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Manufacture of Binderless Particleboard from Kenaf (*Hibiscus cannabinus* L.) core

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Manufacture of binderless particleboard from Kenaf (*Hibiscuscannabinus* L.) core

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This dissertation has been prepared for the partial fulfillment of the requirements of Masters of Science degree in Wood Technology from Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh.

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DECLARATION

I, **Manish Kumar Bala**, Student ID. MS-130502, declare that the thesis is based on my original work except for quotation and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Khulna University or other institutions.

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

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Name of the candidate: **Manish Kumar Bala**

Dedicated To

My Beloved Parents

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Manish Kumar Bala

ABSTRACT

The study was conducted to produce particleboard from kenef core by using conventional hot pressing process. Here different temperature (140^0C, 160^0C, 180^0C, 200^0C) were applied at same pressure (5Mpa) to investigate the optimum temperature as well as time by which particleboard were produced with high mechanical properties. The study found that at 160^0C treated board perform the lowest density ($0.60gm/cm^3$) and 200^0C treated board showed the highest density ($0.92gm/cm^3$). But in case of 200^0C treated board it showed discoloration because of burning. That is why then different hot pressing time(9min,12min,15min) was applied at 180^0C treated board. The study found that 180^0C treated board with 12 minutes hot pressing time performed high mechanical properties as well as physical properties.

CONTENTS

Subject	Page No.
TITLE	i
DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
TABLE OF CONTENTS	vi-viii
LIST OF TABLES	ix
LIST OF FIGURES	x
ABBREVIATIONS	xi
CHAPTER ONE: INTRODUCTION	**1-5**
1.1General introduction	1
1.2 Chemical components of kenef core	2
1.3 Utilization of kenef core	2
1.3.1 Traditional Use of Kenaf	2
1.3.2 Value Added Produces from Kenaf	3-4
1.4 Objectives of the study	5
CHAPTER TWO: REVIEW OF LITERATURE	**6-10**
2. 1 Background of binderless board production	6-8
2 .2 Description of Kenaf (*Hibiscus cannabinus*)	8-10
2. 2.1General Description	8-9
2.2.2 Geographical Distribution	9-10
CHAPTER THREE: MATERIALS AND METHODS	**11-17**
3.1 Materials and Equipments	11
3.1.1 Chipper	11
3.1.2 Hot Press	11

3.1.3 Hydraulic Universal Testing Machine (UTM)	11
3.1.4 Electric Oven	11
3.1.5 Electric Balance	11
3.1.6 Digital Slide Calipers	12
3.2 Methods and Procedures	12
3.2.1 Collection of raw materials	12
3.2.2Manufacturing place	12
3.2.3 Manufacturing procedure	12
3.2.3.1 Particle preparation	12
3.2.3.2 Screening of particles	12
3.2.3.3 Drying of treated particles	19
3.2.3.4 Mat forming	13
3.2.3.5 Hot pressing	13
3.2.3.6 Conditioning and finishing	13
3.2.5 Laboratory tests	14
3.2.5.1 Preparation of samples for testing 3.2.6 Determination of physical properties	14
3.2.6.1 Density	15
3.2.6.2 Moisture content	15
3.2.6.3 Water absorption	16
3.2.6.4 Thickness swelling	16
3.2.7 Determination of mechanical properties	16
3.2.7.1 Modulus of elasticity (MOE)	17
3.2.7.2 Modulus of rupture (MOR)	17
3.2.8 Analysis of data	17

CHAPTER FOUR: RESULTS AND DISCUSSION	**18-24**
4.1.1 Manufacturing of kenaf- core binderlessparticleboard	**18**
4.1.2 Physical Properties	18
4.1.2.1 Density	18
4.1.2.2 Moisture Content	19
4.1.2.3 Water Absorption	20
4.1.2.4 Thickness Swelling	21
4.1.3 Mechanical Properties	22
4.1.3.1 Modulus of Rupture (MOE)	22
4.1.3.2 Modulus of Elasticity (MOR)	23
4.2 Effect of pressing time on board properties	24
CHAPTER FIVE: CONCLUSION 5.1 Conclusion	**25**
5.2 Limitation	**25**
REFERRNCES	**26-28**
APPENDIX	**29-31**

LIST OF TABLES

Serial no.	Title	Page no.
Table 1.1:	Comparision of chemical components between kenef core and soft wood	2
Table 3.2.4:	Specifications of manufacturing binderlessparticleboard.fromKenaf(*Hibiscus cannabinus L.*) core	14

LIST OFFIGURES

Serial no.	Title	Page No.
Figure 1.1:	*Hibiscus cannabinus*stalks	4
Figure 1.2:	Kenaf stalks	9
Figure 1.3:	Kenaf plantation	10
Figure 4.1:	Density of kenaf- core binderless particleboard	18
Figure 4.2:	Moisture contentof kenaf- core binderless particleboard	19
Figure 4.3:	Water absorption of kenaf- core binderless particleboard	20
Figure 4.4:	Thickness swelling of kenaf- core binderless particleboard	21
Figure 4.5:	MOE of kenaf- core binderless particleboard	22
Figure 4.6:	MOR of kenaf- core binderless particleboard	23
Figure 4.7:	Effect of pressing time on board properties	24

ABBREVIATIONS

Anon	Anonymous
ASTM	American Society for Testing and Materials
BFRI	Bangladesh Forest Research Institute
cm^3	Cubic Centimeter
df	Degrees of Freedom
FAO	Food and Agricultural Organization
gm	Gram
GD	Green dimension
IB	Internal Bond Strength
Kg	Kilogram
m^3	Cubic meter
mm	millimeter
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MPa	Megapascal
OD	Oven-dry dimension
OPC	Ordinary Portland Cement
SD	Standard Deviation
N	Newton
TS	Thickness Swelling
WA	Water Absorption

INTRODUCTION

1.1 Introduction

Now a days effective utilization of non-wood lignocellulosic materials has been of great interest due to the followinf key factors[1]:

- Shortages of wood
- Environmental pressures due to deforestation
- Price of wood materials

Non-wood lignocellulosic materials include all lignocellulosic materials except wood. The non-wood lignocellulosic materials suitable for composites stem from two main sources[2].
Namely

1. The by-products of food or feed crops, such as rice husks or cereal straws
2. Second types is those lignocellulosic grown specially for fibre production, such as jute and kenef.

Annual plants have lower densities than wood. Some of the annual plants have completely different chemical composition than wood. Straw can be considered , that it has high amount of silica, that is why it needs special technique for bonding[2-6]. In recent times worldwide sugar cane bagasse has been used for the production of varities of composites such as fibreboard, particleboard, medium density fibreboard and dry process hardboard[3,4].

After bagasse, cereal straw is probably the most important for composite panel production [2].Besides bamboo in recent times becomes an important composite material specially in China for composite panel production[5].

