Jute Technology Mission: Design & Development of JDPS
(Mini Mission IV)

Final Report

Project Title

Development of Jute—Bamboo Composites for Applications in Rural Areas

INDIAN JUTE INDUSTRIES' RESEARCH ASSOCIATION

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Executive Summary

Diversifications of natural fibres from their traditional markets to other potential sectors (building, furniture, automotive components, packaging etc) has gained interest in developing countries to meet the pressing demands of conventional materials, especially wood substitute. . One of the promising applications of natural fibres is in the area of polymer composites where there is a wide scope for exploitations to various types of structural and non-structural useful commodities. The incentive for producing these natural fiber based components originates from their low cost, light weight, and eco-friendly and energy saving processes. Among natural fibres, jute, bamboo may be tried out since they are abundantly available and may find non-conventional new outlets in the form of composites. Jute composites as such have some niche markets where they could not be utilized as structural materials because of higher density, processing problem and moisture absorption.

The incorporation of two or more different fibers into a single matrix (binder) has led to the development of hybrid composites. Using a hybrid composite that contains two or more type's fibre, the advantages of one type of fibre could complement with what are lacking in the other. As a consequence, a balance in cost and performance could be achieved through proper material design. With that concept, the objective was to develop jute – bamboo hybrid composites in the form of board for utilization of rural sector.

Jute in the form of non-woven and bamboo in the form of mat have been chosen as reinforcing fibre component and hydrophilic water soluble phenol formaldehyde resin has been chosen as matrix binder for better compatibility and wettability so that less quantity of binder may be required to produce cost driven composite. Thus, a better outlet as non- conventional and non-textile jute diversified product with optimum utilization of bamboo for a better performance than jute composite could be commercialized. A good number of experiments were conducted to make jute-bamboo hybrid composites at varying parameters like resin content, variation of jute bamboo ratio for reinforcement, temperature , pressure, duration of pressing etc. Jute has been chosen as reinforcement more than 50% in combination with bamboo mat either single or double layers in one face or both the faces. Resin was varied from 15% to 35 % through dilution with with water to be used as binder matrix. After impregnation of jute non-woven and bamboo mat, with subsequent drying, it is then made ready for pressing in a hydraulic press. The conditions of varying pressure (300-800 psi), temperature (145 °C to 160 °C) and pressing time (10 minutes to 20 minutes)

The lab – scale samples thus made are evaluated. The following conclusions may be drawn on the basis of results obtained:

1) Single layer of bamboo mat (plain weaved) along with jute non-woven (750 gsm, 7mm thick) of several layers of jute non-woven (depending on the desired thickness of the end product) are to be used for reinforcing component of the composite. Jute will constitute more than 50 %. Bamboo mat will be in one face.

2) Water dilutable phenol formaldehyde resin 15 % would be the optimum minimum matrix binder part of the composite.

3) Optimum pressing conditions would be – temperature- 152.5 °C, pressure- 550 psi, time for pressing -10 to 15 minutes.

4) Lab-scale trials for optimization of parameters have been verified through two pilot trials made at Composite Technology park, Bangalore, and Indian Plywood Industries Research and Training Institute, Bangalore.

5) Both tensile and flexural strength of Jute-Bamboo Hybrid Composite are improved compared to those of jute composites due to hybridization with bamboo mat. Modulus is reduced a little. The dimensional stability (water absorption, thickness swelling) is better and much improved with increase in matrix resin content. Further improvement is possible with water repellant coating on the composite.

6) The properties of jute-bamboo hybrid composite board have been compared with those of existing products' standard (MDF, high density wood particle board, shuttering plywood, decorative laminates, fibre hard board). Jute- bamboo hybrid composite has been proved to be the best in all respects. Again, they were compared with compressed wood laminates. The properties jute-bamboo boards are more or less equivalent to those of compreg (GM) and slightly inferior as compared to those of compreg (GH).

7) Costing has also been done on two basis:

a) Purchasing all the raw materials like jute non-woven (around 60%) and resin (around 15-20%) and bamboo mat (25 %),
b) Only bamboo mat, jute fibre and raw material for resin making to be procured. It has been found that the second option i.e. starting from jute fibre and the captive resin making unit will be viable and attractive for commercial exploitation.

8) The jute- bamboo composite board will have highly potential domestic and export market as building material, furniture, flooring depending on variation of density.

