usually produced by a dry process that uses a ground wood fiber (Berglund and Rowell, 2005; Youngquist, 1999).

2. Medium – Density Fiberboard (MDF): Medium – density fiberboard has a specific gravity of between 0.6 and 0.8 and is frequently used in place of solid wood, ply wood and particleboard in many furniture applications. It is also used for interior door skins, moldings, and interior trim components (Berglund and Rowell, 2005; Youngquist, 1999).

3. High density fiber board (HDF): High density fiberboard has a specific gravity of between 0.85 and 1.2 and is used as an overlay on workbenches and floors 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).

2.1.5.4. According to Anon (1986), fiberboard are classified as the following

i. Insulation board: Insulation board having the density 445 kgm-3
ii. Wall board: The density of the wall board is about 481 kgm-3
iii. Medium hard board: The density of the Medium hard board is 481 to 890 kgm-3
iv. Standard hardboard: Standard hardboard is one kind of fiberboard having the density more than 890 kgm-3
v. Super hardboard: Super hardboard is also a fiberboard having the density more than 1200 kgm-3

2.1.6.5. According to Desh (1996), fiberboards are classified depends on the density as –

Table – 1: Fiber board classification

Type	Density
Hardboards	>800 kg/m3
Medium boards	350 – 800 kg/m3
Soft boards	<350 kg/m3
MDF	Nearly 790 kg/ m3

2.1.7. Raw Materials for Fiberboard Manufacturing

We are mainly dependent on the wood fiber to manufacture different composite materials. But it should not accomplish creating pressure on the forest. We should consider more on non – woody lingo – cellulosic materials. In production point of view, the production of agriculture fiber is higher than the production of lingo – cellulosic fibers from forest. In 2006, the annual global production of lingo – cellulosic fibers from crops was about 4 billion tons, of which 60% came from agriculture and 40% from the forest (Justiz – smith et al. 2008). The materials that are used in fiber board manufacturing are shown in below –

2.1.7.1. ligno – cellulosic materials

Woody materials

1. Wood (soft wood, hard wood, sap wood, heart wood)
2. Planer savings of timbers,
3. Saw mill residues, such as saw dusts, slabs, edging, trimmings, etc.
4. Residues from timber cutting in furniture and cabinet manufacturing plants.
5. Residues from match factories,
6. Veneer and plywood plant residues,
7. Logging residues, such as short logs, broken logs, crooked logs, small tree tops and branches, forest thinning, etc, and
8. Bark

2.1.7.2. Non – woody materials

Almost any agricultural residue (such as husks, coconut coir etc.) after suitable treatment can be used to manufacture fiber board's (Salehuddin, 1992). Some are the non wood materials are –

1. Jute sticks and jute fiber
2. Bagasse
3. Bamboo
4. Banana plant
5. Dhaincha stalks
6. Elephant grass
7. Flax shaves
8. Cotton stalks
9. Cereal straw
10. Water hyacinth
11. Almost any agricultural residue (such as husks, coconut coir etc.) after suitable treatment (Salehuddin, 1992).

2.2 Binder or Adhesive

Adhesives are substances capable of holding materials together in a useful manner by surface attachment. The principle attribute of adhesives is their ability to form strong bonds with surfaces of a wide range of materials and to retain bond strength under expected use conditions (Lehman, R. L., 2004). ASTM (1997) defines an adhesive as a substance capable of holding materials together by surface attachment. The bond attained must meet the strength requirements for the structure of a whole and this bond must remain unaffected by the condition to which it will be exposed throughout its life.

These adhesives have been chosen based upon their suitability for the particular product under consideration. Factors taken into account include the materials to be bonded together, moisture content at time of bonding, mechanical property and durability requirements of the resultant composite products, and of course resin system costs.

2.2.1. Types of adhesive/ binder

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

2.2.1.1. Synthetic adhesive or synthetic resin adhesive

Adhesives of synthetic origin are called synthetic adhesives. These are man made polymers which resemble natural resins in physical characteristics but which can be tailored to meet specific wood working requirements. The choice of an adhesive is based on many factors, such as cost, structural performance, moisture resistance, adhesive curing needs etc. Synthetic adhesives can be categorized into two groups, namely thermosetting adhesives and thermoplastic adhesives.

2.2.1.1.1. Thermosetting adhesives

These types of adhesives are usually based on formaldehyde. Thermosetting adhesives undergo a chemical change during application and curing. The bonds formed by thermosetting adhesives are generally moisture resistant and support loads under normal use. During the polymerization, or chain – building step, thermoset polymers form links, or chemical bonds, between adjacent chains. The results are a three – dimensional network that is much more rigid than the linear thermoplastic structure. The interlinked chains are not free to move when heat is applied, and the thermoset as the name implies, is "set" into a permanent shape after polymerization. The level of cross linking can be varied. Materials with high cross – linking densities are hard, rigid and somewhat brittle substances. Thermosets with low cross – linking densities can be softened by heating to high temperatures, but they do not melt and their original shape is retained (Gilleo, K. et. Al.). Some characteristics and uses of some thermosetting adhesives are furnish below –

Phenol formaldehyde:

Is the oldest class of synthetic polymers, having been developed at the beginning of the 20th century (Detelefsen, 2002). These resins are widely used in both laminations and composites because of their outstanding durability, which derives from their good adhesion to wood, the high strength of the polymer, and the excellent stability, exhibit high wood failure and resist delimitation.

Polymeric diphenylmethane diisocyanates (PMDI) adhesives have shown increasing use at the expense of other adhesives due to their high reactivity and efficiency in bonding. Polymeric diphenylmethane diisocyanates (PMDI) are commonly used in wood bonding and are a mixture of the monomeric diphenylmethane diisocyanate and methylene-bridgeed polyacromatic poluisocyanates (Frazier, 2003). The higher cost of the adhesive is offset by its fast reaction rate, its efficiency of use, and its ability to adhere to difficult to bond surfaces.

Urea-formaldehyde (UF) resins are typically used in manufacture of products where dimensional uniformity, surface smoothness are of primary concern, for example particleboard and MDF. Products manufactured with resins are designed for interior applications. They can be formulated to cure any where from room temperature (300 F); press time and temperatures can be moderated. Urea-formaldehyde resins (often referred urea resins) are more economical than PF resins and a most widely used adhesives for composite wood product (Youngquist, J. A. 1999). The inherent light color of the UF resins make them suitable for the manufacture of decorative products (Youngquist, J. A. 1999).

A melamine-formaldehyde (MF) resin is typical of those used in the particleboard and MDF (medium density fiber board) industry. The moisture resistance of UF can be improved by adding MF (APA, 2005 and Youngquist, 1999).

Resorcinol formaldehyde (RF) is rarely used on its own because of cost. This is highly water resistance.

Phenol Resorcinol formaldehyde (PRF) is also a resin- based adhesive. This adhesive is reddish – brown in color and typical of those used in the glued- laminated beam and I- joist industry and included filler. It can be recommended for the most sever environments.

2.2.1.1.2. Thermoplastic adhesives

Thermoplastic adhesives are espicially useful because they can be used in a dry form and are already fully polymerized as received. The bonding process basically involves softening or melting the polymer while in contact with their adherents, and allowing the joint structure to cool. The structure can be easily disassembled or repositioned by reheating while applying force. These materials have been used for some time under such terms as heat-activated, hot bond and hot melt adhesives. Thermoplastic adhesives are convenient, safe and highly reliable. These are based on poly-vinyl acetate (PVAC). They generally have less resistance to heat, moisture, and long- term static loading to do thermosetting polymers. Common wood adhesives that are based on thermoplastic polymers include polyvinyl acetate emulsions, contacts, hot-melts etc. (Vick, 1999).