Bast family of plants (kenef,hemp,flux) for composite production in recent years has attracted special interest[6].Because of higher productivity than wood. On the other hand it outer fibre shows exceptional strength in cordage and paper [7].While the core materials , are possible for the potential applications of low-density insulation board, ceiling tiles, particleboard and MDF etc[8].

1.2 Chemical components of kenef core

The chemical components of kenef bast fibre and core are very different from each other. Kenef bast fibre rich in cellulose(69%) and very low lignin content(3%). But kenef core chemical composition more or less similar to soft wood Table 1.1[8]

Table 1.1 Comparision of chemical components between kenef core and soft wood

Chemical components	Soft wood	Kenef core
Cellulose%	44.4	32.2
Lignin%	22.8	25.1
Hemicellulose%	32.7	41.0
Ash%	0.1	1.8

1.3 Utilization of kenef core

From ancient time bast fibre has been used for woven fabrics purpose and the core material for fuel. But because of synthetic fibre and natural gases for fuel purpose it becomes useless or waste material. However kenef core is extremly light in weight with a density of 0.1-0.2 g/cm^3. Many research already have done to develop low density board with kenef core[5]. It was also reported that low density particleboard based on kenef core is produced in Spain[2].

1.3.1 Traditional Use of Kenaf

Kenaf has been cultivated in Egypt since around 4000 B.C. China also has actively developed this plant and now is one of the largest kenaf producers in the world. Kenaf has been used for thousands of years mainly to make cordage, rope, burlap cloth and fish net due to its rot and mildew resistance. Today, one of the major values of kenaf is used on a limited scale to produce pulp and paper in some countries as the substitute for wood. Kenaf offers many significant advantages in this application, including a short harvestable period and no chlorine bleaching. Kenaf paper is stronger, whiter, longer lasting, more resistant to yellowing, and it has better ink adherence than tree paper.

1.3.2 Value Added Produces from Kenaf

The stock of kenaf can be used almost entirely. Kenaf leaves and stems have a potential as livestock feed. Dried leaves contain 30% crude protein and are used as vegetables in some part of the world. In recent years, with increasing concerns for environmental protection, kenaf has found more applications. The breakthroughs and advances in environmental technology have resulted from intensive testing and research in the kenaf industry. Here are some examples:

i) Kenaf Fiber/Plastic Compounds

Kenaf fiber/plastic compounds based on kenaf can replace glass reinforced plastics in many applications such as automotive industry, packaging and construction or housing. The compounds have the mechanical and strength characteristics of glass filled plastics but are less expensive and in many instances are completely recyclable.

ii) The Automotive Industry

The 1996 Ford Mondeo which sold abroad features interior automobile panels made of kenaf fiber. Kenaf international supplies the fiber, which is processed by the supplier to Ford. The company expects that sales to European automobile manufacturers will steadily increase as the industry becomes comfortable with the product and the kenaf products from automotive group are capable of meeting required demand.

iii) Construction and Housing Industry

Kenaf/plastic compounds molded into lightweight panels can replace wood and wood based products in many applications. This product has the potential to be the first economically priced plastic lumber that can be engineered for use as building materials in housing industry. In some cases, emphasis has centered in the utilization of core of the plant. Kenaf core has been used as packaging material, animal bedding, oil absorbents and poultry litter.

iv) Food Packaging Industry

Pellets made from a kenaf/plastic compound can be molded into commercial food storage containers and virtually any other product now made of plastic. Non food related packaging opportunities are also numerous including bulk chemical and pharmaceutical packaging, parts packaging in the electrical and electronics industries and disposable packaging for large consumer appliances. In every instance, fiber composites have distinct technical and pricing advantages over plywood and cardboard and are recyclable as well.

v) Oil & Chemical Absorbents

The core is very absorbent and one of its main uses is to clean up oil spills and similar chemicals. One unique feature of Kenaf absorb is that it absorbs oil before taking on water once oil is absorbed; the product floats on the surface, which makes collection easier. This product is also non toxic, non abrasive and is more effective than traditional remediants like clay and silica. This product is distributed for use in oil fields but the product also absorbs gasoline, diesel, transmission fluid and coolant spills. In addition to use by individuals for personal garages, bulk applications include clean up operations in refineries, utility companies, land and sea spills, oil rigs, industries that handle bulk storage terminals and for military field refueling applications.

vi) Animal Bedding and Poultry Litter

Kenaf bedding is sold in bags to farm and ranch supply stores and in bulk to large buyers such as stables, zoos and poultry farms. This product has superior absorbency, requires fewer changes, is cost competitive with most traditional litter and bedding products comprised of wood shavings, saw dust or shredded paper.

vii) Soil free Potting Mix

This product competes with commercial potting soils and can also be custom mixed for different horticultural applications. Kenaf has a long term supply arrangement with a nursery products wholesale business. The products are blended and mix with peat moss, compete with commercial mixes containing mostly peat moss or pine bark.

Fig 1.1 : *Hibiscus cannabinus* stalks

1.4 Objectives of the study

- To develop kenaf core binderless particleboard by conventional hot pressing
- To evaluate the mechanical and physical properties of kenaf core binderless particleboard

LITERATURE REVIEW

2. 1 Background of binderless board production

Consumption of wood products is annually increasing although other competitive materials such metals and plastics are available. The world wood production by weight is twice than that of steel and 15 times that of plastics [16].

One of the most important wood-based composites is particleboard, which is made from wood or lignocellulosic material particles glued with binder (adhesive) under pressure and temperature. Throughout the world, Sellers [17] reported that the demand for wood composite products has increased substantially.

Growing social demands for various wood-based panel products leads to the continuous efforts to find new wood resources as an alternative to solid wood from natural forests [18-19]. The use of non-timber resources, wood wastes and agricultural residues are a way of saving wood [20]. In order to overcome the wood shortageand to meet the future demand of wood products, studie have been conducted to utilize non-wood materials, agricultural residues, fast growing tree, low-grade wood species and/or underutilized wood species in the forest industry as raw material components for wood-based composite production in several countries.

Synthetic binders are usually used for wood-based panel production. They are not only expensive, but also derived from nonrenewable petro resources. That is why a great deal of work has been done to explore the use of lignin, tannin, carbohydrare, etc, even no-binder technology has been evaluated.

Wet process hardboard is one type of binderless board. Here only less han 2% addisive is used during wet process. During 1980s Shen developed and patened a stem-explosion process for lignocellulosic materials directly converted into panel products without the use of synthetic resin binders[9].

Another method for making binderless board is the hot pressing under high temperature and moisture content with hihg density. Matsumoto et al. developed the binderless particle board from kenefr core using conventional hot pressing.