Summery On Literature Survey on Jute Composites

The use of jute in composite materials was done by Bhatnagar et.al as early as 1926 and efforts were then made to make jute-shellac composites. The next phase of development of jute composites other than shellac was in 1960. Bhattacharya et al investigated the suitability of a single–stage, water soluble phenol formaldehyde resin for making jute laminates. Brotech, afterwards, carried out tests on mechanical properties of jute fabric/polyester resin composites using fabrics of various constructions. Leach measured the thermal expansion of unidirectional jute/polyester laminates. Philip and Fabric Research Laboratories Inc. measured the mechanical properties of laminates composed of woven jute fabric with and without surface layers composed of glass fibres.

During the mid-seventies, IJIRA undertook an elaborate programme on JRP (jute reinforced polymer composites) to develop basic techniques of making them, to develop suitable fabrication techniques for JRP products with a view to find newer end uses of jute. Collaborative programmes of work were undertaken with the FRP Research Centre, IIT - Madras and Atomic Energy Research Establishment (AERE), Harwell, UK. Basic techniques of JRP and fabrication technologies have been developed. Afterwards, felling down of trees was banned by Govt. of India. Due to ecological imbalance and it was strongly felt, therefore, to concentrate research on JRP boards as wood / plywood substitute. On the basis of initial findings, a project on Jute Non-Textile Materials (Composites & Moulded Products) was sanctioned as UNDP assisted project.

Jute Reinforced Polymer Composite products developed at IJIRA:

- Product developed from rigid JRP sheets and molded items- partition, Door and window panels, decorative table tops, chairs, angles, chanels etc.
- Poly jute thermoplastic granules for injection molded products.
- Continuous molded profiles through pultrusion technology.
- Molded chair from jute-glass hybrid composites by RTM technology.
- Products made semi-rigid sheets-allle chests, tea chests, and garment boxes
- Products from flexible JRP sheets- files, wall covering. Table mats greeting cards etc.
- Medium density boards from total jute plant.

Thus, extensive R & D works were done using both thermoplastic & thermosetting resins Low density polyethylene (LDPE) films were used with jute non-woven and fabric for fabrication of sheets for packaging applications. Water soluble phenolic resins were used for development of rigid board as wood substitute. For better dimensional stability, fibre pre-treatment was done using low condensed resins. Jute fibre has also been modified by acetylation / cyano-ethylation to improve fibre- matrix adhesion. It has enhanced both mechanical properties and dimensional stability of jute composites using unsaturated polyester resin.

Chapter 1

Survey

Review on Jute and Bamboo Composites

1.0 Introduction:

Consumer awareness and stringent environmental legislation has forced industries to support long term sustainable growth and develop new technology based on renewable feedstock that are independent of fossil fuels. As the current status quo, the main reinforcement for the composite industry is glass fibres; 22.3 million tons (metric) are produced globally on an annual basis[55]. Although glass fibre products have somewhat superior mechanical properties, their life cycle performance is very questionable. Manufacturing of these products not only consume huge energy but their disposal at the end of their life cycle is also very difficult since there is virtually no recycling option.

Annual industrial crops grown for fibre, have the potential to supply enough renewable biomass for various bio-products including composites. The scope of possible uses of natural fibres is enormous. This is substantiated by the declaration of United Nation for 2009 as International Year of Natural Fibres (IYNF).

All over the world, the bio-composite industry is developing at a significant pace to meet growing consumer awareness and follow new environmental regulations. Lignocellulosic biofibre, derived from various origins such as leaf, bast, fruit, grass or cane, contribute to the strength of bio as well as synthetic polymer composites in various applications. These fibres are renewable, non-abrasives to process equipment, and can be incinerated at the end of their life cycle for energy recovery as they possess a good deal of calorific value. They are also very safe during handling, processing and use.

In terms of physical properties, commonly used natural fibres have the competitive advantage of being at least 40% lower specific gravity compared to glass fibres. The use of natural bast fibres in automotive industry as a reinforcement material in thermoplastic and thermoset resin has already grown into a well established industry. The European automotive industry has already taken the lead and currently uses around 22,000 tones of natural plant fibre in low stress applications in cars[56]. European automobile industries have used natural fibre reinforced polymer composites for door panels, seat backs, headliners, dash boards and trunk liners[57]. Germany has been using natural fibres in composite in automotive production for over decade. In 2005, 19000 tones of natural fibres were used in automotive composite[64]. In North America, the interest within the industrial research and agricultural sector has been high, but the market demand has only recently begun to show some growth.