2.2.1.2. Natural adhesive

Before synthetic adhesives were introduced in the 1930s, adhesives made from natural polymers found in plants and animals were used for bonding wood. These adhesives were made from animal blood, hide, casein, starch, soybean, dextrin and cellulose. While natural adhesives are still being used in some non structural products, they do not provide the necessary strength and durability required for engineered wood products.

Some natural options may some day replace or supplement synthetic resins. Tannins, which are natural phenols, can be modified and reacted with formaldehyde to produce a satisfactory resin. Resins have also been developed by acidifying spent sulfite liquor, which is generated when wood is pulped for paper. In the manufacture of wet- process fiberboard, lignin, which is inherent in lignocellulosic material, is frequently used as the resin (Suchland and Woodson, 1968). Except for two major uncertainties. UF and PF systems are expected to continue to be the dominant wood adhesives of lignocellulosic composites. The two uncertainties are the possibility of much more stringent regulation of formaldehyde- containing products and the possibility of limitations to or interruptions in the supply of petrochemicals.

2.2.2. Other additives

Additives are mainly used to improve the certain properties of fiber board such as moisture repellency, fire retardency etc. Following additives are mainly used –

Paraffin wax or Wax emulsion: This additive is generally used in small amount (1% or less) for imparting liquid-water repellency to the board.

Fire retardants: Firer retardants are used to improve the fire resistance capacity of the board. Ammonium borate, phosphate and sulphate, diamonium phosphate and orthophosphate, zinc chloride and borate, boric acid and borax etc. are used single or in combinations, as fire retardants.

Preservatives: Bio-deterioration is a major problem. So to avoid this, fungicides and/ or insecticides are added to the board for protection.

Hardener: Hardener is a substance or mixture of substances added to an adhesive to promote or control the curing reaction by taking part in it. It is usually required to convert synthetic adhesives from liquid to solid (Selbo, 1975). The most common hardener used in manufacturing fiber board, composite board and particle board is Ammonium Chloride. The addition of 2% or more of Ammonium Chloride (NH_4Cl) reduces the formaldehyde release. The reduction with increasing NH_4Cl is due to combination of ($-NH_4$) groups with formaldehyde to produce hexamethylenetetramine (hexamine). Increasing the proportion of buffering ammonia (i.e. NH_3) also reduces formaldehyde release due to the same reason. Excessive levels of hardener will increase the danger of short storage life and increase procures. Increased buffers, beyond an optimum limit, endanger the resins fast cure rate thereby adversely influencing the strength and dimensional properties of the board. The reaction of Ammonium Chloride (NH_4Cl) with Urea formaldehyde (UF) in this particular Instance will release hydrochloric acid (HCl), hexamethylenetetramine (hexamine) and water as shown bellow:

$$4\ NH_4Cl + 6HCHO \longrightarrow 4HCl + 6H_2O + (CH_2O)^6N_4$$

Filler or extender: Fillers are relatively non adhesive substances added to an adhesive binder to improve working properties, permanence, strength, or other qualities. Usually fillers are either lingo-cellulosic or inorganic in nature and are often added to reduce costs (seller's et al., 2005)

Buffers: Buffers are added for increased storage life of adhesive and to prevent procures (Salehuddin, 1992).

2.3. Some information of Water hyacinth (*Eichhornia crassipes)*

2.3.1. General description

Vernacular name: Water hyacinth, tagar, shaola

Taxonomy

Domain: *Eukaryota* – Whittaker & Margulis, 1978 – eukaryotes

Kingdom: *plantae* – Haeckel, 1866 - plants

Clade : *Angiosperms*

Clade: *Monocots*

(Unranked): *Commelinids*

Order: *Commelinales*

Family: *Pontederiaceae*

Genus: *Eichhornia*

Species: *E. crassipes*

Binomial name

Eichhornia crassipes (Carl Linnaeus in 1753)

Description:

Water hyacinth is one of the world's worst aquatic weeds. It infests rivers, dams, lakes and irrigation channels on every continent except Antarctica. It devastates aquatic environments and costs billions of dollars every year in control costs and economic losses. The Water Hyacinth has special adaptations to allow it to grow and spread rapidly in freshwater. They can withstand extremes of nutrient supply, pH level, temperature, and even grow in toxic water. They grow best in still or slow-moving water. Water hyacinth plants grow floating on the water surface, forming stolons. Plants have very prominent black, stringy roots. Plants sometimes grow stranded in mud and appear rooted.

Water Hyacinths are the only large aquatic herb that can float on the water unattached to the bottom. They float on bloated air-filled hollow leaf stalks which give them their Malay name that means "pregnant tuber". Their roots trail underwater in a dense mat. Water hyacinth is justifiably called the world's worst aquatic weed due to its ability to rapidly cover whole waterways. Water hyacinth grows in still or slow-flowing fresh water in tropical and temperate climates. Optimum growth occurs at temperatures of between 28°C and 30°C, and requires abundant nitrogen, phosphorus and potassium. Although this plant will tolerate a wide range of growth conditions and climatic extremes including frost, it is rapidly killed by sea strength salinity and will not grow in brackish water.

Water hyacinth will rapidly take over an entire waterway. Under favorable conditions it can double its mass every 5 days, forming new plants on the ends of stolons. It also grows from seed which can remain viable for 20 years or longer. Shoeb and Singh (2000) reported that under favorable conditions water hyacinth can achieve a growth rate of 17.5 metric tons per hectare per day. This enormous reproductive capacity causes annual reinfestation from seed and rapid coverage of previously treated areas, making ongoing control necessary. The mats of plants also block sunlight from entering the water, shading submerged plants. The thick mats also crowd out other aquatic plants. Water hyacinth uses up most of the available oxygen in water, killing fish. The fast-growing Water Hyacinth soon becomes a noxious weed outside its native habitat. Plants interlock in such a dense mass that a person could walk on a floating mat of them from one bank of a river to the other. The presence of water Hyacinth disrupts all life on the water.

Geographical distribution:

Water hyacinth is native to the Amazon basin in South America. Water Hyacinth was introduced from its native home in South America to various countries by well-meaning people as an ornamental plant; to the US in the 1880's; to Africa in the 1950's spreading to the Congo, the Nile and Lake Victoria; also in India.

Fig 2.2: Photos of water hyacinth

Botanical feature:

The leathery leaves appear basal, are suborbicular, ovate or broadly elliptic with parallel veins; bases are heart shaped, square, or rounded, apices rounded or flattened. Petioles are usually spongy-inflated. The inflorescence is a spike with light-blue to bluish-purple showy flowers marked with yellow streaks. The fruit is many seeded. The seeds are dispersed by birds and can remain viable for 15-20 years. But the main method of reproduction is vegetative, through stolons. A single plant under ideal conditions can produce 3,000 others in 50 days, and cover an area of 600 sq meters in a year. Mat forming, floating plant Spongy, waxy and glossy leaves Doubles its population in as little as 12 days 95% water, has a fibrous tissue is similar to the native frog's – bit, limnobium spongia.

Reproduction includes

• Sexual—seeds

• Asexual– over wintering stems and the creation of daughter plants

Leaves

Leaves are smooth, hairless and glossy. They are generally a bright green color and can be tinged a rusty yellow on their edges. There are two types of leaves.

- Leaves with non-bulbous petioles. Leaves are up to 60 cm long (including the petiole), narrow and erect – this leaf type is typical of plants in dense, crowded infestations.
- Leaves with bulbous petioles. Leaves are thick stemmed, circular and up to 30 cm in diameter. The stems may be 50 cm long and contain variable amounts of air, which enable the plant to float. This leaf type is typical of plants in open water or on the open-water edge of large infestations.