Almost all the binderless boards introduced in the previous studies were high in density. Low density binderless boards are usually very poor in board properties. However it is belived that in degradation process of hemicellulose two important chemical component produce that are responsible for self bonding. These are Furan(C_4H_4O) and Furfural($C_5H_4O_2$). Furan and Furfural boiling point respectively 31.3°C, 162.7^{0}C.Besides it was found that parts of lignin is also responsible for self bonding. Recent stadies have demonstrated that the characteristics of lignin as a plastic material could improve the mechanical properties [12].

The kenaf core is light and porous, having a bulk density of 0.10-0.20 g/cm3. It can be crushed into light-weight particles. Currently, kenaf core has received less attention compared to bast in paper and bio composite industries, even though numbers of researches have revealed that kenaf core is useful to produce insulation composites [21;22], medium-density particleboards [23;24], fire retardant-treated particleboards [23,24,16], polymer composite [21], thermo-acoustic applications and sound barriers[25-26]. Binderlessboard is well known as composite, which its self-bonding is improved only by activating the chemical components of the board constituents during steam/heat treatment.

No synthetic resin is added in the manufacture of the boards, therefore the properties of the composites were significantly affected by the chemical composition of its raw material. Degradation of hemicellulose during steam/heat treatment to produce furan products is believed to play an important role in self-bonding [27]. Therefore, binderless boards are usually prepared from non-wood raw materials, which are rich in hemicellulose. Widyorini et al. [28] found that partial degradation of the three major chemical components of the kenaf core by mild steam injection treatment increased the bonding performance and dimensional stability of the binderless boards. In addition, cinnamic acid, that ususally found in non-wood materials, was also contributed to the self-bonding mechanism [29]. So far it was still a few reports on manufacture of binderless board made from wood with good performance, especially by hot-pressing. Angles et al. [30] found that by thermomechanically pretreatment, binderless panels made from mixture of softwood (spruce and pine) could be produced with good properties. Ando and Sato (2010)produced sugibinderless particleboards by hot-pressing at 200 0C with relatively high internalbonding, but lower properties in water resistance. In Indonesia, a large amount of woody biomass waste is generated in the manufacturing process of wood industry. Sengon, jackfruit, and teak wood from community forest are now commonly used in wood industry.

Therefore, it is desirable to manufacture these boards without using any synthetic resins. The removal of extractives is usually an important point to produce the good quality of resinbonded boards. The extractives may not be compatible with the conventional resin binders, and may interfere the bonding properties of the composites. Extractives usually consist of extracted sugars, tannin, flavonoids, waxes, resin- and fatty acids, etc. Considering that no synthetic resin is applied in the binderlessboard, the effect of extractive in self-bonding mechanism is interesting to be investigated. It was still a few paper concerned on the effect of extractive on the self-bonding of binderlessboard. Widyorini et al. [28-31]showed that removing extractive could improve bonding properties of bagasse binderlessboards, while it did not affect on properties of kenaf core binderlessboard. It also showed that after removal of ethanol-benzene extractive from bagasse rind, which usually contains silica and waxes, the mechanical properties of its boards were increased significantly.

This research was designed to investigate characteristic of binderless, particleboards made from sengon, jackfruit, and teak wood particles. The effect of the removal hot water-extractives on the board properties is also discussed. Ando and Sato [33] produced sugibinderless particleboards by hot-pressing at 200 0C with relatively high internal bonding, but lower properties in water resistance.

In this study Kenaf (*Hibiscus cannabinus L.*) core is used as non-wood particle for low density particleboard manufacturing and here different temperature is used in hot pressing.

2 .2 Description of Kenaf (*Hibiscus cannabinus*)

2. 2.1General Description

Hibiscus cannabinus, is a warm season, short-day, annual herbaceous fiber plant native to central Africa, and a common wild plant of tropical and subtropical Africa and Asia. It has been cultivated since around 4000 BC for food and fiber. It is known as mesta in India and Bengal, as stock root in South Africa, as java jute in Indonesia and as *ambari* in Taiwan. The plant has a unique combination of long bast (about 35% of the stalk dry weight) with short core fibers in place of the hollow core[10]. Kenaf belongs to the Malvaceae, a family notable for both its economic and horticultural importance. Kenaf has a high growth rate, rising to heights of 4–6 m in about 4–5 months. Strong interest is being shown in this plant in Malaysia as it is fast growing and can yield two crops/ year in the local climate. It can then yield a dry weight of 6000–10,000 kg/ha - year (new varieties may reach 30,000 kg/ha year). It is similar to jute in many of its properties and may be used either as an alternative to, or in admixture with, jute.

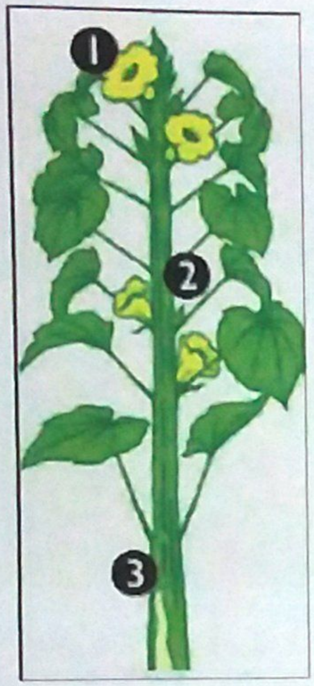

Figure 1.2: Kenaf stalks

2.2.2 Geographical Distribution

Hibiscus cannbinus is of African origin; in most countries south of the Sahara, *H. cannabinus* is a very common wild plant and it is also widely grown as a vegetable or fibre crop. Angola may have been a primary centre of origin, but greatest morphological diversity is found in East Africa. Both *H. cannabinus* and roselle (*H. sabdariffa* L.) may have been domesticated as early as 4000 BC in Sudan. The date of initial introduction into India is unknown. References to *H. cannabinus* cultivation started to be published around 1800 and it first appeared on the London market as 'Bimlipatam jute' in 1901. India has remained as the country with the largest production of *H. cannabinus* with concentrations of cultivation in West Bengal and in coastal areas around Visakhapatnam (Andhra Pradesh) and Madras (Tamil Nadu). *H. cannabinus* was introduced into Indonesia from India in 1904. An extensive programme of *H. cannabinus* cultivation was initiated in the 1920s in the Caucasus region of the Russian Federation (former USSR) and from there; it was introduced into China in 1935. H. cannabinus production was also initiated after 1945 in e.g. the United States, Cuba an South America. *H. cannabinus* is now widespread in the tropics and subtropics, of-ten cultivated as a fiber plant. In Malaysia, it is cultivated but does not grow wild. Today, principal farming areas are China, India, and it is also grown in many other countries such as the US, Mexico and Senegal[11].