Demand of raw materials in India for ply wood, particle board, fibre board and medium density fibre board (MDF) for 2010 was projected in FAO working paper[67]. Raw materials requirement will be

1.92 million cu. m. for plywood, 0.65 million cu. m. for particle board, 0.41 million cu. m. for fibreboard & 0.95 million cu. m. for MDF. Though the main source of raw materials for the panel products is wood, now it is being substituted by agricultural fibres.

Applications of natural fibre composites in the field of building materials are also very bright. Buildings consume[65, 66]:

- 50% of all resources used globally in construction
- 45% of all energy generated through the heating, lighting and ventilating of buildings, and a further 5% during construction
- 70% of global timber products

All the activities for building construction have an adverse effect on environment. These can be minimized by incorporating agricultural crops for development of building materials. So there is enormous potential for natural fibre composites for replacement of conventional items in different fields.

Jute and Bamboo are abundantly available in India especially in east and north east region and still these fibres are under utilized for technical applications. The incorporation of these fibres for reinforcement will pave the new & diversified uses. Increased use of jute & bamboo will have a positive impact to socio-economic structure of the specified regions. Government of India identified this as a thrust area for diversification of jute as sustainable product and allowed to develop the new hybrid natural fibres material for application in rural areas under Jute Technology Mission (Mini Mission-IV) programme through Ministry of Textiles.

2. Raw Materials

2.1 Reinforcement

2.1.1 Jute:

Jute, which is a bio-degradable and environment friendly fibre, grows abundantly in the eastern / north eastern part of the country. The XI th Five year plan has projected target of raw jute & mesta around 129 lakh bales at the end of the plan period[1] Mainly of two varieties i) Tossa (Corchorus olitorius) & ii) White (Corchorus. Capsularies) are used for commercial purpose. Fibre extracted from bast of the plant is used for commercial or industrial applications. Remaining woody stem portion i.e. stick is a cheap fuel source for common villagers though small portion of it is used for fabrication of insulation board. Jute fibre is further processed to produce sliver, yarn, woven / non-woven fabric, woven webbing, carpet and gunny bag. Trend in production of jute goods (quality wise) from 2000-2001 onwards[1] are in Table- 1 where production during the period April – Oct, 2007-2008 sacking is produced up to 645.7 x 10^3 M.T.; Hessian of 207.5 x 10^3 M.T.; yarn of 104.2

x 10^3 M.T. & CBC of 2.7 x 10^3 M.T. Review of works on jute used as substrate for composite materials is presented in section 2.

2.1.1a Chemical composition of Jute

Main constituents of the jute fibres[2] are 58-63% α-cellulose, 20-22% hemicellulose and 12-14% lignin (Table-2). Due to presence of non-cellulosic constituents (37 – 42%), jute is highly susceptible to environmental factors and also to chemical reagents. The properties of jute as other lignocellulosic plants are dependant on cell wall polymers[3] (Table 3) & the nature of degradation reactions[3] due to exposer to environment is described in Table 4. Effect of chemicals on jute[2] is prominent whether it is treated with alkali or acid. Such effects are summarized in Table 5.

Table 1: Trend in Production of Jute Goods from 2000-2001 Onwards (QTY. in'000' M.T.)

(April-March)	Hessian	Sacking	CBC	Yarn	Others	Total
2000-01	338.0	952.8	6.6	212.9	114.9	1625.2
2001-02	275.3	1034.0	5.0	194.8	91.7	1600.8
2002-03	338.3	1000.0	4.7	182.0	96.8	1621.8
2003-04	305.2	979.3	4.7	197.7	84.4	1571.3
2004-05	310.3	992.0	4.1	212.7	94.0	1613.1
2005-06	320.0	1007.4	6.2	114.3	134.2	1582.1
2006-07	250.3	874.7	2.9	108.2	120.2	1356.3
2007-08(Apr/Oct)	207.5	645.7	2.7	104.2	64.0	1024.1
2007-08 (projected)	337.9	952.9	4.6	178.6	150.9	1624

Table 2: Chemical composition of jute

Constituents	Quantity (%)
Cellulose	58 -63
Hemicellulose	20 -22
Lignin	12 – 14
Wax & Fats	0.4 – 0.8
Pectin	0.2 – 0.5
Protein	0.8 – 2.5
Mineral matters	0.6 – 1.2
Some tannin and colouring pigments are also present.	

