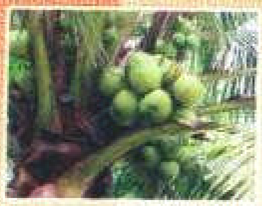
FINAL PROJECT REPORT

UTILIZATION OF COIR FIBRE FOR DEVELOPEMNT OF WOOD SUBSTITUTE BUILDING MATERIAL IN THE NORTH EASTERN REGION OF INDIA






A COLLABORATIVE PROJECT FROM

COIR BOARD
MINISTRY OF AGRO AND RURAL INDUSTRIES
GOVT. OF INDIA
ALPPUAZHA -688522

NORTH-EAST INSTITUTE OF SCIENCE & TECHNOLOGY
JORHAT - 785006 : ASSAM

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NORTH-EAST INSTITUTE OF SCIENCE & TECHNOLOGY
(A constituent establishment of CSIR)
JORHAT-785006, ASSAM

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FOREWORD

The project work involved utilization of Coir fibre alone or in combination with other natural fibres for making particle/composite boards useful as building construction material. Considering the present scenario of shortage of wood from the forest the particle/ composite boards made from coir and other natural fibre may very well be utilized for making such wood substitute products. The strength and other related properties of the resultant boards reveal that there is a good scope for setting up of industries in order to bring awareness for the use of coir fibre along with the local natural fibres in the North Eastern Region of India.

I thank Coir Board, Alppuazha (Kerala) for granting financial assistance to the institute for carrying out of the project work.

Date: 11-06-09
Place: NEIST, Jorhat

(Dr P G Rao)
Director

निदेशक
Director
उत्तर-पूर्व विज्ञान तथा प्रौद्योगिकी संस्थान
North-East Institute of Science & Technology
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TITLE OF THE PROJECT:

Utilization of coir fibre for development of wood substitute building material in the North Eastern Region of India

NAME AND DESIGNATION OF THE PRINCIPAL INVESTIGATOR :

Mr. Dip Chandra Saikia
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Scientist, E-I

COIR BOARD SANCTION LETTER NO

Letter No. CCRI/Res/CP-RRL/2005/2525 dated 21.03.06

TOTAL AMOUNT:

Rs 9.83 lakh

DATE OF START OF THE PROJECT

April , 2006

DATE OF COMPLETION OF THE PROJECT

31st March ,2009

CONTENTS

1.0 INTRODUCTION:

Coir is a coarse fibre obtained from the tissue surrounding seed of the coconut palm *(Cocus nucifera)*. The intact fruit has a leathery skin above the thick fibrous layer. This surrounds the stony dark brown shell, which is actually part of the fruit rather than seed. The fibrous layer forms a strong, shock absorbing mesh that protects the seed from mechanical damage and is water resistant. The individual fibre cell is narrow and hollow with thick walls made of cellulose. They are pale when immature but later they become hardened and yellow when a layer of lignin is deposited on their walls. Matured brown coir fibres contain more lignin and less cellulose than the fibres obtained from flax, cotton etc. and are stronger but less flexible. They are also relatively waterproof and the only natural fibre resistant to damage by saline water.

North Eastern Region of India is the treasure house of wide varieties of plant species. Among the different species of the plants, coconut plants are also available in some restricted areas of this region. Due to the varied topographic and climatic condition, different types of flora with their own distinctive characteristics are available in this part of the country. According to one estimate, there are 1,500 species of tree, 337 climbers and climbing shubs, 700 species of herbs, 300 species of ferns, 800 species of monocot and 350 species of grasses are available in this region. Many of the plant species have medicinal and aromatic value while some plant species contain very good quality fibre in the bark/ sheath as well as in the whole plants. Out of the vast plant resources in the North Eastern region a number of plants like *Hibiscus sabdariffa, Hibiscus esculentus, Hibiscus cannabinus, Alpinea allughas* Rosc (Tora), *Clynogynae dichotoma* (Patidoi) are some of the important plants, whose barks/sheath are reported to possess fibres of high physical strength properties. The fibres are extracted locally for domestic use by adopting crude method of extraction. Considering the present scenario of shortage of conventional high quality fibres, these new sources of fibre can easily be utilized for making different value added products alone or in combination with other fibres.

In recent years, due to the growth of population & industry, the forest areas of our country are also decreasing day by day. However a huge amount of plant raw materials are also being consumed by the different forest based industries like paper, plywood, vineer etc and as a result, there is a considerable shortage of plant raw material to feed such industries. Considering the gradual decreasing in forest areas of our country, the government has prohibited order for felling of trees from the forests both for industrial and private use. Therefore, the demand of wood as building construction materials has also increased proportionately. The time has come to develop a suitable wood substitute product to cop up the growing demand of wood based building construction material.

North East Institute of Science and Technology, Jorhat, Assam, India has carried out extensive work on development of low cost building materials utilizing the natural resources of NE region. In commensurate of the present area of work a project entitled "Utilization of coir fibre for development of wood substitute building material in the North Eastern Region of India" was undertaken in collaboration with Coir Board for development of composite board/particle board utilizing coir and other natural fibre suitable for use in the NE region of India.

The objectives of the approved project were:

- Study on the availability of the suitable natural fibres in different areas of North Eastern Region of India.
- Study of the morphological and chemical properties of coir fibre.
- Utilization of coir fibre alone or in combination with other natural fibre obtained from non woody plants available in NE region for making composite board suitable for use as building construction materials substitute to wood.
- Utilization of natural gums and resins obtained from plant sources fortified with suitable curing agents.
- Utilization of synthetic modified resin free from pollution or health hazard effect for making particle/composite board using coir and other fibres
- Development of coir reinforcement cement boards suitable for ceiling, partition and tile boards useful for building construction.
- Development of a sustainable technology based on coir and other natural fibre in the North Easter Region of India.

1.1 PRACTICAL/SCIENTIFIC UTILITY PROSPECTS

Once an appropriate technology is developed for making particle/composite boards using coir fibre alone or in combination with other fibre useful for building construction, there is possibility to set up industries based on such technologies which may generate employment opportunity. It will also save wood materials from the forest.

1.2 METHODOLOGY

The project was planned for a period of 3 (Thee) years. The programme of work included as follows:

1. Collection of coir fibre and study their morphological properties.
2. Chemical constitutional analysis of coir fibre and determination of physico chemical composition.
3. Selection of some non-conventional fibre yielding plants from N.E. region particularly non-woody cultivated/wield plants from the forests and extraction of fibre and evaluation of their physical strength properties.
4. Preparation of coir fibre by mechanical, chemical and mechano chemical process for making composite board.
5. Extraction of other cellulosic fibres by mechanical, chemical and mechano-chemical process for blending with coir fibre to enhance the physical strength properties.
6. Preparation of particles of different sizes for making particle boards of different densities and determination of bulk density.
7. Preparation of coir fibre by chemical and mechano-chemical process

prior to make fibre reinforced cement board and tiles.

8. Preparation of different adhesive solution using guar gum, gum Arabic and modified starch of different concentration and mixed with the coir and other fibre for manufacture of particle / composite board.

9. Optimization of process parameters for making coir composite/particle boards in laboratory scale and determination of their physical strength properties.

10. Optimization of process parameters for making particle/composite boards from the mixture of coir and other fibres in lab scale and determination of physical strength properties.

11. Optimization of process parameters for making coir reinforced cement boards in laboratory scale and determination of physical strength properties.

1.3 ACHIEVEMENTS AIMED AT

I. Development of a process for manufacturing particle/composite board using coir and other fibres with different resin/binding materials suitable as building material in the NE region.

II. The outcome of this project work will be published in national/international journals with the acknowledgment to Coir Board, Alppuazha.

PART I

DETAILS OF WORK CARRIED OUT

STUDY ON COIR FIBRE:

1.0 COLLECTION OF COIR FIBRE:

Approximately 100 kg of Coir fibre was procured in the form of packed bundles from the Jorhat market. After collection, the moisture content of the fibre was determined in a laboratory moisture meter. The fibres were screened to remove the dust and dirt particles and cleaned properly with cold fresh water and dried in sun. The dried fibres were packed in polythene bag and kept for chemical analysis and subsequent studies.

2.0 STUDIES ON PHYSICO-CHEMICAL PROPERTIES OF COIR FIBRE

2.1 Proximate chemical analysis:

For determination of chemical constituents of the coir fibre, an analytical method suggested by Technical Association of Pulp and Paper Industry TAPPI (USA) was adopted. For carrying out proximate chemical analysis, the washed and dried fibres were taken and kept for 1-2 h in oven at 70-80°C temperature and then converted to powder form. The powder was then screened though 40 and 60 BS mesh. The powdered fraction passed though 40 BS mesh and retained on 60 BS mesh was taken for proximate chemical analysis.