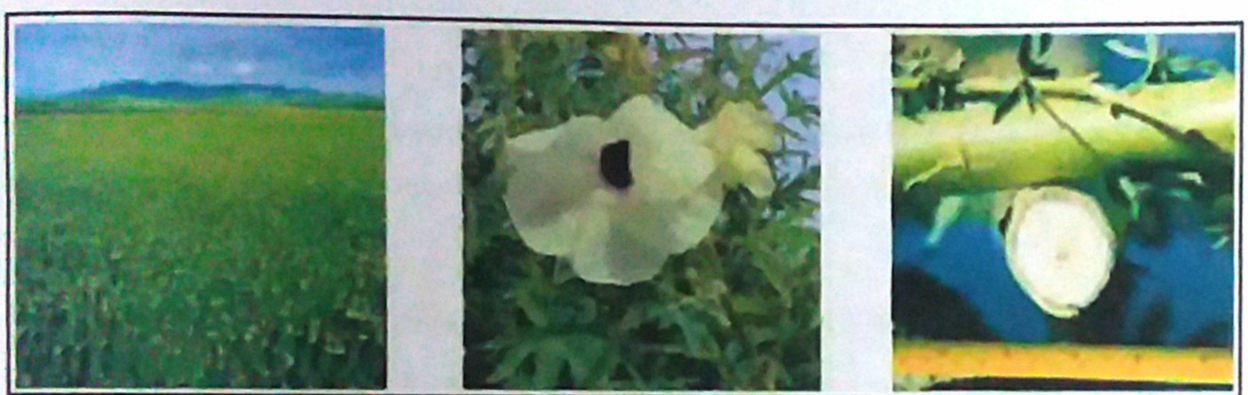

Figure 1.3: Kenaf plantation

MATERIALS AND METHODS

3.1 Materials and equipment

3.1.1 Chipper

A locally made small lab scale chipper was used to chip the raw materials. The rpm of the chippers' motor was 1420.

3.1.2 Hot press

A digital hydraulic hot press was used to press the mat. It has multi layer plate. The both platen were movable up and down. Maximum temperature range within 400℃ and pressure up to 40 MPa commonly occur.

3.1.3 Hydraulic Universal Testing Machine (UTM)

An analogue hydraulic Universal Testing Machine (UTM), model: WE-100, made by Time group Inc. was used to determine the mechanical properties of the particleboard.. There were two units of this machine, one was control unit and another was working unit. A meter was attached with the control unit for measuring the load (kN). And a scale (mm) was attached with the working unit to measure the deflection. The length of the span, on which the samples were laid, was 248 mm. Another part of the working unit was used to determine the tensile strength, which works vertically.

3.1.4 Oven

A lab scale ventilated oven (Name: Gallennkamp, Size 1, made in UK) was used to determine the moisture content (%) of raw materials as well as the particleboard. A digital indicator outside the oven indicated the inside temperature.

3.1.5 Electric balance

An air tight digital balance (Model: AB 204, made in Switzerland) was used to measure the weight of the raw materials as well as particleboard.

3.1.6 Digital Slide Calipers

For density measurement a Digital Slide Calipers is used.

3.2 Methods and procedures

3.2.1 Collection of raw materials

Kenaf (*Hibiscus cannabinus L.*) was collected from Gopalgang District as raw material for the manufacturing of particleboard. For the purpose of preparing samples the defect free bole is selected and then it chipped by chopper machine. After chipping, the non-wood chips are run into grinder machine. In this study the size of wood particle ranges < 1mm is used.

3.2.2Manufacturing place

The particleboard was manufactured at wood lab that is controlled under by Forestry and wood technology discipline, Khulna University, Khulna.

3.2.3 Manufacturing procedure

3.2.3.1 Particle preparation

To produce particles of the stem chipping was done with chipper machine. The small pieces of stem and branch were inserted separately into the chipper machine. The holes in the perforated mesh that was used in the chipper machine were approximately 8 mm in diameter. From the chipper machine the particles were collected manually (Salehuddin, 1992; AWPA, 2001).

3.2.3.2 Screening of particles

Then all types of particle were screened manually by sieve no. 16. The fines under the sieve were rejected and the retaining particles on the sieve were collected separately. Oversized particles are again fed into the chippers (Youngquist, 1999).

3.2.3.3 Drying of treated particles

After treatment the particles of each type were inserted in to the oven for drying. In the oven the temperature was 103°C.

3.2.3.4 Mat forming

The particles were formed into mat separately on the separate steel sheet. The mats of each type were formed manually. And the average mat thickness was about 5 times of the targeted board thickness (6 mm) for each type.

3.2.3.5 Hot pressing

After mat formation, a steel sheet was placed onto the mat (for each type) and then inserted manually into the hot press (each type separately) for pressing. After inserting the mat into the hot press, the pressure was raised manually by digital hydraulic hot press up to 5MPa. There hot pressing time was 12 minutes, colling time was also 12 minutes. But we used different temperature when pressing, that was 140℃.160℃., 180℃ and 200℃. We also used 9 and 15 minutes hot pressing for achieving our terget density though our colling time was same.

3.2.3.6 Conditioning and finishing

After stopping temperature the board was remained fixed for cooling or conditioning.The boards of each type were produced separately, these were trimmed at edges with the fixed type circular saw. The dimensions of each type of boards were then 30 cm×20 cm. The board is trimmed to obtain the desired length and width and to square the edges. Trim losses usually amount to 0.5% to 8%, depending on the size of the board, the process employed, and the control exercised [26]

3.2.4 Specifications of manufactured Kenaf-Core binderless particleboard

Dimensions (mm)	200x100
Thickness (mm)	6(Average)
Layer	Single
Board Types	4
Replications	2 (for each type)
Total board manufactured	12

Table 3.1 Specifications of manufacturing binderless particleboard.from Kenaf (*Hibiscus cannabinus L.*) core

3.2.5 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 particleboards (ANSI A208.1–1993) (NPA, 1993) as well as the Indian standard for particleboards (IS: 3087-1985) (Anon, 1985).

3.2.5.1 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 three (3) for each type of particleboard for testing of physical properties. The Density and Moisture Content were determined on the same three (3) samples and the Water Absorption, Thickness Swelling determined on the other three (3) samples. For testing mechanical properties, three samples were collected from each board of each type. So the total number of sample was three (3) for each type of particleboard for testing of mechanical properties. The MOR and MOE were determined on the separate samples.

The dimension of samples for testing the physical properties was averagely (50 mm x 35 mm) and for testing the mechanical properties was averagely (180 mm x 35 mm).

3.2.6 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 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 hours. Finally, the wet dimension are taken and all the physical properties are calculated by using following formula-

3.2.6.1 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.

3.2.6.2 Moisture content

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

$$MC\,(\%) = \frac{m_{int} - m_{od}}{m_{od}} \times 100$$ (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).