Table 3: Cell wall polymers responsible for the properties of lignocellulosics in the order of importance

Biological Degradation	Moisture Sorption	Ultraviolet Degradation
Hemicellulose *Accessible Cellulose* *Non-Crystalline Cellulose*	*Hemicellulose* *Accessible Cellulose* *Non-Crystalline Cellulose* *Lignin* *Crystalline Cellulose*	*Lignin* *Hemicellulose* *Accessible Cellulose* *Non-Crystalline Cellulose* *Crystalline Cellulose*
Thermal Degradation *Hemicellulose* *Cellulose* *Lignin*	**Strength** *Crystalline Cellulose* *Matrix (Non-Crystalline Cellulose + Hemicellulose + Lignin)* Lignin	

Table 4: Degradation reactions that occur when lignocellulosic resources are exposed to nature

Biological Degradation Fungi, Bacteria, Insects, Termites *Enzymatic Reactions* *Chemical Reactions* *Mechanical*	 - Oxidation, Hydrolysis, Reduction - Oxidation, Hydrolysis, Reduction - Chewing
Fire Degradation Lighting, Sun, Man *Pyrolysis Reactions*	 - Dehydration, Hydrolysis, Oxidation
Water Degradation Rain, Sea, Ice, Acid Rain *Water Interactions*	 - Swelling, Shrinking, Freezing, Cracking
Weather Degradation Ultraviolet Radiation, Water, Heat, Wind *Chemical Reactions*	 -Oxidation, Reduction, Dehydration, Hydrolysis
Mechanical Degradation Dust, Wind, Hail, Snow, Sand *Mechanical*	 *- Stress, Cracks, Fracture, Abrasion*

Table 5: Effect of Chemicals on Jute

Reagents	Effect
Alkali	Poor resistance to alkali due to presence of hemicellulose. Weakened the fibre but not dissolved. Treatment with strong alkali caused irregular swelling and develops crimp.
Acid	The cellulosic chain disintegrates due to hydrolysis of the glucocide oxygen atom. Mineral or inorganic acids have more adverse effect on jute than organic acids.
Bleaching	The most common bleaching agents for jute are sodium chlorite and hypochlorite. Sodium chlorite / hypochlorite dissolve out lignin from jute. Due to removal lignin, jute becomes weaker as the middle lamella (major location of lignin) between the ultimate cells gets weakened.

2.1.1b Physical and Mechanical Properties of Jute

The physical properties of jute both white & tossa varieties are given in Table 6[2, 4] where physical properties of ultimate cell to bundle of jute fibres were reported. Length & breadth of ultimate cell are 0.8 to 6.0 mm and 5 to 25 μm respectively. Fineness of single fibre is 1.25 to 5. tex, tenacity is 30 to 50 g/tex, transverse swelling ranges 20 to 22%. Whereas bundle tenacity is 13-35 g/tex. Moisture regain properties of jute in general at 65% & 100% R. H. are 13.8% and 36% respectively. Some mechanical properties of jute fibre are reported in Table 7[2, 4, 9]. Young's modulus of the jute fibre is 0.86-1.94 dynes/cm^2, specific heat is 0.324 cal/g°C, water retention capacity is 70% and ignition temperature is 193 °C.

2.1.1c Chemical Composition & Pyrolatic Properties of Jute Stick

Chemical constituents of jute stick[4] are similar to jute fibre. Jute stick contains higher lignin (23.5%) & less α-cellulose (40.8%) than fibre are reported in Table 8.

Mohammad Rofiqul Islam et al[5] analysed the pyrolatic properties of jute stick and these are summarized in Tables 9 & 10.