2.1.1 Cold water solubles

For determination of cold water solubles, 2 g of OD powdered material was taken and kept for 48 h in distilled water. The stirring was done from time-to-time during the period. After 48 h, it was filtered and the powdered fraction was dried in oven and weighed till a constant weight is obtained. The differences in weight of the material gave the cold water soluble materials like gums, starch of low molecular weight present in the fibre. The results were recorded from the average of five determinations.

2.1.2 Hot water solubles

For determination of hot water soluble materials present in coir fibre 3g powdered material was taken and cooked in distilled water at boiling temperature for 1 h. The water level was maintained during the period of boiling. After 1 h, the powdered material was separated out by filtration and then kept in an oven till a constant weight was obtained. The difference of weight indicated the hot water soluble materials such as gums, starch of high molecule weight present in the fibre.

2.1.3 1% NaOH solubles

For determination of NaOH solubility 2 g of powdered material was taken and cooked in 1% NaOH solution for 3 h. After cooking the powdered material were screened and then washed thoroughly with cold fresh water till it was free from alkali. The differences of weight of the powdered material gave the 1% NaOH soluble materials present in the coir fibre.

2.1.4 Alcohol-Benzene solubles

The alcohol-benzene soluble materials such as wax, fat, sugars of high molecular weight etc. were determined by alcohol benzene (1:2) mixture. 3 g of powdered material were extracted in soxhlet apparatus for 8 h. After 8 h the powder material was taken out from extraction thimble and then dried in an oven at 100±3^{0}C. The difference of weight indicated the alcohol benzene soluble materials present in the fibre.

2.1.5 Determination of cellulose content:

Cellulose content of the coir fibre was determined as per the method suggested by TAPPI (USA). For determination of cellulose content; the fibres were initially extracted with alcohol benzene (1:2) solution for 6-8 h. The alcohol benzene extracted samples were taken and used for determination of cellulose content using TAPPI standard method, T-203.

2. 1.6 Determination of lignin content:

The lignin content of the coir fibre was determined by TAPPI test method, T-222. For Determination of lignin, the fibre samples were first treated with alcohol benzene (1: 2) solution for 6-8 h and determined the lignin content of the alcohol benzene extracted samples following above method.

2.1.7 Determination of ash content:

For determination of ash content, approximately 2 g of fibre samples were taken in a silica crucible and initially burnt outside and then put in a muffle furnace at 573±25°C for a period of 6 h and the percentage of ash was calculated following T- 211 method.

2. 1.8 Determination of silica content

The silica content of coir fibres was determined by TAPPI test method, T-245. The residue obtained from the ash content was treated with conc. H_2SO_4 and put in the muffle furnace at 573±25°C for 3h and calculated the percentage of silica present in coir fibre.

The results of the different chemical constituents of coir fibre determined as above are presented in *Table*-1.

Table-1: Proximate chemical constituents of coir fibre

Sl No	Particulars		Results
1	Cold water Solubules	%	10.50
2	Hot water Solubules	%	13.90
3	1% NaOH Solubules	%	17.00
4	Alcohol benzene Solubules	%	13.70
5	Cellulose content	%	36.44
6	Lignin content	%	39.84
7	Ash Content	%	01.80
8	Silica content	%	00.02

3.0 PHYSICAL CHARACTERISTICS OF COIR FIBRE

3.1 Determination of water absorbency:

For determination of water absorbency of coir fibre, 10g of fibres samples were taken and soaked in cold distilled water for 3-4h and 24 h respectively. The fibres were then taken out from water and soaked the surface water with an absorbent media and weighed immediately. The percentages of water absorbed by the fibres at two different periods were recorded in *Table-2*.

3. 2 Determination of fibre dimension and density:

A) The length and diameter of the crude coir fibres was determined with the help of measuring tap and density of the fibres was measured by volumetric method (*Table-2)*

B) For determination of morphological characteristics of individual coir fibre, 20 g fibre were taken and cut into 3 cm length. This was then digested with 10% alkali solution for 3h at boiling temperature. After digestion, the fibres were washed thoroughly with cold fresh water and then air dried. The air-dried fibres were taken in a stainless steel container with sufficient distilled water and disintegrated till the fibres were free from bundles. The bundle free fibres were taken for studying fibre dimensions using microscope The diameter of the fibres was measured in two different microscopic fields and finally an average value was taken for width of each individual fibre. The fibre length and width are shown in *Tablo- 2*.

Table-2: Physical characteristics of untreated coir fibre

Sl no	Properties		Results
1	Water absorbency		80-90%
2	Fibre length, cm		
		Max	25
		Min	18
		Ave	20
3	Fibre diameter, μ	Ave	220
4	Density, g/cc		0.24

4.0 COLLECTION OF OTHER CELLULOSIC PLANT MATERIALS FOR BLENDING STUDY WITH COIR FIBRE:

A number of cellulosic raw materials bearing good quality fibres are available in this region. These plants contain fibres either in bark or in the whole plants. Some of them are cultivated and others are growing wild in the forest. The cultivated plants after harvesting the fruits/crops are remain as agro waste in the field. Whereas the wild species growing in the forests every year and decay without any proper utilization. These annually renewable plants contain substantially good and strong fibres. Some of such cultivated and wild plant species were selected

Based on the availability and fibre quality the following plants species were taken for investigation.

Name of the selected plant species:

1. *Hibiscus esculentus*
2. *Hibiscus sabdariffa*
3. *Hibiscus cannabinus*
4. *Alpinea allughas*
5. *Clynogynae dichotoma* (Patidoi)

Approximately 500 Kg of each sample in the form of bundles were collected from Gorumora area of Jorhat Assam. The plants after removing the leaves and roots were cut into 90 cm length. These were then debarked with the help of Respoder. After removing the bark from the stems, these were digested with NaOH and Na_2C0_3 to get soft and uniform fibres required for blending study.

4.1 DESCRIPTION OF THE PLANT SPECIES

4.1.1 *H esculantus*

It is an annual, soft, small shub cultivated for its edible fruits, which are used as vegetables. The plant is considered to be African or Asian origin. It is grown as a garden crop or home yard plant throughout the tropical and subtropical parts of the world. It is found under cultivation throughout India upto an altitude of 4,000 ft. It is seldom cultivated as a field crop. Bark portion of the plant contain fibres which can be used for making cheap cordage. The mucilage of the fruit and seed is useful in ailment of certain diseases.

H esculantus plant

H esculantus in bundles

4.1.2 *Hibiscus sabdariffa*

It is an erect shub with red green stem, particularly unbranched or with branches near the base. The stems are glabrous or slightly hairy with minute tubercles. The leaves are serrate. The seeds are numerous, large reniform, black brown colour. It is native of Tropical Africa or Asia and cultivated throughout the tropics and comprises a large number of cultivated types. Some varieties are edible. Fibre extracted from the plant is employed for sacking, ropes, fishing nets and generally for all purposes for which jute is used. The calyces

Hibiscus sabdariffa plant

are rich in acid and are used for preparation of Jelly of good quality. These are also used for making refreshing drinks. It has a unique advantage of having long and short fibre in outer and woody part of the plant respectively, making it almost a naturally blended raw material for paper industry.

Hibiscus sabdariffa in bundle

4.1.3 *Hibiscus cannabinus*

It is a herbaceous, hermaphrodite, mostly with bristles annual plant and under favorable climatic conditions, grows as an un-branched stalk to height as tall as 6 meter with a basal diameter of 1.0 – 2.5 cm. Branching are found when it grows in isolation. The colour of flower is yellowish to white. Seeds are nearly glabrous grey and kidney shaped. There are many cultivated varieties commonly known as Mesta. It is fast-growing in nature and in recent years much attention has been given as a potential cellulosic material for paper industry, apart from the normal use as fibre yielding plant.

Hibiscus cannabinus plant

4.1.4 *Alpinea allughas* Rosc.

This is a perennial herb that grows in wild in swampy and marshy lands. It is a naturally growing perennial non-woody plant, which grow in abundance throughout the North Eastern States. *Alpinia allughas* Rosc belong to Alpinia Roxb, the family of 40 species of aromatic herbs. It is a wild plant with rapid growth, having leafy stem of average 0.5 m – 3 m tall, 5 – 15 cm in diameter and the leaves are about 0.30 – 0.50 m in length and 7.5 – 20 cm in breath, smooth and glossy on both surfaces. The branches are pubescent and fewer. The mature *Alpinia* plant contains inner cores surrounded by leaf sheath. The fibres can be extracted from both sheath and core. The sheaths of the plants are mostly used for making ropes.

Alpinea allughas plant

Alpinea allughas in bundle

4.1.5 *Clynogynae dichotoma* (Patidoi)

It is a shub with an erect, glossy green stem of 3– 4m high and 1-3cm diameter. It is distributed widely in Assam, Bengal, Coromondol Coast. Propagation is done by either transplanting root stocks or by cutting. Split stem of the plant are used for making ropes and mats.