3.2.6.3 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-

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

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).

3.2.6.4 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).

3.2.7 Determination of mechanical properties

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

3.2.7.1 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-

$MOE = \frac{PL^3}{4\Delta bd^3}$ (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).

3.2.7.2 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).

3.2.8 Analysis of data

Completely randomized design was used in the experiment and all the data produced during the laboratory tests for characterization of physical and mechanical properties of each type of boards, were analyzed by using Microsoft Office Excel 2007 and IBM SPSS Statistics 20 software for ANOVA (Analysis of Variance) test.

RESULTS AND DISCUSSION

4.1.1 Manufacturing of kenaf- core binderless particleboard

It was observed that the dimension of the manufactured particleboard was 200 mm× 100mm and the thickness was approximately 6 mm.

4.1.2 Physical Properties

4.1.2.1 Density

The study found that there is a strong effect on different hot pressing temperature on the kenef core binderless particle board(Appendix , Table 1). In case of density there is a significant difference($p<0.05$) among the different hot pressing temperature. It was found that, the highest density($0.92 g/cm^3$) of kenaf core binderless particleboard at 200^0C treated board and lowest density($0.60 g/cm^3$) at 160^0C treated board (Fig. 4.1). Parts of lignin and hemicellulose act as a binder[14,32]. Maximum parts of lignin decomposed between 100^0 C to 200^0C[15].

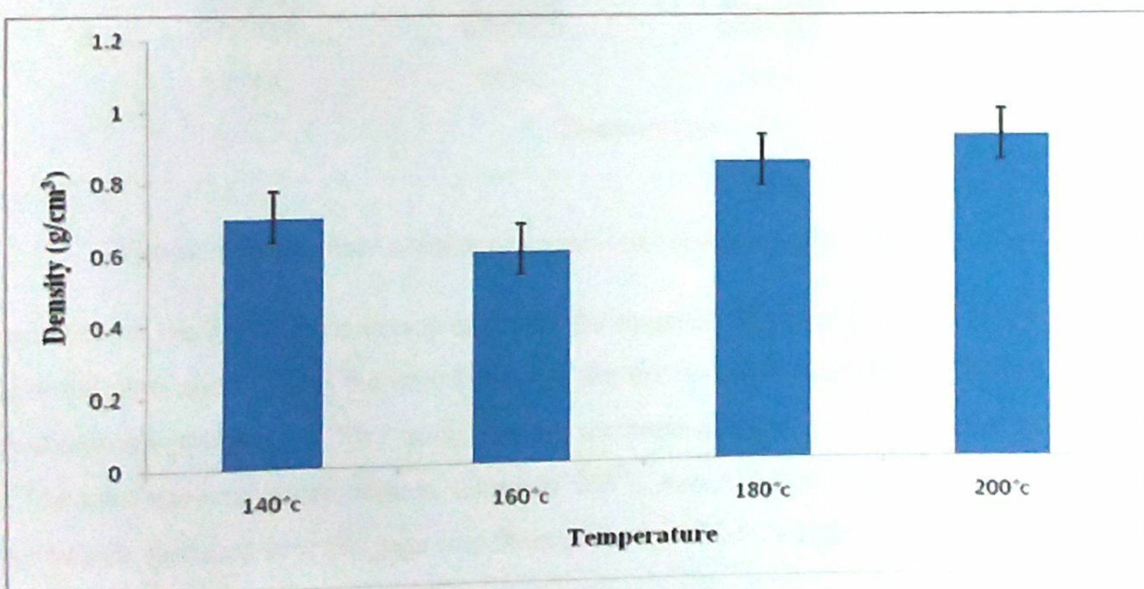

Figure 4.1: Density of kenaf- core binderless particleboard

The most important indicator is that hemicellulose act as a binder from 150^0C to 190^0C [32]. That is the reason density increasing for increasing the temperature.

4.1.2.2 Moisture Content

The study found that there is a strong effect on different hot pressing temperature on the kenef core binderless particle board(Appendix , Table 2). In case of moisture content there is a significant difference($p<0.05$) among the different hot pressing temperature .With increasing the hot pressing temperature, moisture content percentage is reducing.

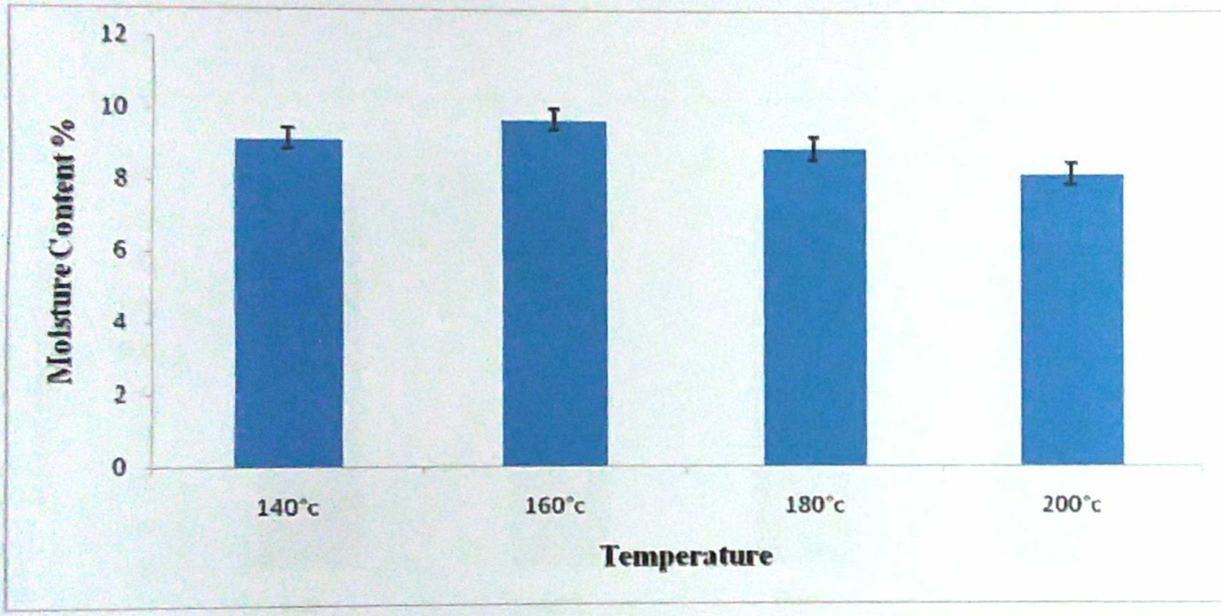

Figure 4.2: Moisture content of kenaf- core binderless particleboard

In addition to the hydrophilic nature of wood, the moisture absorption in particleboard is mainly due to the gaps and flaws at the interfaces, and the micro-cracks in the matrix formed during the manufacturing process[12]. The study showed moisture content percentage range is 9.72 to 8.2 %. The maximum moisture content found in 160^0C treated board which density is lower than other boards. Because here the gaps and flaws at the interfaces is higher than other boards.