Stems

There are two types of stems:

- erect stems up to 60 cm long, with flowers,
- horizontal vegetative stems (stolons) 10 cm long, which produce new daughter plants.

Seeds

Seeds are 1 to 1.5 mm long and roughly egg-shaped, with ridges from end to end. They are long-lived and may survive in mud for up to 20 years. Seeds have also remained viable over very long periods in dry soil.

Roots

Roots are fibrous and featherlike. In deep water they may trail below the plant and can be up to 1 m in length. In shallow water the roots may take hold in the substrate of mud or sediment.

Flowers

Flowers are 4 to 7 cm across, funnel-shaped, light bluish-purple or dark blue with a yellow centre and have six distinct petals. The upper petal is darker purple with a yellow mark in the centre. Flowers can self-fertilize and are formed on upright stems with between 3 and 35 (but commonly 8) flowers on each spike.

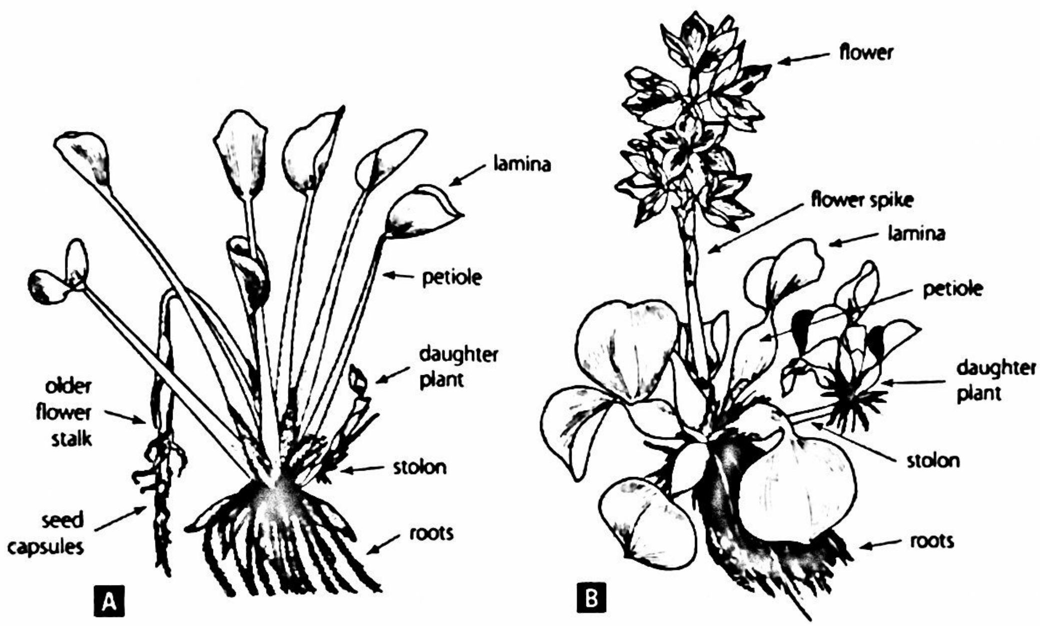


Fig 2.3: Water hyacinth

Water hyacinth can show variation in form depending on growth conditions (Julien, Griffiths & Wright 1999).

Life cycle

Water hyacinth reproduces from seeds and horizontal stems. Flowers open for only one or two days from mid to late summer before beginning to wither. When all the flowers on a spike have withered, the stalk gradually bends into the water and after two to three weeks the seeds are released and sink. Autumn and winter frosts cause the leaves to die off but the crowns are able to overwinter. These will commence new growth in the following spring along with the germination of seeds.

Spread

Water hyacinth infestations increase most rapidly by the production of new daughter plants. During high water flows and flooding, infestations can break up and be moved to new locations. Most spread can be attributed to human activity such as the deliberate planting of water hyacinth in ornamental ponds or dams. Unwanted aquarium plants that are discarded into waterways are a major form of spread. Water hyacinth can also be spread by contaminated boating equipment. Seeds are the main source of new infestations and are carried in water, mud (e.g. on machinery or boots) and by birds

How water hyacinth dispersed in the world?

Water hyacinth originally comes from South America. In the last two centuries, water hyacinth has spread throughout the tropics. People like the purple bloom to decorate their gardens, so they bring it with them when they move around the world. The Water Hyacinth was introduced from its native home in South America to various countries by well-meaning people as an ornamental plant; to the US in the 1880's; to Africa in the 1950's spreading to the Congo, the Nile and Lake Victoria; also in India.

Identifying Characteristics

Size/Form: Water hyacinth is an emergent, aquatic perennial, with thick, spongy leaves and spike-like floral stalks, which may grow up to 3' (feet) tall. The plants have fibrous, black roots.

Leaves: The leaves are simple, alternately-arranged and oval to elliptical, with a sub-circular base. The thick, leathery, spongy leaves often curl inward around the leaf base. Venation is parallel.

Fruit: The fruit is a three-celled capsule, containing many, small seeds. The flowers are loose, spike-like clusters of tiny lavender blossoms, borne on upright stalks.

Stem: The stem is thick and spongy, with an inflated bulb visible on the lower stem.

Habitat: Water hyacinth grows in shallow, fresh water wetlands. It is often seen in pure stands along the edges of ponds, lakes, canals, ditches and slow-moving streams.

2.3.2. Positive and Negative impacts Water hyacinth

2.3.2.1. Negative impacts Water hyacinth:

Water hyacinth grows fast from seeds and from shoots that break off and grow into new plants. The number of plants doubles every 5 to 15 days, so in a single season, 25 plants can multiply up to 2 million! This means that if water hyacinth gets into a new river or lake, it grows and grows until it covers the water with a thick floating mat of tangled weed. It is a global problem which affecting approximately 56 countries currently. The United States is struggling with this plant. In The United States Florida, Louisiana and Texas spend approximately $11 million every year controlling this plant. This causes terrible problems for people using the waterway. So the problems are summarized bellow-

- blocking irrigation channels and rivers
- restricting livestock access to water
- destroying natural wetlands
- eliminating native aquatic plants
- reducing infiltration of sunlight
- changing the temperature, pH and oxygen levels of water
- reducing gas exchange at the water surface
- increasing water loss through transpiration (greater than evaporation from an open water body)
- altering the habitats of aquatic organisms
- restricting recreational use of waterways
- reducing aesthetic values of waterways
- reducing water quality from decomposing plants
- destroying fences, roads and other infrastructure when large floating rafts become mobile during flood events, and
- Destroying pastures and crops when large floating rafts settle over paddocks after flood events.
- Fish and other river creatures die because of lack of oxygen. People can no longer go fishing.
- Mosquitoes and other disease-carrying organisms breed in the water hyacinth, making diseases like malaria, schistomiasis and cholera more common.
- Tourists no longer visit the infested area.