Clynogynae dichotoma plant

C. dichotoma in bundle

5.0 EVALUATION OF MORPHOLOGICAL CHARACTERISTICS OF SELECTED PLANT MATERIALS

The morphological characteristics such as plant height, length and diameter of the stem, moisture content, specific gravity of bark and wood, thickness of bark etc. were determined. Some of the morphological characteristics were studied in the field, while some others in the laboratory. The results obtained from different species are recorded in *Table*-3

Table-3: Morphological characteristics of the selected plant species

Sl. No.	Particulars	Name of the plant materials				
		H.esculentus	*H. sabdariffa*	*H. cannabinus*	*A. allughas*	*C. dichotoma*
1.	Height of the plant (Av), m	2.50	2.75	3.60	2.85	3.35
2.	Diameter of the plant (Av), cm	3.5	1.8	1.9	3.0	3.0
3.	Length of the Pseudostem (m)	2.30	3.20	3.25	2.70	3.15
4.	No. of leaves	10-15	Numerous	Numerous	16	10-12
5.	No. of sheath	-	-	-	12	-
6.	Diameter of the Core, (cm)	1.45	0.98	0.7	-	1.5
7.	Moisture content, Av, %					
	Bark	74.8	75.8	74.0	-	72.5
	Wood	73.9	74.2	73.5	-	-
	Sheath	-	-	-	83	-
	Pith / Core	74.6	74.6	72.8	84.3	70.5
	Whole plant	75.0	75.0	73.4	82.0	70.5
8	Wood : Bark	74 : 22	78 : 25	80 : 20	-	-
9	Bark thickness mm	0.85	0.72	0.82	-	0.68
10.	*Specific gravity*					
	Bark	0.25	0.30	0.25	0.26	0.31
	Wood	0.29	0.34	0.29	0.28	0.34
11.	*Average plant constituents% (on OD basis)*					
	Sheath	-	-	-	45	-
	Central Core/Pith	-	18	18	45	79.5
	Leaves & twig	18	20	20	10	20.5
	Bark	20	20	18	-	-
	Wood	60	52	54	-	-

5.1 STUDIES ON PROXIMATE CHEMICAL CONSTITUENTS OF PLANT MATERIALS

The chemical constituents of the plants / barks were determined as per TAPPI standard and suggested methods (Technical Association of Pulp and Paper industry, TAPPI press, Atlanta, USA, 1980). For carrying out proximate analyses, the representative plant parts viz. sheath/barks or whole plants were taken and washed properly with cold fresh water and then dried. The dried plants / plant parts were cut into small pieces and then powdered in a Wiley mill. The powdered samples were then screened though 40 and 60 BS mesh. The powdered fraction passed though 40 BS mesh and retained on 60 BS mesh were used for carrying out proximate chemical analyses following TAPPI standard method. The results of the proximate analyses of different plants (both bark and whole plants) are recorded in *Table* – 4 a & 4 b

Table- 4a. Proximate chemical constituents of the plant materials (Whole plant)

Sl. No	Name of the plants	Moisture content %	Solubility in %				Pantosan content %	Lignin content %	Cellulose content %	Ash content %
			Cold water	Hot water	1 % NaOH	Alcohol benzene				
1	*H. esculantus*	76.8	4.7	7.6	22.6	10.2	11.2	12.6	58.2	0.92
2	*H. sabdariffa*	74.4	3.75	7.20	23.75	4.82	19.0	17.5	58.5	1.15
3	*H. cannabinus*	72.8	3.80	7.50	25.0	6.50	18.0	15.3	58.0	1.35
4	*A. allughas*	82	10.40	13.2	39.4	7.3	15.3	13.5	48.5	2.5
5	*C. dichotoma*	70.5	2.30	6.93	33.11	3.45	20.29	16.26	46.6	5.7

Table- 4b: Proximate chemical constituents of Bark / Sheath materials of the plant

Sl. No.	Name of the plants	Sample	Moisture content %	Solubility in				Pentosan content %	Lignin content %	Cellulose content %	Ash content %
				Cold water	Hot water	1 % NaoH	Alcohol benzene				
1.	*H. esculentus*	Bark	74.8	6.3	10.4	17.3	6.4	10.4	8.7	62.3	2.6
2.	*H. sabdariffa*	Bark	73.7	3.5	7.62	29.8	6.4	13.4	14.6	70.7	4.0
3.	*H. cannabinus*	Bark	70.6	3.2	8.95	31.0	5.2	15.5	12.8	68.2	4.7
4.	*A. sillughas*	Whole plant	78.5	10.4	13.2	39.4	7.3	15.3	13.5	48.5	5.1
5.	*C. dichotoma*	Whole plant	71.3	2.1	5.6	27.4	3.1	22.5	18.7	46.6	8.1

PART II

6.0 PREPARATION OF PLANT MATERIALS FOR EXTRACTION OF FIBRES

6.1 Preparation of coir fibre

Approximately 10 kg of coir fibre was taken and cut into the size of 3 cm length. These were then digested in a stainless steel vessel under pressure free condition using 10% cooking chemicals. The chemicals used for digestion were NaOH and Na_2CO_3 at 1:3 ratios. The fibres were cooked for 3h at boiling temperature maintaining the bath ratio at 1:6. After digestion the fibres were washed properly with cold fresh water till the fibres free from alkali.

The fibres were then air dried and packed in a Polyethylene bag for further studies. The cooking conditions and the removal of lignin from the fibre are presented in *Table*- 5.

Table- 5: Kraft cooking of coir fibre and removal of lignin at different chemical concentrations

Cook no	Chemical used	Chemical concentration,(%)	Cooking time (h)	Lignin removed, (%)	Remarks
1	NaOH: Na_2S	10	3	40	-
2	3:1	12	3	52	"
3	"	14	3	60	"
4	"	16	3	68	"
5	"	18	3	76	Uniform cooking with comparatively soft fibre
6	"	20	3	80	Fibres affected due to higher concentration of cooking liquor

6.2 Extraction of fibres from *Hibiscus esculentus* plant

H. esculentus plant cultivated in the horticultural farm of NEIST-Jorhat was collected in the form of bundles for extraction of fibres. These were washed with cold fresh water to remove the dirt and dust and air dried. The leaves and the roots were removed from the plants and the stem portions were cut into 90 cm length. The barks were removed from the plants mechanically with the help of a fibre extractor. The moisture content of the extracted bark materials was determined prior to cooking. The barks were made into bundles and digested with sodium hydroxide and mixture of sodium hydroxide and Sodium carbonate separately. The chemical concentrations were varied from 4 – 12 % and bath ratio at 1:8. The cooked materials obtained after digestion were washed with cold fresh water and then air-dried. The yield and quality of fibres obtained from both the digestions were determined and presented in the *Table–6*.

Table –6: Cooking conditions and yield of fibres obtained from *H. esculentus* plant

Cook No.	Chemical conc. (%)	Chemical used	Cooking Time (h)	Bath ratio	Fibre Yield (%)	Remarks
1	4	NaOH	3	1:8	-	Uncooked
2	6	-do-	3	1:8	-	Partially cooked
3	8	-do-	3	1:8	53.4	Uniform cooking with good quality fibres.
4	10	-do-	3	1:8	50.5	Uniform fibre with lower yield.
5	6	$NaOH:Na_2CO_3$	3	1:8	-	Uncooked.
6	8	-do-	3	1:8	-	Partially cooked
7	*10	-do-	3	1:8	54.5	Uniform cooking with good quality fibres.
8	12	-do-	3	1:8	52.6	Uniform fibre with less yield.

*Optimum cooking condition with higher yield of fibre.

6.3 EXTRACTION OF FIBRES FROM *Hibiscus sabdariffa*

H. sabdariffa plants cultivated in the horticultural farm of NEIST-Jorhat were collected in the form of bundles. The leaves and roots were removed from the plants and the stem portion was cut into 90 cm length. The bark was removed from the plants with the help of fibre extractor and washed with cold water and air dried. The air dried fibres were then made into bundles by tying both ends with jute twines. The moisture content of the fibres was determined prior to digestion. Like previous experiments, two types of cooking conditions using sodium hydroxide and mixture of sodium hydroxide and sodium carbonate were used. The bath ratio was maintained at 1:8. The cooking chemicals varied from 6 – 12 % at boiling temperature. After the digestion, the cooked materials were washed thoroughly with cold fresh water and then air-dried. The yield and quality of the fibres obtained from both the cooks were determined and presented in the *Table*-7.

Table –7. Cooking conditions and fibre yield of *H. sabdariffa*.

Cook No.	Chemical conc. %	Chemical used	Cooking Time (h)	Bath ratio	Fibre Yield %	Remarks
1	6	NaOH	3	1:8	-	Uncooked
2	8	-do-	3	1:8	56.2	Partially cooked
3	10	-do-	3	1:8	52.6	Uniform cooking with good quality fibre.
4	12	-do-	3	1:8	51.2	Uniform fibre with less yield.
5	8	NaOH: Na_2CO_3	3	1:8	-	Uncooked
6	10	-do-	3	1:8	-	Partially cooked
7	*12	-do-	3	1:8	58.5	Uniform cooking with good quality fibre.
8	14	-do-	3	1:8	51.2	Uniform fibre with lower yield.