However the study showed moisture content percentage range is 9.72 to 8.2 which is appropriate moisture content in the standard particleboard was found as per ANSI A208.1–1993 (NPA, 1993) and IS: 3087-1985 (Anon, 1985) as well as British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761[13].

4.1.2.3 Water Absorption

The study found that there is a strong influence on water absorption of different hot pressing temperature on the kenef core binderless particle board(Appendix , Table 3). In case of water absorption there is a significant difference($p<0.05$) among the different hot pressing temperature. With increasing the board hot pressing temperature water absorption percentage is also increasing. The study showed water absorption percentage range is 172 to 177%.

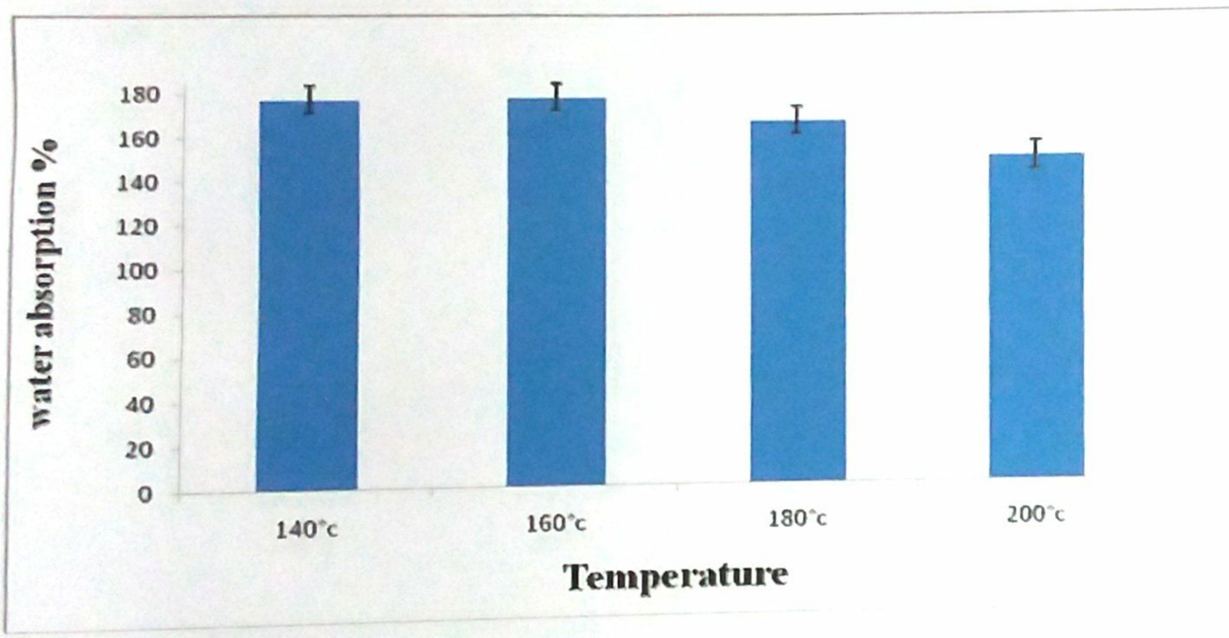

Figure 4.3: Water absorption of kenaf- core binderless particleboard

It was found that water absorption percentage at different hot pressing temperature was different. Here after 24 hours of immersion in water at room temperature (25°C) highest amount of water absorbed by 160^0C temperature treated board and lowest water absorption percentage found in 200^0C temperature treated board. Here water absorption percentage capability may be responsible of the density of the board.

4.1.2.4 Thickness Swelling

It was found that there is a strong influence on thickness swelling at different hot pressing temperature on the kenef core binderless particle board(Appendix , Table 4). Here in case of thickness swelling there is a significant difference($p<0.05$) among the different hot pressing temperature .With increasing of the board hot pressing temperature thickness swelling percentage is correspondingly reducing.

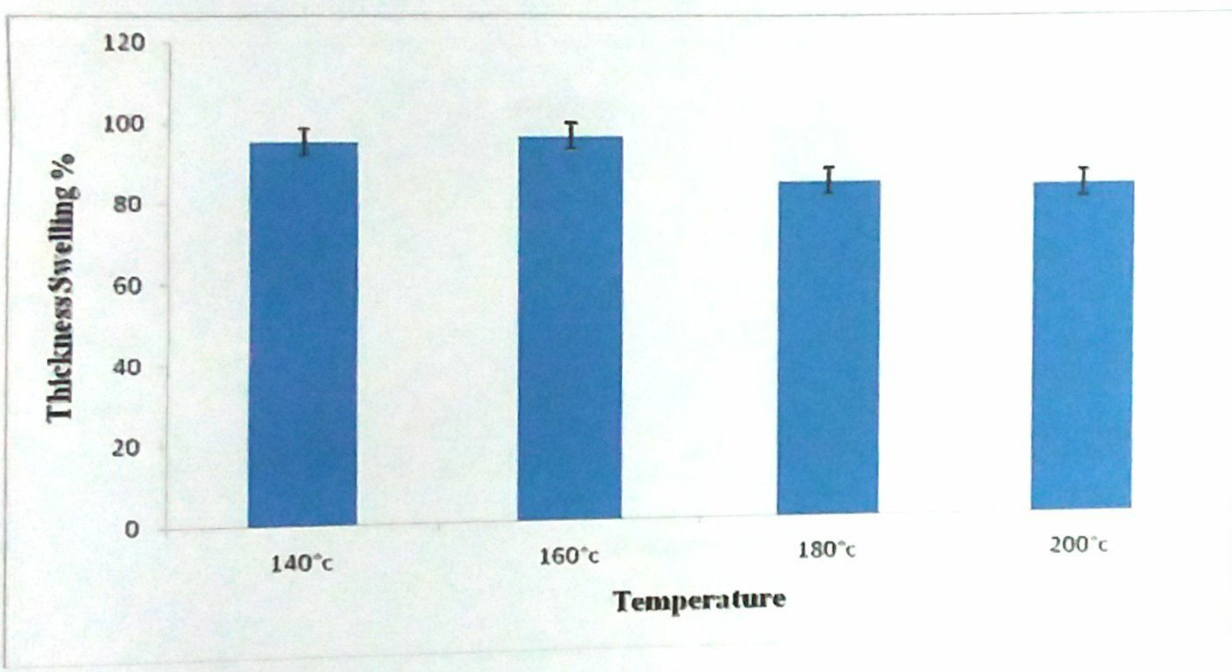

Figure 4.4: Thickness swelling of kenaf- core binderless particleboard

It was found that after 24 hours of immersion in water at room temperature (25°C) the highest thickness swelling was (96.49%) in 160^{0}C temperature treated board and lowest thickness swelling was found (83,78%) in 200^{0}C temperature treated board .