2.3.2.2. Positive impacts Water hyacinth:

Though it has a lot of negative impact, similarly it has a light of hope also. In these days of diminishing natural resources, it is boldly proposed that water hyacinth be regarded positively as an abundantly available source of biomass. Seen in this positive light, the excessive growth of water hyacinth is not only to controlled, but can be seen as a resource -

- For use as fertilizer; compost, mulch and ash. The technique of growing vegetables on a raft of water hyacinth. The use as a substrate for growing mushrooms.
- For use as animal feed; as green fodder, hay, silage and leaf protein concentrate. For use as feed for farm animals and fish.
- For making rope, and then a range of crafts and furniture.
- For use as fuel; burning in the hearth, making briquettes, producing biogas.
- For making paper and boards.
- For other village scale uses.
- For larger scale use - possibilities for industrial manufacture of building boards, greaseproof paper, cardboard, fuel and electricity, carbon black, food, chemicals, pharmaceuticals and fertilizers.
- For water purification.
- For the production of second-generation bioethanol due to their cellulose ratios and carbohydrate potentials.
- For the use of ornamental purpose.
- Animal feed, organic fertilizer for farms and gardens, biogas production, fuel briquettes, and craft-making are among the list of possible uses.
- Women at the WHUP (Water Hyacinth Utilization Project) in Kenya are making money from the menace, selling handmade water hyacinth chairs, tables, baskets, shades, paper, books, and cards.
- They are also used in traditional medicine as their root and leaf extracts are known to cure certain diseases (swelling, burning, hemorrhage, and goiters).
- They are also used to treat certain inflammatory conditions of veterinary animals.
- They are also used as a vegetable crop (leaves, petiole and flowers) in some parts of the world (Phillipines, Java) and are known to be rich in carotene, protein and carbohydrates.

- The green biomass can be used as an animal fodder and also used to make hay and silage (Lindsey and Hirt, 1999a).
- They are also used in furniture manufacture, which are in high demand and available through online stores (typical examples, http://www.balifurnish.com and http://www.whup.20m.com).
- They are also used to manufacture building board. They can be also used in processing coffee beans and even as laundry detergents (Hassan et al., 2006).
- Further they can be used in paper production and also in grease- proof papers manufacture (De Groote et al., 2003).
- They are used as briquettes for cook stoves. Rural folks also use the plant to manufacture rope or coir.
- In some South Asian countries they are used to make floating vegetable gardens. Water hyacinths can be used in reclamation of water bodies containing high levels of lead and mercury.
- Al Ramalli et al., (2005) have demonstrated that even dried hyacinth roots are very effective in removing arsenate from the contaminated water system.
- Water hyacinths also provide food sources to aquatic fauna like snails, fish, crabs etc.
- Water Hyacinth can be brought to make compost, mulching and to clean the sewage. It is a good way to change waste products into useful things.

2.3.3. Biological Attributes of Water Hyacinth

Attributes of Water Hyacinth are:

1. Naturally grown vegetation, preferably perennials.
2. High cellulose with low lignin content per unit volume of dry matter.
3. Easily degradable.
4. Should not compete with arable crop plants for space, light and nutrients.
5. Resists pests, insects and disease.
6. Not prone to genetic pollution by cross breeding with cultivated food crops.

2.3.4. Status of the Water hyacinth Resources in Bangladesh:

Water hyacinth is one of the world's worst aquatic weeds. In Bangladesh it is considered as aquatic weeds also. Bangladesh is a riverine country. A lot of rivers, canals, lake have crissed crossed in our country. In Bangladesh there is no any special use of water hyacinth. Some times it is used in fodder or manufacturing compost manure. But this proportion is very little. So a vast portion of water hyacinth remains unused, rather it creates different problems for the water body. So water hyacinth can play a vital role for a vast source of lingo-cellulosic material especially in Bangladesh.

2.3.5. Chemical properties of water hyacinth

Biomass composition of water hyacinth:

Water hyacinth is low in lignin content (10%) and contains high amounts of cellulose (20%) and hemicellulose (33%) (Bolenz et al.1990, Poddar et al. 1991, Gressel 2008). Average biomass compositions of water hyacinth are here

Table 2: Average biomass composition of water hyacinth

Components	% composition
1. Lignin	10
2. Cellulose	25 or 25.24
3. Hemicellulose	35 or 16.50
4. Ash	20
5. Nitrogen	03
water hyacinth fiber length	1.53 mm (according to Zerrudo et al. 1978),
cell wall thickness	1.6 µm (according to Onggo and Tri Astuti (1998)'Erwinsyah *et al.* (1998), Onggo and Tri Astuti (2003b))

Source: Adapted from Poddar et al (1991); Gunnarsson and Petersen (2007).

Aquatic plants like water hyacinth are naturally low in lignin content and they grow at a rapid pace (Ripley et al. 2006;). Gunnarsson and Petersen (2007) estimated the presence of lignin in aquatic plants at less than 10%.

Mineral composition of fresh water hyacinth:

Water Hyacinth can absorb metals like copper and lead from industrial sewage and living place sewage. It also can absorb mercury and lead melt in the liquid. Mineral composition (Dry Matter = DM) of fresh water hyacinth are given below

Table 3: Mineral composition (DM) of fresh water hyacinth (g/100g DM)

Macro mineral	(g/100gDM)	Micro minerals	Mg/kg
Calcium	3.08	Manganese	1738.69
Phosphorus	0.28	Iron	2387.98
Magnesium	0.65	Copper	10.97
Potassium	4.13	Zinc	69.18
Sodium	0.13	Cobalt	3.03
		Lead	5.83

Fiber fractions of fresh water hyacinth (g/100g DM):

Table 4: Fiber fractions (g/100g DM) of fresh water hyacinth

Parameters	(g/100g DM)
Neutral detergent fiber	44.50
Acid detergent fiber	28.00
Acid detergent lignin	2.76
Hemicellulose	16.50
Cellulose	25.24

Here, DM = Dry matter

Table 3 reveal the fiber fractions of fresh water hyacinth. The value of Hemicellulose and cellulose were 16.50 and 25.24 g/100g DM respectively. The neutral detergent fiber (NDF) value of 44.50 g/100g DM obtained is lower than 56.29 g/100g DM reported by Mako and Akinwande (2010). Acid detergent fiber (ADF) content of 28.00 g/100g DM compares well with 33.00 g/100g DM obtained by Jantrarotai (1990). Fiber is known to increase with ageing of a plant. Wolverton and McDonald (1976) suggested that the higher content of fiber in older hyacinth could be a result of increased cellulose content.

Proximate composition of water hyacinth:

Table 5: Proximate composition (g/100g DM) of fresh water hyacinth

Parameters	(g/100g DM
Dry matter	9.84
Crude protein	10.01
Crude fibre	22.75
Ether extract	11.89
Ash	14.98
Nitrogen free extract	40.44

Table 4 is the proximate composition of water hyacinth. The crude protein of 10.01 g/100g reported in the present study compares with 10.20 to 12.80 g/100g reported by Dada (2002) and Mako and Babayemi (2008). The differences in crude protein may have resulted from age variability of water hyacinth. As water hyacinth ages, protein content decreases (NAS, 1976). The concentration of most chemicals in aquatic species varies when harvested at similar stages of maturity but from different sites or environment (Boyd, 1979; cited by Okoye *et al.*, 2002).This variation could be due to differences in the age of plants from one location to another. Ash content could decline as plants age because of probable increase in cellulose content. Ash represents inorganic matter which mainly includes plant minerals. High content of ash in water hyacinth is probably due to accumulation of minerals absorbed from water. Boyd (1968) found that floating aquatic plants contained very large quantities of ash similar to levels in submerged plants. Water hyacinth naturally absorbs pollutants including toxic chemicals like lead and others as well as some organic compounds believed to be carcinogenic in concentrations 10,000 times than in the surrounding water (National Academy of Science, 1976). Since the normal ash content of most legume grass forages is about 9.0 g/100g DM (Hoffman, 2010) the level in water hyacinth could be said to be high indicating availability of minerals to livestock fed water hyacinth. This is an indication that WH will supply the mineral requirements for animals. The macro and micro mineral content of WH are higher than the conventional forages.