*Optimum cooking with higher fibre yield.

6.4 EXTRACTION OF FIBRES FROM *Hibiscus cannabinus*

Hibiscus cannabinus plants cultivated in the horticulture farm of NEIST, Jorhat were taken for the present investigation. Approximately 300kg green plants were collected from the farm in the form of bundles. After removing the leaves, branches and roots, the stem portions were washed with cold fresh water and then air-dried. The barks of the plants were removed with the help of fibre extractor. The moisture content of the bark was determined prior to digestion. Digestion was carried out in a SS cubical vessel varying chemical concentrations from 4–10% using the similar cooking conditions mentioned above. After cooking, the fibres were washed thoroughly with cold fresh water till the fibres were completely free from alkali. The material was then air-dried. The yield and quality of fibres cooked under different conditions were recorded in the *Table* –8.

Table –8: Cooking conditions and fibre yield of *H. cannabinus*

Cook No.	Chemical conc.(%)	Chemical used	Cooking Time (h)	Bath ratio	Fibre Yield (%)	Remarks
1	4	NaOH	3	1:8	-	Uncooked
2	6	-do-	3	1:8	-	Partially cooked
3	8	-do-	3	1:8	55.7	Uniform cooking with higher fibre yield.
4	10	-do-	3	1:8	54.2	Uniform fibre with less yield.
5	6	Na_2CO_3	3	1:8	-	Uncooked.
6	8	-do-	3	1:8	-	Partially cooked
7	*10	-do-	3	1:8	58.0	Uniform cooking with good quality fibre.
8	12	-do-	3	1:8	56.4	Uniform fibre with less yield.

*Optimum cooking with higher fibre yield.

6.5 EXTRACTION OF FIBRES FROM *Alpinea allughas*

A. allughas Rosc, growing wild in the forests areas nearby Jorhat were collected for the present investigation. Approximately 500 kg matured green plant materials were collected from Melang (Jorhat district) and Kaziranga area of Golaghat district. Initial moisture content of the plant material was determined at the time of harvesting. The leaves were removed from the plants and the stem portion was taken for extraction of fibres. The stems were cut into an average length of 90 cm and then washed with cold fresh water. The cleaned stems were then crushed in a two-roll crusher to remove the excess water present in the plant materials. The moisture content of the plants after crushing was also determined. The crushed plant materials were then made in to small bundles and tied at both ends with jute twines.

The digestion of the plant material was carried out in a SS cubical vessel of 90 x 90 x 90 cm size with proper arrangement of heating with LPG. For each digestion 10 kg crushed material was taken and cooked at boiling temperature maintaining bath ratio at 1:10 for 3 h. The chemicals used for cooking were sodium hydroxide and the mixture of NaOH and Na_2Co_3 at 2:1 ratio as in the earlier experiments. A number of experiments were carried out by varying chemical concentration from 6-10% for optimization of cooking conditions. After digestion the cooked materials were washed with cold fresh water till the fibres free from alkali. The yield and quality of the fibres obtained from both the cooking are presented in the *Table*- 9.

Table-9: Cooking conditions and fibre yield of *A. allughas* Rosc.

Cook No.	Chemical conc.(%)	Chemicals used	Cooking time (h)	Bath ratio	Fibre yield (%)	Remarks
1	6.0	NaOH	3	1:10	-	Under cooked
2	7.0		3	1:10	-	-do-
3	8.0		3	1:10	56.5	Uniform cooking with good quality fibre.
4	9.0		3	1:10	52.1	Uniform fibre with less yield
5	10.0		3	1:10	50.2	Over cooked with less fibres yield.
6	6.0	NaOH+ Na_2Co_3 (2:1)	3	1:10	-	Uncooked
7	7.0		3	1:10	-	Partially cooked
8	*8.0		3	1:10	58.75	Strong coarse fibre.
9	9.0		3	1:10	53.4	Uniform cooking with good quality fibre.

*Optimum cooking with higher fibre yield.

6.6 EXTRACTION OF FIBRES FROM *Clynogynae dichotoma.*

Clynogynae dichotoma plants growing wild in the swampy areas in the forest nearby Jorhat were collected for the present investigation. Approximately 200 kg of green matured plants were collected and after removing the leaves and roots the stem portion were cut into 90 cm length and washed with cold fresh water. The cut stems were made into strips by longitudinal splitting to an average of 2.5 – 3.0 cm in width including pith material. Prior to cutting into strips, the moisture content of the green plants was determined. After cutting, the strips were made into bundles and digested with 8-12% NaOH under pressure in a rotary digester of 10 L capacity at 135°C for 3 hours. After digestion, the cooked materials were washed with cold fresh water and air-dried. The yield and quality of the fibres were determined and presented in the *Table*–10.

Table – 10: Cooking conditions and fibre yield of *Clynogynae dichotoma*

Cook No.	Chemical conc.(%)	Cooking Time,(h)	Bath ratio	Yield (%)	Remarks
1	8	3	1:8	-	Uncooked
2	9	3	1:8	51.1	Partially cooked
3	*10	3	1:8	48.5	Uniform cook with good quality fibres.
4	11	3	1:8	46.3	Uniform cook with good quality fibres comparatively less yield.
5	12	3	1:8	42.8	Overcooked with less fibre yield.

*Optimum cooking condition.

FIBRES EXTRACTED FROM DIFFERENT PLANT SPECIES

PART III

7.0 PREPARATION OF RESIN / ADHESIVE:

Some resin/binders were initially selected for making the composite/particle boards from coir and other natural fibre. Based on the physical strength properties of the boards a few resin/binder were selected and used for subsequent investigations. The different resin/binder initially prepared in the laboratory are as follows:

7.1 Urea-Formaldehyde Resin:

Urea formaldehyde (UF) resin was selected as binding material for making boards from coir and other fibres. The UF co-polymer was prepared in the laboratory using urea and formaldehyde at a ratio 1:1.5 and refluxed in presence of a catalyst for 15-20min at 40-45°C. The P^H of the solution was adjusted by adding ammonia solution. After the reaction, the resin solution was cooled down to room temperature and determined the solid content of the prepared resin.

7.2 Phenol-Formaldehyde Resin

Phenol–formaldehyde pre-condensate. 2 mol of phenol (188.0 g) were mixed with 5 mol of formaldehyde solution (405.8 mL) and the P^H was adjusted to 8.0 with about 15.8 mL of a solution of NaOH (0.1mol/L). The mixture was then heated in a hot water bath for 1 h under close observation. Observation was made from time to time till the drops of reaction mixture turns white when added to cold water. The reaction was then stopped and allowed to cool the solution to room temperature and kept in an airtight container. The solid content of the resin was determined before board making.

7.3 Preparation of Guar gum:

Approximately 300 g of Guar gum was taken and mixed with 1000 ml of water; the solution was then boiled till a homogeneous solution is obtained. An anti fungal chemical approximately 0.75% was also added to the solution prior to use. The viscosity and adhesive property of the Guar-gum solution thus prepared was tested before board making.

7.4 Preparation of Polyvinyl alcohol binder:

300 g of polyvinyl alcohol was taken in a glass container and mixed with 1000 ml of water and heated gently till a homogeneous solution is obtained. Stirring was done time to time during the preparation of the solution. The viscosity and the adhesive property of the solution were tested prior to board making.

7.5 Preparation of Polyvinyl Acetate binder:

500g of polyvinyl acetate was taken in a glass container and soaked in acetone (1000ml) for 2-3 h and then mixed with a stirrer till it gets completely dissolved in the solvent. The viscosity of the prepared solution was measured by Brukfield viscometer. The solution thus obtained was kept in an air tight container prior to board making.

7.6 Preparation of Cellulose Acetate binder (CAB):

200 g Cellulose acetate was taken and dissolved in 1000 ml acetone with mild heating. Stirring was done till a homogeneous solution was obtained. After complete dissolution of cellulose acetate the viscosity of the solution was measured in Brukfield viscometer. The prepared solution was kept in air tight container for board making.

7.7 Preparation of polystyrene binder :

100g of polystyrene beads were taken and soaked in 300ml of xylene for 2-3 h. When the polystyrene beads softened, 200 ml of more xylene was added and stirred with 15-20 min till a homogenous solution is obtained. The viscosity of the solution was measured in Brukfield viscometer prior to use.

7.8 Preparation of Natural rosin binder:

300 g of rosin was taken in round bottom flask and added 1000 ml of methanol and then heated in a water bath till it completely dissolved. A fortifying agent was added during the preparation of the solution to enhance the reactivity and binding efficiency of rosin with coir fibre. The binding solution thus obtained was kept in an air tight container for further study.