4.1.3 Mechanical Properties

4.1.3.1 Modulus of elasticity (MOE)

The study found that there is a strong effect on modulus of elasticity (MOE) at different hot pressing temperature on the kenef core binderless particle board(Appendix , Table 5). Here there is a significant difference ($p<0.05$) among the different hot pressing temperature. The highest modulus of elasticity (2714 N/mm^2) of kenaf core binderless particleboard was found in 200^0C treated board and lowest modulus of elasticity (2145 N/mm^2) was found in 140^0C treated board.

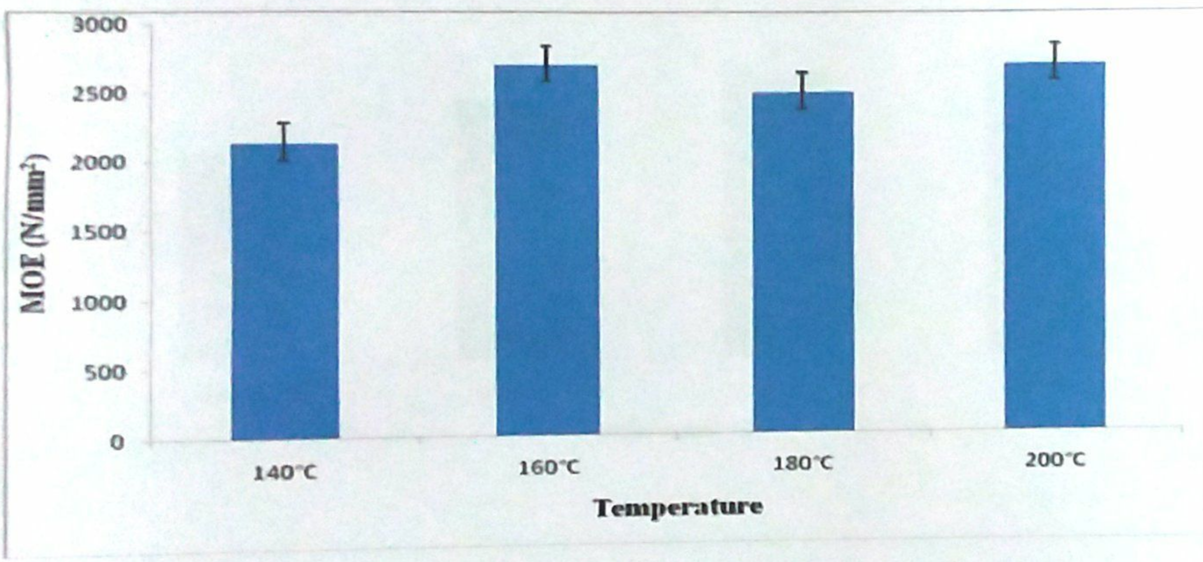

Figure 4.5: MOE of kenaf- core binderless particleboard

The most important indicator is that hemicellulose act as a binder[32] from 150^0C to 190^0C temperature in hot press method in case of binderless particleboard manufacturing process. Maximum parts of lignin decomposed between 100^0 C to 200^0C[15]. That is why density increasing correspondingly.Some study found that with increasing density its modulus of elasticity also increased [12]. This study showed modulus of elasticity (MOE) range is 2714to 2145. Modulus of elasticity (MOE) is low in case of 140^0C treated board, though it's density was high than other boards. Because here internal self bonding was low, it may be the low contribution of linnin decomposition as wellas hemicellulose.

4.1.3.2 Modulus of rupture (MOR)

The study found that there is a strong influence on Modulus of rupture (MOR) at different hot pressing temperature on the kenef core binderless particle board(Appendix , Table 6). Here there is a significant difference ($p<0.05$) among the different hot pressing temperature. The highest modulus of rupture (23.31 N/mm^2) of kenaf core binderless particleboard was found in 200^0C treated board and lowest modulus of elasticity (15.54 N/mm^2) was found in 140^0C treated board.

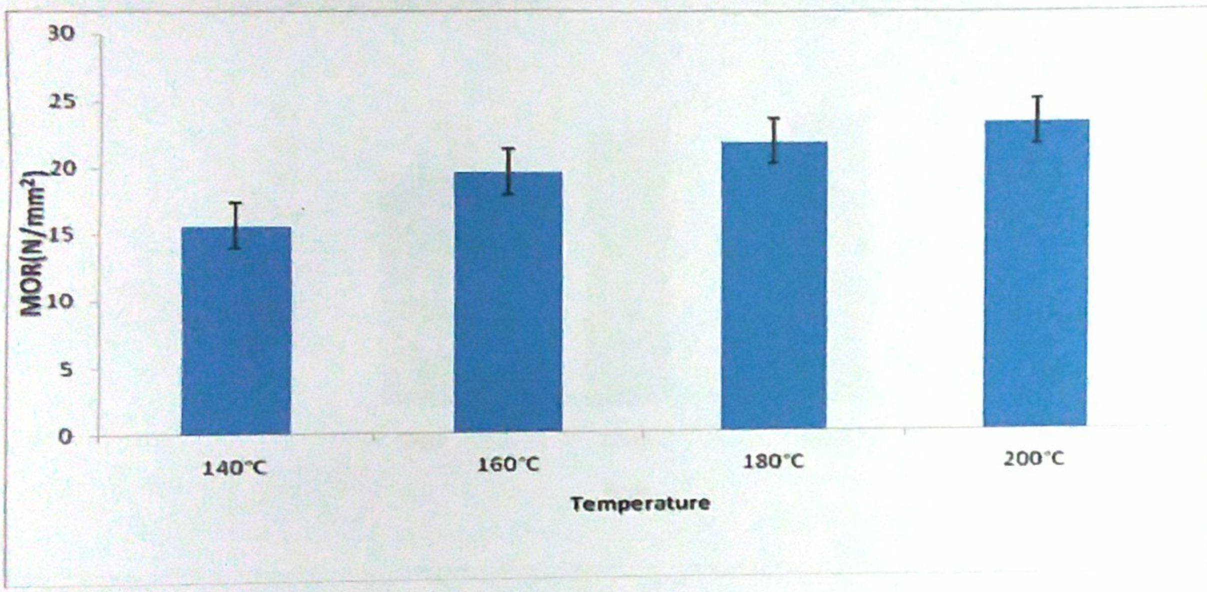

Figure 4.6: MOR of kenaf- core binderless particleboard

The most important indicator is that hemicellulose act as a binder[32] from 150^0C to 190^0C temperature in hot press method in case of binderless particleboard manufacturing process. Maximum parts of lignin decomposed between 100^0 C to 200^0C[15]. That is why density increasing correspondingly.Some study found that with increasing density its modulus of rupture also increased [12]. This study showed modulus of rupture (MOR) range is 23.31to 15.54. Modulus of rupture (MOR) is low in case of 140^0C treated board, though it's density was high than other boards. Because here internal self bonding was low, it may be the low contribution of linnin decomposition as wellas hemicellulose.