CAPTER THREE

MATERIALS AND METHOD

3.1 Manufacturing of fiberboards:

3.1.1 Raw materials collection:

At the beginning of manufacturing of fiber board, raw material was collected. We collected water hyacinth as a raw material from the Khulna University campus (22° 48' 0" N and 89° 33' 0" E), Khulna, Bangladesh. In the Khulna University campus raw material were collected in front of the central library near the 3rd academic building. For raw material collection only bigger size water hyacinth was taken for easy handling and transportation.

Fig 3.1: Green water hyacinth

3.1.2 Preparation of raw material:

For raw material preparation root and leaves of the water hyacinth was discarded and only the petiole of the leaves of water hyacinth was taken. Then the petiole of the leaves of water hyacinth were washed and cut into chips as 1.0 – 1.15 inch. Then the chips were dried on open air. Then the chips were preceded to the fiber preparation stage.

Fig 3.2: Sized, dry raw material

3.1.2.1 Fiber preparation:

Sodium hydroxide solution should require for fiber preparation. Sodium hydroxide should mix with water to make 20% sodium hydroxide solution. Water hyacinth (dried or green) was submersed and cooked for 4 hours in 20% sodium hydroxide solution so that

Fig 3.3: Dry isolated

the internal bonding within the fibers is loosened. After 24 hours the fibers were collected from the solution. The fibers were washed with water for several times to remove Sodium hydroxide solution from the fiber.

3.1.2.2 Drying of fiber:

The fibers were dried on oven at 95°c for 24 hours. Oven machine is used in this case. The fibers were sorted manually to remove the united fibers.

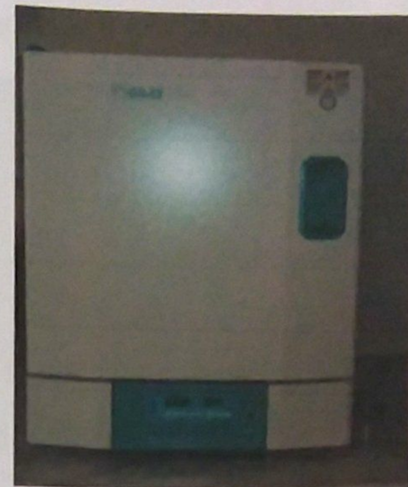


Fig 3.4: Picture of Oven machine

3.1.3 Adhesive preparation and blending:

Urea formaldehyde (UF) is one of the most common adhesives for assembly of fiber board manufacturing. Urea formaldehyde (UF) resin is the main ingredient of the adhesive. Flour as extender and Ammonium Chloride (NH_4Cl) as hardener were used in the adhesive. At first UF resin was poured into the water and mixed manually with spoon for 20 minutes. Then flour was added into the mixture and mixed properly for another 7 minutes. After which the hardener was added to the mixture and agitated for 3 minutes with a total mixing period of 30 minutes. The composition of the adhesive solution was as follows –

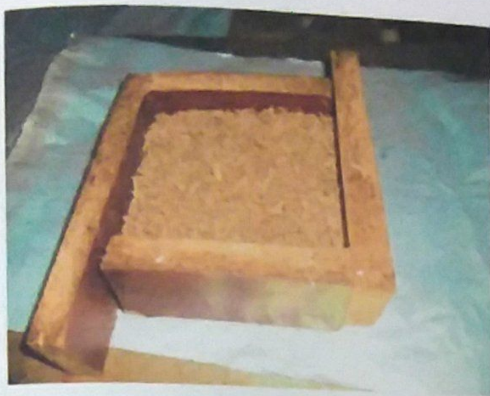
Table -6: The composition of the ingredients in the prepared adhesive

Ingredients	**Percentage (%)**
Urea formaldehyde (UF)	35
water	55
Flour	9.5
Ammonium Chloride (NH_4Cl)	0.5
Total	100

After adhesive preparation, the adhesive was mixed with fibers by hand. Adhesive was used at 20% of the weight of fibers.

3.1.4 Mat formation:

The glued fibers were then kept on a steel sheet to make a mat of fibers. The mat should be the five times of the fiber board. So the mat will be 15 mm if the target board is 3 mm.



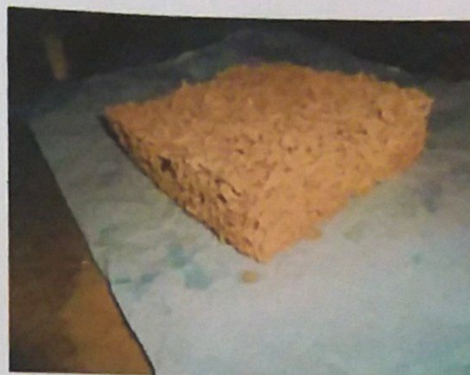


Fig 3.5: Mat formation

3.1.5 Hot pressing:

The hot press is a machine where pressure is created with a hydraulic jack and at the same time the temperature increases. The mat was covered with another steel sheet and then inserted manually into the hot press for pressing. Before keeping the mat into the hot press, switch on the hot press to raise temperature at 140 degree centigrade. Then the pressure was raised by hydraulic jack. Pressure depends on a number of factors, but it is usually in the range of 1.37 to 3.43 MPa (199 to 498 lb/in2) for medium-density boards (Youngquist,1999).

Fig 3.6: Hot press machine

The temperature was raised to a maximum of about 140˚c after proceeding 10 minutes. The pressure was 2 MPa and continued for 7 minutes with an increasing temperature. Then the board was kept 30 minutes for cooling and keeping the same pressure, so that the board may balance with environmental condition.

3.1.6 Trimming:

After the board is manufactured, the edges of the board are trimmed with the fixed type circular saw. The well pressed boards are then cut into standard sizes to test the boards.

Trimmed board

Prepared board

Fig 3.7: Prepared board and Trimmed board

3.1.7. Flow chart of the board formation process

Flow chart of the process

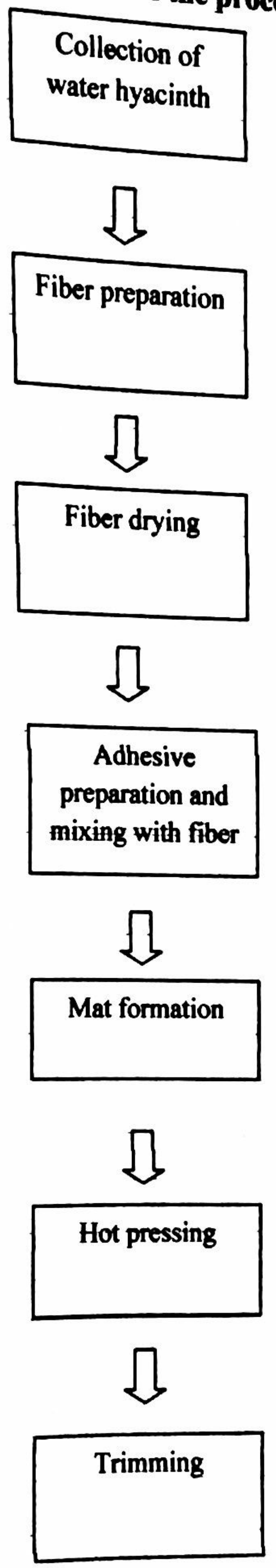


Fig 3.8: Flow diagram of fiberboards production

3.2. Preparation of samples for testing

Three replications of each type of boards were manufactured as stated earlier. For testing physical properties, three samples were collected from each board of each type. So the total number of sample was nine (9) for each type of particleboard for testing of physical properties. The Density and Moisture Content were determined on the same nine (9) samples and the Water Absorption, Thickness Swelling and Linear Expansion were determined on the other nine (9) samples. For testing mechanical properties, three samples were collected from each board of each type. So the total number of sample was nine (9) for each type of fiberboard for testing of mechanical properties. The MOR and MOE were determined on the separate samples. The dimension of samples for testing the physical properties was approximately (50 mm x 35 mm x 5mm) and for testing the mechanical properties was approximately (150 mm x 50 mm x 5mm).