PART IV

8.0 EXPERIMENTS ON BOARD MAKING

8.1. BOARD MAKING WITH COIR FIBRE USING UF RESIN

The UF resin prepared earlier in the laboratory was diluted to 20% solid content by adding measured quantity of water and then mixed with the coir fibre. The boards were made by varying the percentage of resin for optimization of resin requirement to get higher physical strength properties of the boards. For each batch 350g fibres were taken in a stainless steel tray and mixed with required quantity of PF resin binder manually. After proper mixing, the fibres were dried in sun for sometime to maintain the moisture content 12 ± 2 %. These were then put into the wooden mould of size 14" X 14" and spread uniformly to form a mat. It was then put into the hydraulic press maintaining temperature 140± 5°C and pressures 180± 10 kg/cm^2 for 15 min. after that the pressure of the hydraulic press was released and kept the boards under normal temperature.

A separate experiment was also conducted in the laboratory by varying the curing time, temperature and the pressure for optimization of these parameters for board making. The physical strength properties of the boards made from coir fibre varying percentage of resin are presented in *Table-11*

Table-11: Physical strength properties of boards made from coir fibre using UF resin

Sample No	Resin used %	Thickness mm	Density g/cm^3	Moisture content %	MOR Kg/cm^2	Water absorption %	Total swelling due to surface absorption , %
A		8.15	0.70	9.4	112	28	24
A1	15	8.18	0.72	9.2	114	26	20
A2		8.16	0.70	9.6	115	29	21
B		8.18	0.74	9.2	120	20	19
B1	*20	8.14	0.72	9.1	118	20	21
B2		8.16	0.74	9.0	122	19	18
C		8.18	0.75	9.0	120	18	14
C1	25	8.16	0.74	9.8	124	20	15
C2		8.14	0.72	9.6	118	21	13

* Optimum resin requirement for board making.

8.2 BOARD MAKING WITH COIR FIBRE USING PF RESIN

The PF resin prepared earlier in the laboratory was taken for the present investigation on board making. The solid content of the prepared PF resin was determined. The required quantity of PF resin was taken and diluted to 25% by adding water and then mixed with the fibres. The boards were made by varying the percentage of resin to get optimum resin requirement and boards of higher physical strength properties. For each batch, 350g fibres were taken in a stainless steel tray and mixed with the resin binder manually. After proper mixing with the resin, the fibres were dried in sun for sometime to maintain the moisture content 12±2%. These were then put into the wooden mould of the size 14"X14" and spreaded uniformly to form a mat. It was then put into a hydraulic press maintaining temperature 140±5^{0}C and pressure 180±10kg/cm^2 for 15 min. The pressure of the hydraulic press was released and the boards were taken out and kept under normal temperature for conditioning.

A series of experiments were also conducted in the laboratory, by varying the curing time, temperature and pressure for optimization of the process parameters. The physical strength properties of the boards obtained by varying resin quantity are presented in *Table- 12*.

Table-12: Physical strength properties of boards made from coir fibre using PF resin

Sample	Resin used %	Thickness mm	Density g/cm^3	Moisture content %	MOR Kg/cm^2	Water absorption %	Total swelling due to surface absorption , %
A		8.10	0.78	8.4	115	12.8	1.8
A1	10	8.09	0.80	8.3	120	12.6	1.7
A2		8.15	0.80	8.6	122	12.5	1.8
B		8.11	0.85	8.8	152	12.4	1.6
B1	*15	8.08	0.84	8.6	155	12.2	1.6
B2		8.15	0.85	8.9	154	12.5	1.5
C		8.10	0.86	8.8	158	12.6	1.5
C1	20	8.12	0.87	8.6	156	12.4	1.6
C2		8.15	0.86	8.5	151	12.0	1.5

* Optimum resin requirement for board making

8.3 BOARD MAKING WITH COIR FIBRE USING PF & UF MIXTURE:

Board samples were also made from the mixture of UF and PF resin at different ratio. For making the boards 350 g coir fibre of the same fibre length as in earlier experiments were taken and mixed with the required quantity of PF & UF mixture. After proper mixing, the fibres were dried in air till the moisture content came around 12±2%. These were then put into the wooden mould of size 14″ X 14″ as in the case of earlier experiments and then put into a hydraulic press maintaining temperature 120±5^{0}C and pressure 180±10 kg/cm^2 for 15 min. The pressure of the hydraulic press was released after 15 min and kept for sometime under normal temperature. The results of the board samples made from different ratio of UF & PF mixture are reported in *Table* -13.

Table-13: Physical strength properties of boards made from coir fibre using PF & UF mixture.

Sample No	Blend ratio PF:UF	Thickness mm	Density g/cm^3	Moisture content, %	MOR Kg/cm^2	Water absorption, %	Total swelling due to surface absorption, %
A		8.25	0.75	8.2	135	18	1.6
	25:75	8.25	0.72	8.3	138	19	1.4
		8.20	0.74	8.5	136	18	1.5
B		8.10	0.80	8.5	145	16	1.5
	*50:50	8.12	0.82	8.2	148	14	1.3
		8.08	0.80	8.2	147	16	1.3
C		8.00	0.84	8.0	151	15	1.4
	75:25	8.10	0.86	8.1	152	14	1.5
		8.10	0.82	8.3	150	14	1.3

* Optimum resin requirement for board making.

8.4 BOARD MAKING WITH COIR FIBRE USING UF AND GUAR GUM MIXTURE:

Experimental boards of the size 30X30cm were made from coir fibre using the mixture of UF and Guar gum solution at different ratio. The required quantity of the mixture solution was added to the coir fibre and mixed properly for sometime and then dried in air to maintain moisture content at 12 ± 2 %. Then the fibres were put into the wooden mould of 30 X 30 cm size and the boards were made as per the procedure followed in the earlier experiments. The board samples thus made were tested and the results of the physical strength properties obtained at different blend ratio are presented in *Table*-14

Table-14 Physical strength properties of boards made from the mixture of UF and Guar gum at different blend ratio

Sl No	Blend ratio UF:Guar-gum	Thickness of boards, mm	Density, g/cm^3	Moisture content, %	MOR Kg/cm^2	Water absorption, %	Total swelling due to surface absorption, %
1	100:0	8.25	0.72	9.8	120	18	18
2	75:25	8.28	0.78	10.0	98	20	20
3	*50:50	8.35	0.75	10.2	95.6	22	20
4	25:75	8.43	0.73	10.5	92.3	24	22

*Optimum blend ratio for board making

8.5 BOARD MAKING WITH COIR FIBRE USING PF AND GUAR GUM MIXTURE.

Experimental board samples of 30 X 30cm size were also made from coir fibre using the mixture of PF and guar gum at different ratio. For making the boards, approximately 500g of coir fibre sample of 1cm length was taken and mixed with different proportion of PF and guar gum. The board samples were made adopting the similar conditions mentioned in the earlier experiments. The physical strength properties of the board sample made from PF and Guar gum mixture are tested and the results are presented in *Table- 15*.

Table- 15: Physical strength properties of boards made from mixture of PF and Guar gum

Sl No	Blend ratio PF: Guar gum	Thickness of boards, mm	Density, g/cm^3	Moisture content, %	MOR Kg/cm^2	Water absorption, %	Total swelling due to surface absorption, %
1	100:0	8.00	0.85	8.2	155	14	15
2	75:25	8.30	0.80	9.4	105	16	18
3	*50:50	8.42	0.75	9.8	100	18	20
4	25:75	8.58	0.71	10.6	95	22	24

* Optimum ratio of PF and Guar gum for board making

8.6 BOARD MAKING WITH COIR FIBRE USING POLYVINYL ALCOHOL (PVA) BINDER:

Experiments were conducted for making boards from coir fibre using polyvinyl alcohol binder. 500 g coir fibre of 1 cm length was taken and mixed with polyvinyl alcohol solution of different concentration and then air dried. Boards of 30cmX30 cm were made under hot press maintaining the same conditions as in the earlier experiments. These were then conditioned and kept for determination of physical strength properties. The physical strength properties of the board samples made from different concentration of polyvinyl alcohol solution were tested and the results are presented in *Table*-16.

Table-16: Physical strength properties of boars made from coir fibre using polyvinyl alcohol binder.

Sl No	Concentration of PVA solution %	Thickness of boards, mm	Density, g/cm^3	Moisture content, %	MOR Kg/cm^2	Water absorption, %	Total swelling due to surface absorption, %
1	15	8.25	0.82	11.2	105	30	25
2	20	8.30	0.80	12.4	110	28	20
3	*25	8.35	0.78	12.0	120	25	20
4	30	8.42	0.76	11.8	132	22	18

* Optimum PVA requirement for board making

8.7 BOARD MAKING WITH COIR FIBRE USING POLY VINYL ACETATE (PVAc) BINDER:

200g of digested coir fibre of 1cm length was taken and mixed with 10-25 % PVAc solution on OD weight of the fibre. A hardening agent i.e. Poly amido amine was used during the time of mixing of coir fibre with PVAc solution. These were kept for sometime in the open air and then put into the wooden mould of the size 15 X 15cm. The boards were made as per the conditions mentioned in the earlier experiments. The boards were kept some time for conditioning and the the physical strength properties were tested and presented in *Table-17*.