4.2 Effect of pressing time on board properties

The study was done to develop particleboard from kenef core. The former graph (figure 4.1) represented that 180^0C treated board given our target density. That is why here only further study was done on pressing time effect 180^0C treated board. Figure 4.7 shows the effect of pressing time on the properties of kenef core binderless particleboard at different time, namely 9min,12min,15min. The particleboard showed almost same value in case of density, MOR and MOE. But in case of moisture content the highest value showed in 12min treated board and lowest value showed in 9min treated board.

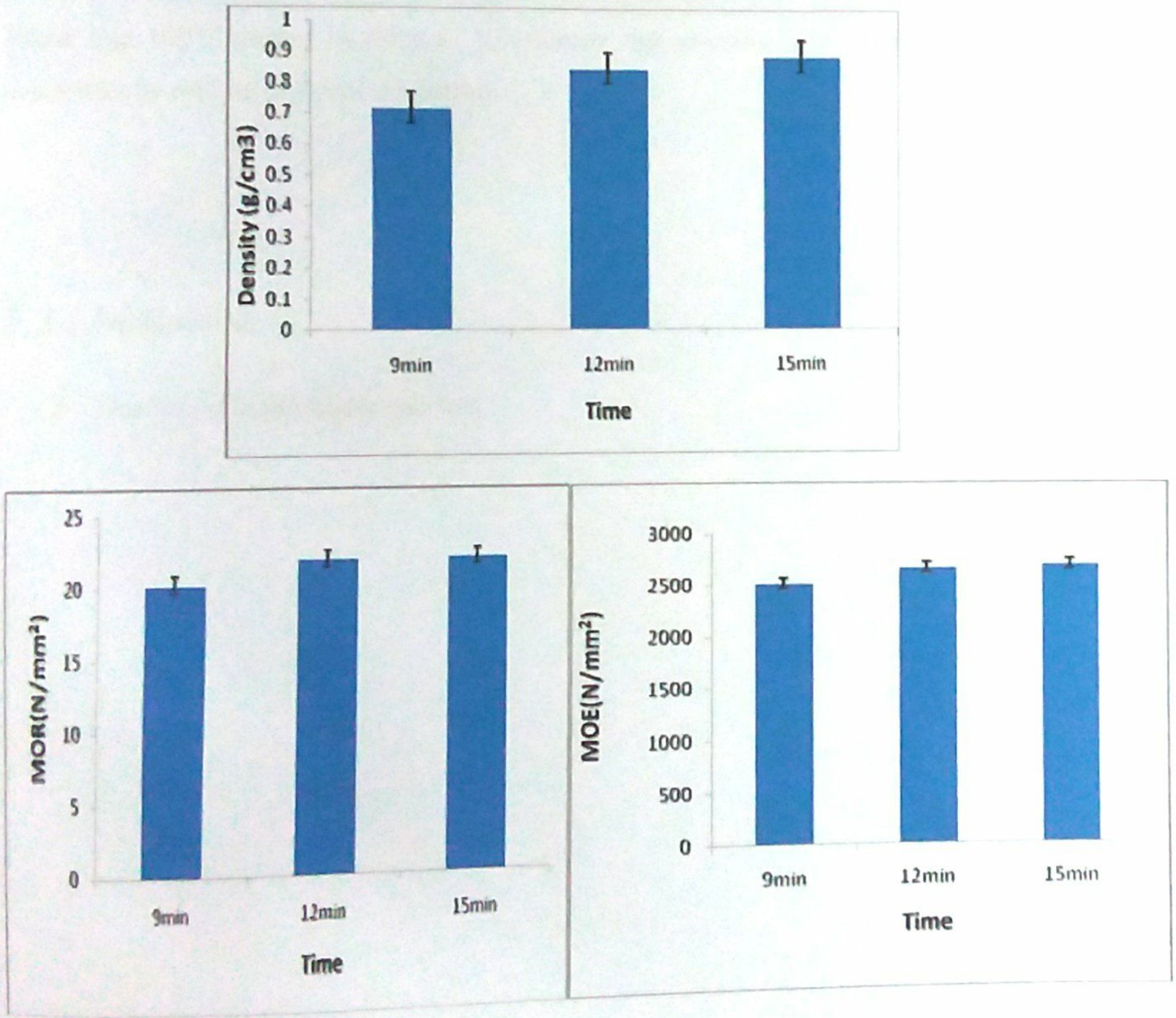

Figure 4.7: Effect of pressing time on board properties

CONCLUSION AND LIMITATION

5.1 Conclusion

The study aimed to develop binderless particleboard from kenef core. Binderless particleboard were successfully developed from kenef core. The former product was manufactured using hot pressing time at differenet temperature. The study found that 160^{0}C treated board performed the lowest density (0.60gm/cm^3) and 200^{0}C treated board showed the highest density (0.92gm/cm^3). But in case of 200^{0}C treated board it showed discoloration because of burning. That is why then different hot pressing time(9min,12min,15min) was applied at180^{0}C treated board. The study found that 180^{0}C treated board with 12 minutes hot pressing time performed high mechanical properties as well as physical properties.

5.2 Limitation

- Number of replication was less

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APPENDICES: ANALYSIS OF VARIANCE

Table 1: ANOVA for Density

Dependent Variable: Density

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.125	3	.042	83.567	.000
Within Groups	.002	4	.000		
Total	.127	7			

Table -2. ANOVA for Moisture content

Dependent Variable: Moisture content

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.388	3	.796	35.204	.002
Within Groups	.090	4	.023		
Total	2.479	7			

Table 3. ANOVA for Water absorption (24 hours)

Dependent Variable: Water absorption

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1130.000	3	376.667	188.333	.000
Within Groups	8.000	4	2.000		
Total	1138.000	7			

Table 4. ANOVA for Thickness swelling

Dependent Variable: Thickness swelling

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	276.477	3	92.159	1145.901	.000
Within Groups	.322	4	.080		
Total	276.799	7			

Table 5. ANOVA for MOE

Dependent Variable: MOE

ANOVA

MOE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	440982.375	3	146994.125	355.810	.000
Within Groups	1652.500	4	413.125		
Total	442634.875	7			

Table 6. ANOVA for MOR

Dependent Variable: MOR

ANOVA

MOR

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	68.493	3	22.831	266.796	.000
Within Groups	.342	4	.086		
Total	68.836	7			