3.3. Laboratory tests

The laboratory tests for characterization of physical properties and mechanical properties for each type of particleboards were carried out respectively in the Wood Technology Laboratory of Forestry and Wood Technology Discipline of Khulna University and in the Laboratory of Civil Engineering Department of Khulna University of Engineering and Technology, Khulna. The properties were tested according to the procedures defined in the American standard for Medium Density fiberboard (ANSI A208.2–2002) (CPA, 2002) as well as the Indian standard for particleboards (IS: 3087-1985) (Anon, 1985).

3.3.1. Determination of physical properties

All the samples are cut into (50 mm x 35 mm) dimension for testing physical properties. The laboratory test for characterization of physical properties is carried out in the Pulp and paper laboratory of Forestry and Wood Technology Discipline, Khulna University, Bangladesh. At first all the specimens are weighted and green dimension are taken at room temperature. Then all the samples are kept into oven for 24 hours. After drying oven dry weight and dry dimension are also measured. Next, the samples are soaked into water for 24 hour. Finally, the wet dimension are taken and all the physical properties are calculated by using following formula-

3.3.1.1. Density

Density of each sample was measured in the Wood Technology Laboratory of FWT Discipline of Khulna University, Khulna. Density was calculated with the following formula-

$$\rho = \frac{m}{v}$$ (Desch and Dinwoodie, 1996)

Where, ρ = Density in gm/cm^3; m = Mass of the sample in gm and v = Volume in cm^3.

3.3.3.2 Moisture content

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

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

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

3.3.3.3 Water absorption

Water absorption is defined as the difference in weight before and after immersion in water and expressed in percentage. The water absorption was calculated by the following formula-

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

Where, A_w = Water absorption (%), m_2 = The weight of the sample after (24 hr.) immersion in water (gm), m_1 = The weight of the sample before immersion in water (gm).

3.3.3.4 Thickness swelling

Thickness swelling was calculated by the following formula-

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

Where,

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

3.3.3.5 Linear expansion

The Linear Expansion was calculated by the following formula-

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

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

3.3.2. Determination of mechanical properties

According to the procedure of ASTM standard D-1037, all samples were carefully prepared and tested to evaluate the physical and mechanical properties of this fiberboard. For fiber board generally its length is cut into 20 times more than its thickness. Mechanical properties were measured by using universal testing machine (E.L.E. LTD; 1155 – 3 – 1239; 2KN) according to the ASTM standard. The laboratory tests for characterization of mechanical properties of fiberboard were carried out in the Laboratory of Geotechnical Engineering of Civil Engineering Department of Khulna University of Engineering and Technology, Khulna, Bangladesh. The sample size was 150 mm × 50 mm × 5 mm for mechanical properties determination.

3.3.2.1 Modulus of rupture (MOR)

Modulus of rupture (MOR) was measured with the Universal Testing Machine (UTM), model: WE-100, made by Time Group Inc. in the Laboratory of Civil Engineering Department of Khulna University of Engineering & Technology, Khulna.

The MOR was calculated from the following equation-

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

Where, *MOR* is the modulus of rupture in (N/mm^2), *P*= Load in N, *L*= Span length in (mm), *b*= width of test sample in (mm), *d*= Thickness of test sample in (mm).

3.3.3.2 Modulus of elasticity (MOE)

The Modulus of elasticity (MOE) was also measured with the Universal Testing Machine (UTM) in the Laboratory of Civil Engineering Department of Khulna University of Engineering & Technology, Khulna. The modulus of elasticity (MOE) was calculated from the following equation-

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

Where, *MOE* is the modulus of elasticity in (N/mm^2), P' is the load in N at the limit of proportionality, L is the span length in (mm), Δ is the deflection in mm at the limit of proportionality, b is the width of sample in (mm), d is the thickness/depth of sample in (mm).

3.4. ANALYSIS OF DATA

All the data, produced during the laboratory tests for characterization of physical and mechanical properties of each type of fiberboard, were analyzed by using Microsoft Office Excel 2007; SAS (Statistical Analysis System) software; ANOVA (Analysis of Variance); LSD (Least Significant Difference) and SPSS (Statistical Package of Social Survey) software to analyze the data.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1. The physical test

There is a significant difference of physical properties (Density, moisture content, water absorption and thickness swelling) among different types of fiber board. In describing these properties of boards, here we considered 5 mm water hyacinth fiberboard as (S_5) and 5 mm medium density fiberboard collected from market as (S_m). The result and discussion of physical properties among different types of fiber board are explained below –

4.1.1. Density

It was found that the density of water hyacinth board (S_5) was 0.78 gm/cm^3 and medium density market board 0.75 gm/cm^3

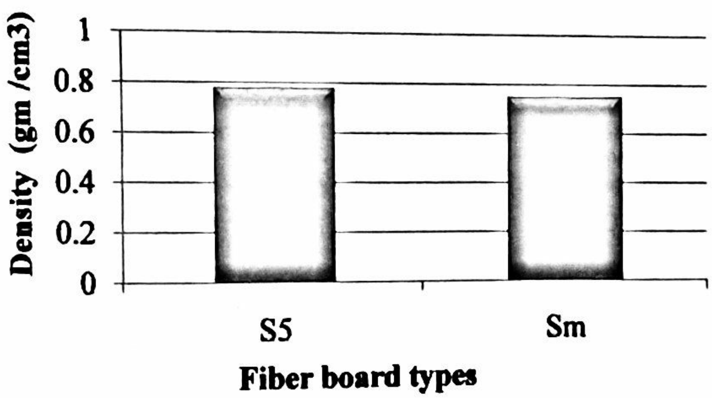


Fig 4.1: Density of water hyacinth fiberboard (S_5) and market fiberboard(S_m).

In this study, it is obvious that 5 mm fiberboard of water hyacinth (S_5) is denser than market fiberboard (S_m). Medium density fiberboard has a density between (0.65 – 0.80) gm/cm^3 and can be produced both with and without wax and sizing agents (Berglund and Rowell, 2005; Youngquist, 1999). So this variation (density) may be due to the raw materials used, raw materials chemical constituent, fiber length, types of adhesive applied, moisture content of the board, intense of pressing, hot pressing condition and many other factors interact to create variability of density among the boards.

4.1.2. Moisture content

Moisture content is a vital physical property that causes change of other physical and mechanical properties of the boards. From the test the moisture content was 10.28% in (S_5) and 10.03 % in (S_m).

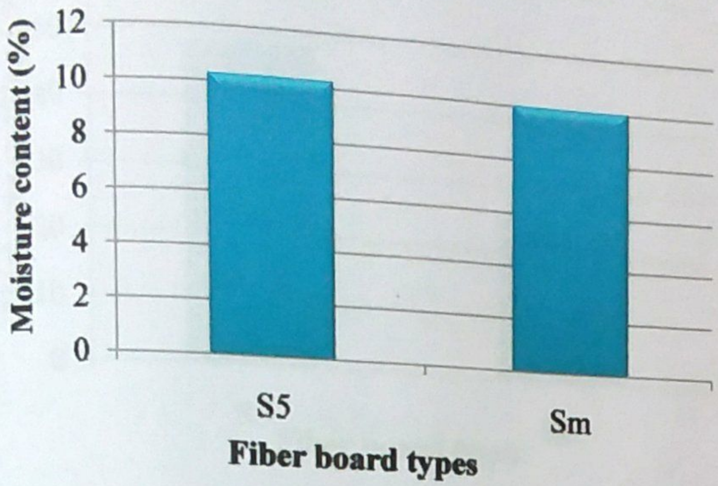


Fig 4.2: Moisture content (%) of water hyacinth fiberboard (S_5) and market fiberboard(S_m).