Table-17: Physical strength properties of boards made from coir fibre using Poly Vinyl Acetate binder

Sl No	PVAc Used %	Thickness of boards, mm	Density, g/cm^3	Moisture content, %	MOR Kg/cm^2	Water absorption, %	Total swelling due to surface absorption, %
1	10	7.75	0.78	10.2	120	15	4.8
2	15	7.80	0.78	8.4	125	11	3.8
3	*20	7.85	0.80	9.0	132	10	1.7
4	25	7.88	0.80	8.2	130	8	1.7

* Optimum PVAc requirement for board making

8.8 BOARD MAKING WITH COIR FIBRE USING BLACK LIQUOR LIGNIN:

Board samples were also made from the mixture of coir fibre and black liquor lignin extracted from coir fibre adopting soda process. Approximately 500g coir fibre was taken and mixed with black liquor lignin of different concentration varying from 8-20%. A hardening agent was also used during the time of mixing. The mixture of coir fibre and black liquor lignin was then put in the wooden mould and pressed under hydraulic press maintaining the similar conditions mentioned above. The board samples thus made were conditioned and tested for different physical strength properties.

The physical strength properties of the boards made from the mixture of coir fibre and black liquor lignin are presented in *Table-18*.

Table-18: Physical strength properties of boards made from coir fibre using black liquor lignin

Sl No	% of Black liquor lignin	Thickness of boards, mm	Density, g/cm^3	Moisture content, %	MOR Kg/cm^2	Water absorption, %	Total swelling due to surface absorption, %
1	8.0	8.20	0.68	20.6	85	22	20
2	12.0	8.10	0.70	18.4	90	20	16
3	*16.0	8.00	0.75	16.3	110	16	15
4	20.0	8.0	0.78	15.2	115	15	14

* Optimum black liquor lignin requirement for board making

8.9 BOARD MAKING FROM COIR FIBRE USING WASTE POLYETHELENE BAG CUTTINGS:

A series of experiments were conducted in the laboratory for making composite board from the mixture of coir fibre and waste polyethylene bags cuttings at different proportion. Polyethylene bags (PE) of lower density were considered for the present investigation. The waste bags were first screened and after removal of dust and foreign particles, these were cut in a chopping machine. The cut pieces obtained from the chopper were mixed with coir fibre for making the boards.

Approximately 400g of coir fibre was taken and mixed with 200gms of waste PE bag cuttings. These were then mixed with coir fibres in such a way that the cut pieces were uniformly distributed all around the fibre mass. These were then put into the wooden mould of size 15 X 15 cm and then hot pressed at 80±5°C for 20 min and at 150±5 kg/cm^2 pressure. A releasing agent was spreaded in the both side of the fibre mass before hot pressing. After that, the pressure was released from the hot press and the boards were kept for sometime in open air for conditioning. The physical strength properties of the boards made from the different proportion of PE waste bag cuttings and coir fibre are presented in *Table-19*.

Table-19: Physical strength properties boards made from the mixture of coir fibre and waste Polyethylene bag

Sl No.	Blend ratio Coir: PE	Thickness of boards, mm	Density, g/cm^3	Moisture content %	MOR Kg/cm^2	Water absorption %	Total swelling due to surface absorption, %
1	75:25	8.3	0.78	4.8	140	2.5	0.5
2	*50:50	7.2	0.70	3.7	175	1.8	0.2
3	40:60	7.8	0.74	3.0	161	2.0	0.5

* Optimum condition for board making.

8.10 BOARD MAKING FROM COIR FIBRE USING CELLULOSE ACETATE BINDER (CAB):

450g of digested coir fibre was taken and mixed with different percentage of CAB binder prepared earlier and dried in air for 30 min. The fibres were then put into the wooden mould of 30 X 30 cm and boards were made as per the conditions mentioned in the earlier experiments. A number of experiments were conducted for optimization of process parameters for making boards. The physical strength properties of the boards using different percentage of CAB are presented in *Table-20*.

Table -20: Physical strength properties of the boards made from Coir fibre using Cellulose acetate binder

Sl No	CAB used %	Thickness of boards, mm	Density, g/cm^3	Moisture content %	MOR Kg/cm^2	Water absorption, %	Total swelling due to surface absorption, %
1	10	8.10	0.73	8.4	120	14	1.6
2	15	7.98	0.78	8.0	128	12	1.2
3	*20	7.65	0.80	7.0	130	9.0	1.0
4	25	7.60	0.84	6.9	140	8.5	0.8

* Optimum CAB requirement for board making.

8.11 BOARD MAKING FROM COIR FIBRE USING NATURAL ROSIN BINDER:

450g of digested coir fibre was taken and mixed with different percentage of natural rosin solution prepared earlier in the laboratory and then dried for 30-45 min in air till the moisture content came down to 15±2 %. The fibres were then put into the wooden mould of 30X 30cm size and boards were made as per the conditions mentioned earlier. For optimization of process parameters, a series of experiments were conducted in the laboratory. The physical strength properties of the boards using different percentage of natural rosin solution are presented in *Table-21*.

Table-21: Physical strength properties of boards made from Coir fibre using rosin binder

Sl No	Rosin used, %	Thickness of boards, mm	Density, g/cm^3	Moisture content,%	MOR Kg/cm^2	Water absorption, %	Total swelling due to surface absorption, %
1	10	8.30	0.68	10.0	105	24	3.0
2	15	8.12	0.73	9.2	120	20	2.1
3	20	7.90	0.78	9.1	135	19.5	1.9
4	*25	7.85	0.80	8.4	150	14.8	1.8
5	30	7.65	0.85	8.0	155	14.5	1.2

* Optimum rosin requirement for board making

PART-V

9.0 UTILIZATION OF COIR FIBRE FOR BLENDING WITH OTHER NATURAL FIBRES IN BOARD MAKING:

A series of experiments were conducted for utilization of other natural fibre along with coir fibre in order to improve quality as well as to make it economically feasible. The coir fibre is not locally available in this region and whatever it is available in the local market are mostly brought from outside. Therefore for development of a product based on coir fibre becomes cost intensive. Based on the above fact, it was considered to utilize locally available suitable cellulosic waste material in order to retain the quality as specified by IS specification, at the same time it is cost effective. For blending 50% of coir fibre and 50% of other natural fibre were mixed in a pulvarizer and then mixed with required quantity of resin/binders. Based on the results obtained form the earlier experiments only those binders which gave encouraging results were selected for blending studies.

9.1 BOARD MAKING FROM THE BLENDS OF COIR AND OTHER NATURAL FIBRE USING UF, PF AND MIXTURE OF UF& PF RESIN.

The board samples were made from the blends of coir and other natural fibre extracted from *H. esculentus, H. sabderiffa, H. cannabinus, A. allughas, C. dicotoma* using UF, PF and the mixture of UF and PF resin. The test results of the boards made from the above blends are presented in the *Table-22a*, *Table-22b* and *Table-22c*.

Table-22a: Physical strength properties of boards made from the blends of Coir and other natural fibre using UF (20%) resin

Sample	Thickness mm	Density g/cm^3	Moisture content, %	MOR Kg/cm^2	Water absorption, %	Total swelling due to surface absorption,%
Coir and *H. sabdariffa*	8.16	0.84	8.0	128	15	1.8
Coir and *A. allughas*	8.25	0.76	9.5	130	16	1.5
Coir and *H. esculentus*	8.20	0.80	9.6	115	18	2.5
Coir and *H. cannabinus*	8.15	0.86	8.2	128	16	1.9
Coir and *C. dichotoma*	8.22	0.78	9.4	112	20	2.8

Table-22 b: Physical strength properties of boards made from the blends of Coir and other natural fibre using PF (15%) resin

Sample	Thickness mm	Density g/cm^3	Moisture content, %	MOR Kg/cm^2	Water absorption %	Total swelling due to surface absorption, %
Coir and *H. sabdariffa*	8.00	0.78	9.5	156	10.4	1.9
Coir and *A. allughas*	8.26	0.75	9.8	158	11.3	1.2
Coir and *H. esculentus*	8.45	0.80	8.9	135	11.2	1.3
Coir and *H. cannabinus*	8.01	0.83	9.9	155	10.8	1.5
Coir and *C. dichotoma*	8.56	0.75	8.5	135	11.9	2.1

Table -22c: Physical strength characteristics of boards made from the blending of Coir and other natural fibre with PF: UF (50:50) mixture

Sample	Resin used % (PF: UF 50:50)	Thickness mm	Density g/cm^3	Moisture content, %	MOR Kg/cm^2	Water absorption %	Total swelling due to surface absorption, %
Coir and *H. sabderiffa*		8.20	0.82	9.6	152	15	1.5
Coir and *A. allughas*		8.18	0.78	9.0	156	12	1.4
Coir and *H. esculentus*	20	8.25	0.75	8.9	140	16	1.8
Coir and *H. cannabinus*		8.30	0.73	9.3	150	14	1.7
Coir and *C. dichotoma*		8.35	0.70	9.8	130	13	1.6

9.2 BOARD MAKING FROM THE BLENDS OF COIR AND OTHER NATURAL FIBRE USING CELLULOSE ACETATE BINDER (CAB).

The board samples were made from the blends of coir and other natural fibre using *H. esculentus*, *H. sabderiffa*, *H. cannabinus*, *A. allughas*, and *C. dicotoma* with 20% cellulose acetate binder and the test results are presented in the *Table-23*.