We observed differences in moisture between water hyacinth fiberboard (S_5) and market fiberboard(S_m). According to the ANSI (1999) standard, the mean moisture content of the board will be (4% - 13%). Here market wood fiberboard showed less moisture content value than water hyacinth fiberboards. This variation within the boards may due to the types of materials used, its fiber characteristics, and chemical behavior of fibers, fiber dispersion, glue dispersion and characteristics of the glue.

4.1.3. Thickness Swelling

In this study, the thickness swelling found of the boards (S_5 and S_m) is 48.41% and 25.15% respectively after 24 hours soaking period in the cold water.

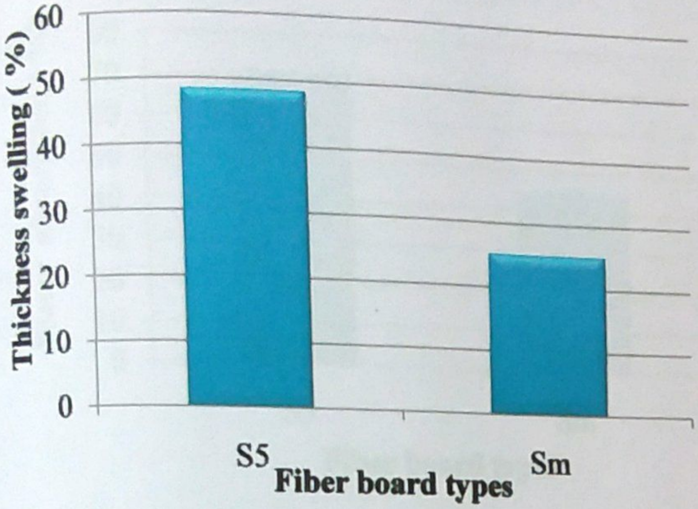


Fig 4.3: Thickness swelling (%) of water hyacinth fiberboard (S_5) and market fiberboard(S_m).

There was a prominent high variation in the thickness swelling of two categories of fiberboard. Water hyacinth fiberboard exhibits more thickness swelling than market fiberboard(S_m). According to the Australian / New Zealand Standard (AS/NZS 1860.2); the standard value for thickness swelling for the fiberboard is (20 – 30%). So here the thickness swelling of water hyacinth fiberboard is very high. So it can not satisfy the standard. In this case the probable cause may be the fiber is very hygroscopic in nature. No sizing matter like wax or any coupling agent was used. For this reason it absorbs more water than the standard and causes thickness swelling more.

On the other hand the findings of the study indicated that the density of the fiber board's affected the mean thickness swelling percentage of most of the produced fiber boards. Mean thickness swelling differed according to fiber board types, fiberboard density and fiber's affinity to absorb water. Thickness swelling of fiber board's depends on several factors including insufficient resin content and distribution, furnish moisture, poor compability of the adhesive used, chemical composition of fibers, fiber volume fractions etc. (Akgul *et. al.*, 2010)

4.1.4. Water absorption

The water absorption of the water hyacinth fiberboard (S_5) and market fiberboard(S_m) was 71.03% and 45.25% respectively after 24 hours soaking period in cold water.

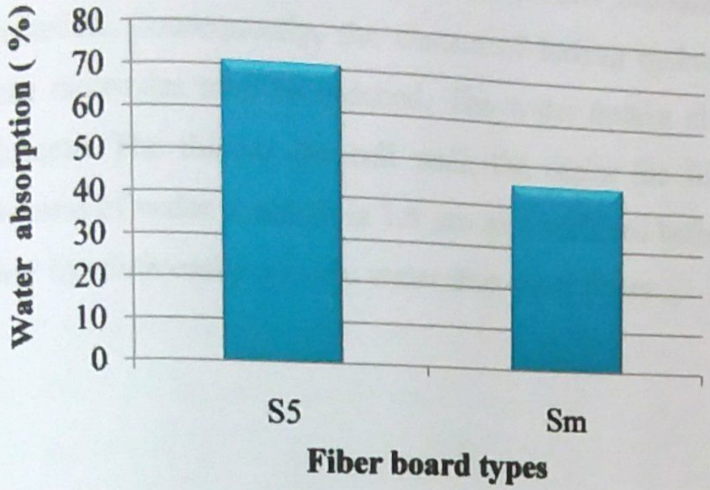


Fig 4.4: Water absorption (%) of water hyacinth fiberboard (S_5) and market fiberboard (S_m).

In the above graph (Fig 4.6), there is a variation of water absorption among these two types of fiberboards. S_5 fiberboard exhibits more water absorption capacity (71.03%) than S_m (45.25%).

The water absorption values of the fiberboards differed according to density. Significantly less water was held by the fiberboards when fiberboard's density decreased. Denser water hyacinth fiberboards having a great amount of fibers and when the fiberboard is exposed to moisture, the hydrophilic water hyacinth fiber swells. Due to the presence of free –OH group in the molecular structure, cellulose and hemicelluloses are responsible for water absorption as reported by Wardrop. In-addition Skaar found that hygroscopicity of hemicellulose is higher than the cellulose and lignin. Water hyacinth contains higher hemicellulose (35%) than cellulose (25%). As a result of fiber swelling, micro cracking of the adhesive occurs. The high cellulose content in water hyacinth fiber, further contributes to more water penetrating into the interface through the micro cracks induced by swelling of fibers (Dhakal *et al.*, 2006). The fibers within the boards loosen, that is why more space created. So this water hyacinth fiberboard absorbs more water. The fiber volume fractions, the fiber chemical characteristics, temperature of water and water absorption time have influence on water absorption capacity. The absorption of water depends mostly on the fiber quality. As the fiber loading increased the cellulose content increased, which in turn resulted in the absorption of more water. George *et al*. have reported that the hydrophilicity of the fibers can be reduced by a suitable chemical treatment. In the presence of a coupling agent, the water uptake was reduced as better interfacial bonding was established. As a result of the chemical treatment, the hydroxyl group of the cellulose reacted with the functional group of the coupling agent, which in turn bonded to the polymer matrix and thus established a good fiber/matrix bonding interaction. Consequently, the chance of having hydroxyl groups come into contact with water molecules may be reduced. The water uptake ability also relates with the cell wall thickness. The thinner the cell wall, the easier the fiber to absorb water. The cell wall thickness of water hyacinth is 1.6 µm as mentioned before (Table – 2, pg 23). Consequently water hyacinth easily absorbs water than other fibers.

4.2. Mechanical test

The mechanical test is the static bending test which includes Modulus of Rupture (MOR) test and Modulus of Elasticity (MOE) test. These are discussed below –

4.2.1. Modulus of Rupture (MOR) test

The modulus of rupture of two categories of fiberboard (S_5 and S_m) is 31.25 N /mm² and 31.15 N/mm² respectively.