Table- 23: Physical strength properties of boards made from the blends of Coir and other natural fibre using cellulose acetate binder (20%)

Sample	Thickness mm	Density g/cm^3	Moisture content. %	MOR Kg/cm^2	Water absorption%	Total swelling due to surface absorption %
Coir and *H. sabdariffa*	7.85	0.75	8.2	145	9.2	1.2
Coir and *A. allughas*	8.01	0.80	7.5	150	8.5	1.1
Coir and *H. esculentus*	7.85	0.74	7.9	135	8.2	2.1
Coir and *H. cannabinus*	8.0	0.78	7.8	150	9.8	1.3
Coir and *C. dichotoma*	7.5	0.72	8.4	130	8.5	1.8

9.3 BOARD MAKING FROM THE BLENDS OF COIR AND OTHER FIBRE USING NATURAL ROSIN BINDER.

The board samples were made from the blends of coir and other natural fibre using *H. esculentus*, *H. sabderiffa*, *H. cannabinus*, *A. allughas*, and *C. dicotoma* with 25% rosin binder and the test results are presented in the *Table- 24.*

Table- 24: Physical strength properties of boards made from the blending of coir and other natural fibre using natural rosin binder (25%)

Sample (50:50)	Thickness mm	Density g/cm^3	Moisture content, %	MOR Kg/cm^2	Water absorption %	Total swelling due to surface absorption, %
Coir and *H. sabderiffa*	8.0	0.72	9.5	150	9.3	2.0
Coir and *A. allughas*	8.2	0.75	8.7	160	8.8	1.5
Coir and *H. esculentus*	8.4	0.78	8.8	135	9.0	2.3
Coir and *H. cannabinus*	7.9	0.74	8.5	151	10.0	1.9
Coir and *C. dichotoma*	8.0	0.78	9.0	130	11.3	2.4

9.4 BOARD MAKING FROM THE BLENDS OF COIR AND OTHER NATURAL FIBRE USING POLYVINYL ACETATE BINDER.

The board samples were made from the blends of coir and other natural fibre mentioned earlier using 20% polyvinyl acetate binder and the test results of the boards samples are presented in the *Table-25*

Table -25: Physical strength properties of boards made from the blends of coir and other natural fibres using PVAc (20%)

Sample (50:50)	Thickness mm	Density g/cm^3	Moisture content, %	MOR Kg/cm^2	Water absorption,%	Total swelling due to surface absorption,%
Coir and *H. sabderiffa*	8.0	0.73	11.3	128	12	2.1
Coir and *A. allughas*	7.9	0.75	10.0	135	11	1.8
Coir and *H. esculentus*	7.6	0.78	10.6	120	10	2.2
Coir and *H. cannabinus*	8.2	0.70	11.2	130	09	1.7
Coir and *C. dichotoma*	8.0	0.74	11.8	115	13	2.5

9.5 BOARD MAKING FROM THE BLENDS OF COIR AND OTHER NATURAL FIBRE USING WASTE POLY ETHYLENE BAG CUTTINGS.

The board samples were made from the blends of coir and other natural fibre (50:50) using 40% poly ethylene bag cuttings adopting the procedure mentioned earlier. The results of the board samples made from the blends of coir and other natural fibre are presented in the *Table-26*.

Table-26: Physical strength properties of boards made from the blends of coir and other natural fibres using waste polyethylene bag

Sample (50:50)	Thickness mm	Density g/cm^3	Moisture content, %	MOR Kg/cm^2	Water absorption, %	Total swelling due to surface absorption , %
Coir and *H. sabderiffa*	7.8	0.80	1.8	168	1.6	0.75
Coir and *A. allughas*	7.4	0.75	1.5	170	1.4	0.62
Coir and *H. esculentus*	7.0	0.78	1.6	148	1.8	0.85
Coir and *H. cannabinus*	7.2	0.70	1.8	168	1.3	0.78
Coir and *C. dichotoma*	7.1	0.68	2.1	140	1.5	0.92

10.0 INVESTIGATION ON COIR FIBRE - CEMENT COMPOSITE BOARDS:

An exploratory investigation was carried out for making composite boards from the blends of coir fibre and Portland cement similar to that of asbestos cement board. Thin sheet made of Portland cement alone is too brittle and rigid. Addition of requisite amount of fibrous material reinforces cement products and improves its tensile strength. The use of fibre as reinforcing material was known since making the first sun baked mud bricks. Conventionally asbestos fibres are used with the cement for manufacturing asbestos cement building boards. As asbestos fibres are found to be health hazards therefore in recent years search for alternative fibre resource for making such building are going on in various parts of the world. It is thought that certain cellulosic fibre of higher physical strength properties may be a suitable alternative to asbestos fibre for making building board. Considering the physical strength properties of coir fibre an investigation was carried out for utilization of Coir fibre for making of building boards using Portland cement comparable to asbestos cement baord.

10.1 Preparation of Coir fibre for reinforcement with cement

Approximately 1kg of coir fibre was taken and cut into 1cm length. The cut fibres were digested with 10% Sodium hydroxide at 100°C maintaining bath ratio at 1:6 for a period of three hour. After the digestion the cooked fibres were properly washed with clean fresh water till the fibres free from alkali. The fibres were then air dried and again treated with 10% ammonium oxalate solution for 30-45 minutes with mild heating. The fibres were then washed properly and then beaten in a laboratory valley beater at 35-40 SR freeness.

10.2 Fibre Cement-Board Making

Experiments were conducted in lab scale for making coir fibre cement cement board using different proportion of coir fibre and Portland cement. For preparation of cement fibre stock, the required quantity of cement and water was taken in an aluminum container and mixed in a high speed stirrer. Fibres were added to the stock at different proportion during stirring. A wetting agent was added to the stock during stirring. After 30 mins, the stirring was withdrawn and multilayered boards were made with the prepared stock. The sheets were then pressed in hydraulic press for 5 minutes at a pressure 64Kg/cm^2. The initial application of load was slow to prevent damage or crushing of internally bonded fibres. The boards were made from the stock of coir fibre and cement at different proportions was cured in water for 28 days. The physical strength properties the boards after 28 days of conditioning are tested and results are presented in *table 27*.

Table 27: Physical strength properties of the coir fibre cement boards

Sl no	Coir fibre	Cement	Density g/cm^3	Breaking load Kg (Total)	Breaking load Kg/cm2 (Width)	Bending stress Kg/cm2	Water absorption %
1	5	95	1.38	6.5	0.26	19.2	30
2	7.5	92.5	1.43	6.8	0.25	22.6	32
3	10	90.0	1.50	5.2	0.22	18.7	31
4	12.5	87.5	1.65	4.8	0.20	15.4	30

It has been observed from the results that the boards made out of different ratio of coir fibre and cement composite showed good physical strength properties however certain properties such as smoothness, water absorbency, density, breaking load etc were not found up to the mark. Hence further investigation in this line was not continued.

Table-28. Comparative study on test results of laboratory samples as per IS specification.

Sl no	Particulars of test	Particle board samples using								
		UF	PF	UF& PF	PVAc	CAB	Rosin	PE	Medium density particle board. IS: 12833:1990	
									Grade I	Grade II
1	Density variation, (Max) %	0.82	0.84	0.85	0.80	0.78	0.80	0.70	±10	±10
2	Water absorption, (Max %)									
	2 h								7.0	15.0
	24 h	20	12.2	15	10	9	18	1.8	15.0	30.0
3	Modulus of rupture (Min) N/mm^2	11.8	12.5	15	13.0	14.8	15.5	16.5	15	11
4	Tensile strength, perpendicular to surface, N/mm^2 (average)	0.38	0.40	0.42	0.44	0.45	0.45	0.48	0.45	0.30
5	Falling hammer impact test	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	passed
6	Screw withdrawal strength, (min)N									
	Face	1250	1275	1275	1280	1290	1250	1300	1250	1250
	Edge	750	750	780	780	800	780	850	850	750

DIFFERENT STAGES OF BOARD MAKING

RAW COIR FIBRE

MACHANICAL TREATMENT OF COIR FIBRE

FIBRES PASSING THROUGH CARDING MACHINE

MIXING WITH BINDING CHEMICALS

PREPARATION OF FIBRES FOR BOARD MAKING

BOARD MAKING

BOARDS FROM COIR FIBRE

PART -VI

11. RESULTS AND DISCUSSION:

It has been observed from the above experimental work that coir fibre alone or in combination with other natural fibre may easily be utilized for making particle/composite board of suitable grades. The results of the present investigation are summarized as follows.