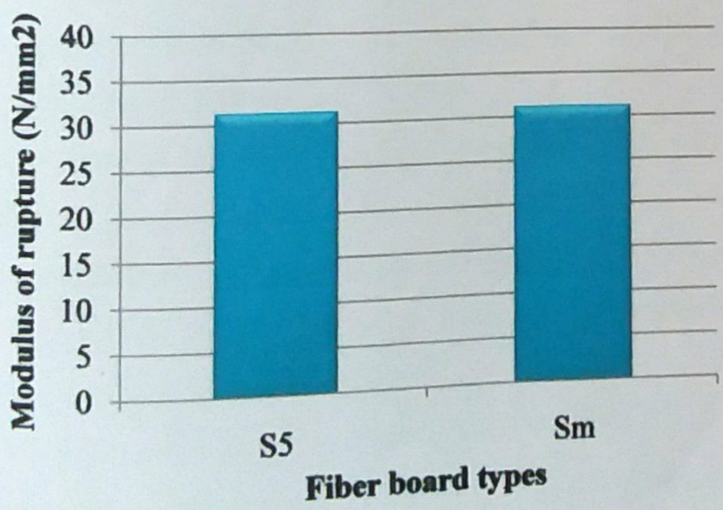


Fig 4.5: Modulus of Rupture (N/mm^2) of water hyacinth fiberboard (S_5) and market fiberboard (S_m).

This result represented variability of MOR among two categories of fiber board. According to ANSI A208.2–2002 the MOR of standard Medium Density Fiberboard [Thin Board (Thickness ≤ 9.5 mm) MDF] for interior application is 31 N/mm² which is determined in accordance with ASTM D 1037 – 96a Part B Test methods. Here S_5 fiber board (31.25N /mm²) shows a higher MOR than S_m (31.15 N /mm²). So the MOR of the water hyacinth fiberboard (S_5) is more than the standard requirement (31 N/mm²). It is observed that with the increases of the density, the MOR increases (Xie et. al., 2011). Here the density of the water hyacinth fiberboard and market fiberboard (S_5 and S_m) is (0.78 gm/cm3 and 0.75 gm/cm3) respectively and their corresponding MOR value is (31.25 N /mm² and 31.15 N /mm²) as orderly. The specific MOR of the two boards (S_5 and S_m) is (40.06 N /mm² and 41.53 N /mm²) respectively, which are very close to each other.

The MOR also depends on the raw materials used, the inherent properties of fiber and spatial arrangement of fibers (Xie et. al., 2011). Micro-fibril in fiber was strongly linked due to the fiber hydrogen bonding that makes fiber hardly dispersed each other easily. So it may affect the mechanical properties of the board like Modulus of rupture (MOR) and Modulus of elasticity (MOE). It also depends on chemical constituents of fiber, fiber volume fraction, moisture content of the boards, the nature and extent of the adhesives.

4.2.2. Modulus of Elasticity (MOE) test

The modulus of elasticity of two categories of fiberboard (S_5 and S_m) is 3135 N/mm² and 3115 N/mm^2 respectively.

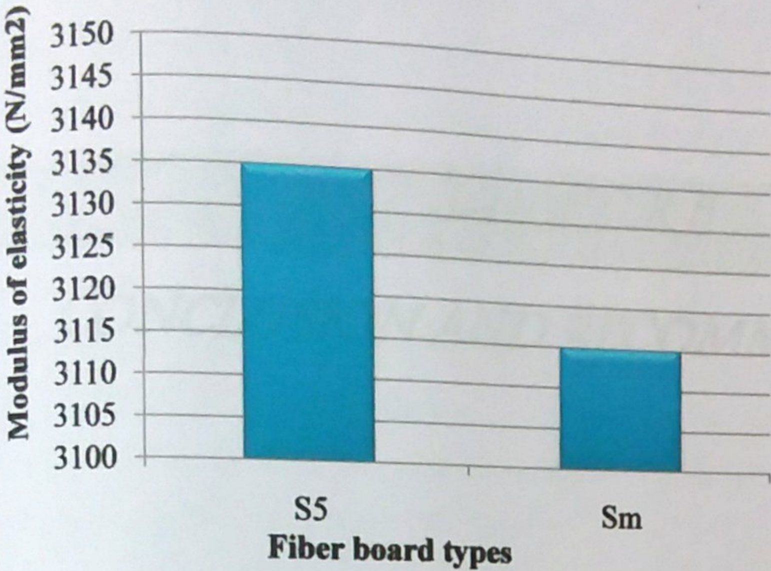


Fig 4.6: Modulus of Elasticity (N/mm^2) of water hyacinth fiberboard (S_5) and market fiberboard(S_m).

This result represented variability of MOE among two categories of fiber board. According to ANSI A208.2–2002 the MOE of standard Medium Density Fiberboard [Thin Board (Thickness ≤ 9.5 mm) MDF] for interior application is 3100 N/mm² which is determined in accordance with ASTM D 1037 – 96a Part B Test methods. Here S_5 fiber board shows higher MOE (3135 N/mm²) than S_m (3115 N/mm²). The specific MOE of the two boards (S_5 and S_m) is (4019 N /mm² and 4153 N /mm²) respectively. It was observed that with the increases of the density, the MOE increased.

MOE is affected by the factors that are the same for MOR. On the other hand Cellulose content of fiber plays an important role in the tensile strength. Cellulose is a homopolysaccharide composed of β-D-glucopyranose unit which are linked together by (1→4)-glycosidic bonds. Cellulose molecules are completely linear and have a strong tendency to form intra and intermolecular hydrogen bonds. Bundles of cellulose molecules are thus aggregated together in the form micro-fibrils, in which crystalline regions alternate with amorphous region. Micro-fibrils build up fibrils and finally cellulose fibers. As consequence of its fibrous structure and strong hydrogen bonds, cellulose has a high tensile strength. Consequently, the higher the cellulose content, the higher the tensile strength.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study investigated the potentiality of using water hyacinth as a raw material for the production of the Medium density Fiberboard (MDF) and its basic physical and mechanical properties. It appears that manufacturing of water hyacinth fiberboard (MDF) is technically feasible for various structural purposes.

Therefore, from the above presented results and discussion the following specific conclusions can be drawn:-

The density of 5 mm water hyacinth fiberboard was 0.78 gm/cm^3 and the moisture content was 10.28%. The water absorption and thickness swelling were 71.03% and 48.41% respectively. The MOR of the water hyacinth fiberboard was 31.25 N/mm^2 and the MOE of water hyacinth fiberboard was 3135 N/mm^2.

The MOR of water hyacinth fiberboards satisfied world standard value (31 N/mm^2) of ANSI A208.2–2002 (According to the test Method of ASTM D 1037 – 96a Part B). The MOE of water hyacinth fiberboards satisfied world standard value (3100 N/mm^2) of ANSI A208.2–2002 (According to the test Method of ASTM D 1037 – 96a Part B).

It has been observed that all the properties of the boards meet the requirements of the international standard like ANSI; ISO; AS/ NZS. Based on the experiment it is also found that the water hyacinth fiberboard shows quite satisfactory results in case of physical and mechanical properties in comparison with the market fiberboard. In future, these types of fiberboards will have a good potentiality to be introduced for commercial purposes.

5.2. Recommendation

Water hyacinth fiberboard has satisfied the physical and mechanical properties of the international standards. It would be better to use different adhesives like Phenol Formaldehyde (PF), Melamine Formaldehyde (MF), Poly vinyl chloride (PVC), Poly-vinyl acetate (PVCA) etc, with different additives like talc, wax, Coupling agents etc. to enhance interaction among the fiber and which may have the ability to reduce the moisture absorbance of the fiber, and thus, could ensure the adequate physical and mechanical properties of fiberboard and also to give new variation to the board manufactured from water hyacinth (*essornia crassipes*). Further study may be conducted in future.

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