The proximate chemical constituents of coir fibre have been reported in *Table 1*, which shows higher lignin content (39.84%) with less percentage of cellulose (36.44%). The other constituents of the coir fibre are comparable to conventional cellulosic plant material. The physical characteristic of coir fibre shows less water absorbency to that of other cellulosic fibre. The fibres as such are long measuring an average of 20cm. (*Tabel-2*).

Apart from coir fibre, a few other potential fibre yielding plants of NE region were also studied in order to blend with coir fibre for making boards. The morphological characteristics of these plant materials are given in *Table-3*, shows luxuriant growth and development under the climatic condition of North eastern region. The chemical constituents of these plants show the cellulose content varies from 46.6-58.5% and lignin from 12.6-17.5% (*Table-4a*). In a separate study on chemical constituent of the bark/sheath material, it is revealed that the cellulose content is significantly higher in the bark/sheath portion and varies from 46.6-70.7 (*Table-4b*).

Table- 5 shows the cooking condition of coir fibre along with the percentage of lignin removed during cooking. The fibres obtained after cooking were soft in comparison to that of raw fibre and suitable for blending with other cellulosic fibres. As the coir fibre as such is comparatively harder, therefore a mild cooking with alkali is required to make the fibres soft prior to board making.

The extraction of fibres from *H.sabderiffa*, *H.cannabinus*, *A.allughas*, and *H esculentus*, *C.dichotoma* plants are presented in *Table 6-10*. The requirement of cooking chemicals at which these plants produced maximum fibre yield was from 9-12 % and the respective fibre yield was from 48.5-58.5%. The highest yield of fibres is recorded 58.5 % in *H.sabderiffa* followed by *H.cannabinus* 58.5%, *A.allughas* 53.4% *H esculentus*54.5%, and C. *dicotoma* 48.5%.

The different resin/adhesive used in the present investigation such as UF, PF, Guar gum, Polyvinyl alcohol, Polyvinyl acetate, Cellulose acetate, Polystyrene and Natural rosin were prepared in the laboratory. These were prepared under certain specific condition and studied certain physical properties prior to board making.

The test results of the board samples made from coir fibre alone using different resin/ binding materials are presented in *Table 11-21*. It has been observed from the investigation, that the boards made from UF, PF, UF and PF mixture, Guar gum, Cellulose acetate and Rosin adhesive shows better physical strength properties. Board samples were also made from the mixture of coir and waste polyethylene bag cuttings which show satisfactory physical strength properties with minimum water absorbing property.

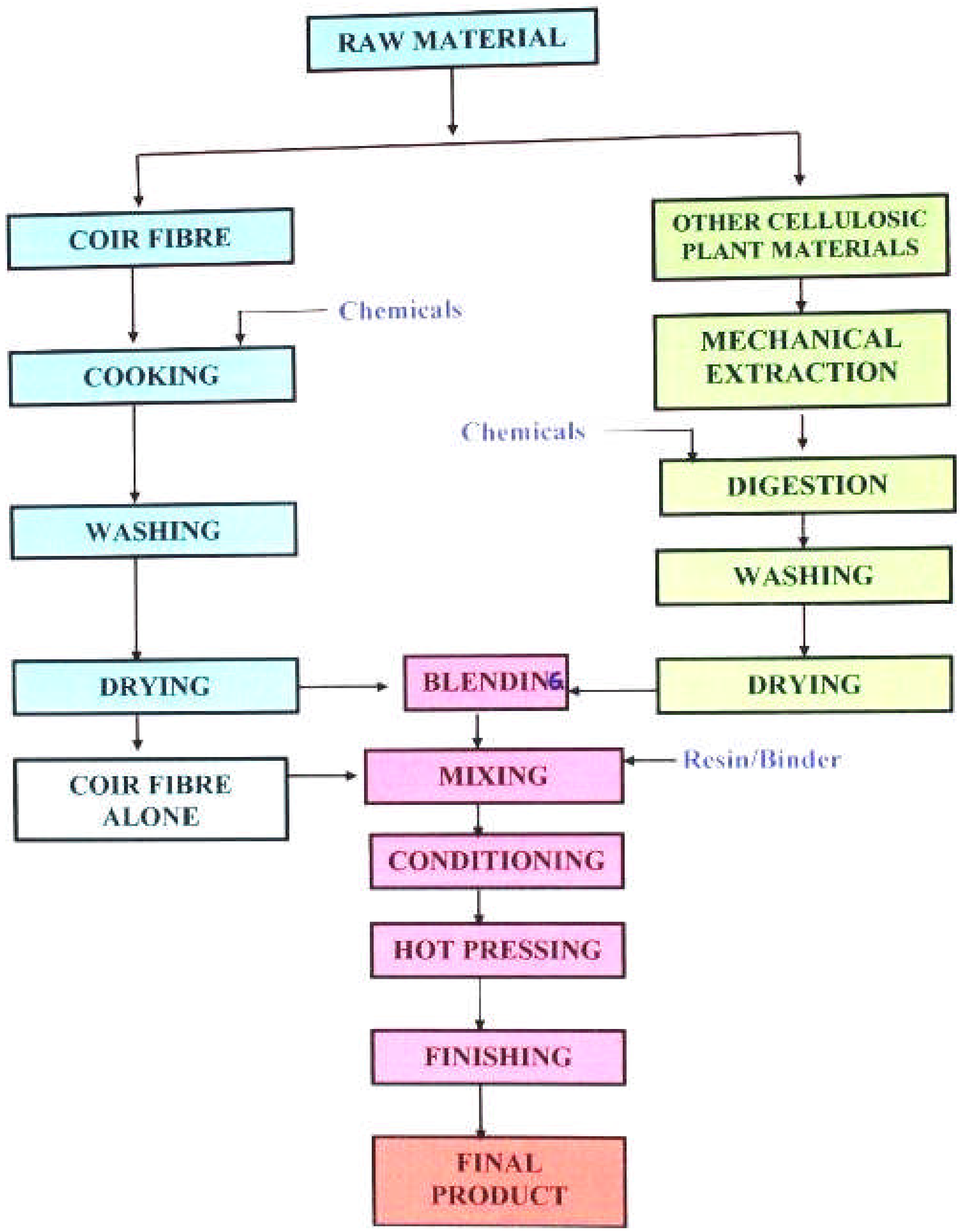
The use of natural rosin binder for making particle/composite board from coir fibre may play an important role because rosin is a natural substance which is eco friendly and has no hazardous affect on human health as well on the environment. Boards made from the coir fibre using rosin, shows MOR value 155 kg/cm^2 with better smoothness. The physical strength properties of the boards may further be enhanced by blending of certain cellulosic fibre with coir fibre (Table-22a-26). Additions of such fibres enhanced MOR, surface smoothness, compactness and bonding efficiency in the board samples. The fibres of *H. sabderiffa*, *H. cannabinus*, and *A. allughas*, are comparatively soft and flexible to that of coir fibre. During the processing of the boards, these fibres filled the gaps between coir fibre matrix and enhanced the surface smoothness as well as compactness of the boards and higher MOR value.

Among the different cellulosic raw material selected for blending study, the species such as *H.sabdariffa*, *A. allughas* and *H. cannabinus* gave better results in comparison with *H.esculentus* and *C.dichotoma*. Therefore *H.esculentus* and *C. dichotoma* were not selected for blending study.

Out of the different resin used in the above investigation PF, UF, PF and UF mixture PVAc, Cellulose acetate, Natural Rosin and waste polyethylene bag cuttings showed better physical strength properties in the board samples meeting IS specification for particle board.

Among the other resin/binder such as Polyvinyl alcohol, guar gum, black liquor lignin were not found suitable for board making because of higher absorption of moisture by the boards during storage, affecting physical strength properties. Therefore these resin/adhesive were not considered appropriate for use as a binder for making particle/composite board.

PROCESS FLOW CHART FOR BOARD MAKING



CONCLUSION:

A conclusion may be drawn from the above investigation that coir fibre alone or with the mixture of other cellulosic fibres such as *H sabderiffa*, *H cannabinus*, and *A allughas* have been found suitable for making particle/composite board of desired property. The binder/adhesive which showed better results were UF, PF, UF and PF mixture, Cellulose acetate, polyvinyl acetate and natural rosin binder. The waste polyethylene carry bag cuttings can also be utilized with coir fibre for making composite boards of higher physical strength properties.

Considering the environmental problems caused by various industries of our country, it may be suggested that the use of formaldehyde free binding material for manufacturing building construction materials like particle/composite board may be found potential in the coming years. The natural rosin and cellulose acetate binder have certain advantages, as they are eco-friendly and doesn't create any pollution during the manufacturing of the boards.

The use of waste polyethylene bag cuttings for making composite board from coir fibre has certain added advantages as it not only helps in enhancing the physical strength properties, but also helps in keeping the environment clean.