Table 6: Physical Properties of Jute (White and Tossa)

	Properties	Jute- White (Corchorus. Capsularies)	Jute- Tossa (Corchorus olitorius)
1.	Ultimate Cells		
a	Length (mm)	0.8-6.0	0.8-6.0
b	Breadth (µm)	5-25	5-25
c	Length / Breadth ratio (Aspect ratio)	110	110
2.	Fibre Single		
	Gravimetric Fineness (tex)	1.25-4.0	2-5
	Tenacity (g/tex)	30-45	35-50
	Extension at break (%)	1.0-1.8	1.0-2.0
	Modulus of torsional rigidity x 10^{10} dynes/cm^2	0.25-1.25	0.25-1.30
	Flexural Rigidity (dynes/cm^2)	3.0-5.5	3.5-6.0
	Transverse swelling in water (%)	20-22	20-22
3.	Fibre Bundle		
	Tenacity (g/tex)	13-30	16-35
	Density (g/cc)		
	True	1.45	1.45
	Apparent	1.23	1.23
4.	General		
	Moisture Regain (%) at 65% RH		
	i) Absoption	13.8	13.8
	ii) Desorption	13.7	13.4
	at 100% RH	36.0	36.0

Table 7: Special Properties of Jute Fibre (White and Tossa)

	Properties	Range of Values
1.	Young's Modulus (dynes/cm^2)	0.86-1.94
2.	Bulk density (g/cc)	0.38-0.48
3.	Breaking Twist angle (degrees)	80 / 83
4.	Co-efficient of static friction	0.45-0.54
5.	Specific gravity	1.48
6.	Swelling in water (area-wise)	40%
7.	Water retention	70%
8.	Dielectric constant (at 50Hz)	2.2-7.2
9.	Dielectric constant (at 2 kHz), Dry Wet	1.8 2.4
10.	Insulation Resistance (ohm)	$10^{14} – 10^{17}$
11.	Specific Heat (cal/g/°C)	0.324
12.	Thermal conductivity (mwatt/metre Kelvin)	59.73
13.	Thermal resistance (Km^2/w) x 10^{-2}	5.17
14.	Heat of combustion (Joules/g)	17.5
15.	Ignition temp. (°C)	193

Table 8: Chemical Composition of Jute Stick

Constituents	Quantity (% Wt.)
Major Constituents	
Alpha-Cellulose	40.8
Pentosan	22.1
Uronic anhydride	7.5
Acetyl content	4.5
Lignin	23.5
Minor Constituents	
Fat & Wax	1.9
Nitrogenous Matter	1.1
Ash	0.8
Monosaccharide Constituents	
Glucose	43.2
Xylose	18.7
Mannose	1.6
Galactose	1
Arabinose	0.6
Rhammose	0.4

Table 9: Bulk Density and Gross Calorific Value of the Jute Stick

Bulk density (kg/m3)	178.84
Gross calorific value (MJ/kg)	17.32

Table 10: Proximate and Ultimate Analysis of Jute Stick

Proximate analysis		Ultimate analysis	
Content	**Qty (%)**	**Element**	**Qty (%)**
Volatile	78.40	C	44.94
Fixed carbon	11.80	H	4.38
Moisture	9.02	N	
Ash	0.78	O	49.90
		S	

2.1.1d Available Physical Forms of Jute

Jute as a substrate is available in the following physical forms:

* Raw fibre
* Sliver
* Yarn
* Woven / non-woven fabric
* Stick

2.1.2 Bamboo:

India has the second largest reserve of bamboos. Bamboos are naturally distributed in all the states of India except in Jammu and Kashmir. Maximum number of genera has been reported from West Bengal and Arunachal Pradesh (11 nos.). The state-wise distribution of bamboo[6] genera is given in Table 11. Bamboos are distributed in the country starting from sea level to an elevation of 3700 m above msl. Although bamboos prefer regions of high rainfall of about 1200 mm to 6350 mm, Dendrocalamus strictus is reported from regions of Rajasthan where the rainfall is about 700 - 1000 mm. Different species of bamboos have different optimum temperatures, humidity, soil types, altitudes and physiography for their best performance. The available form of bamboo is the culm. The epidermal and endodermal layers of the culm are normally removed as first step for conversion of bamboo to end products. This de-skinned culm is manually or mechanically splitted into strips, sticks, slivers and chips. Also skin removal operation can be done after splitting. Half splitted (longitudinal) bamboo culm is also flattened to make block by compressing with hydraulic press after steam treatment. Physical forms of bamboo fibre as above are easily available in India and other countries and the main physical forms of input for manufacturing processes for various end products including bamboo composite.

There are some publications[26, 27, 28] on preparation of bamboo fibre by defibrilisation or refining for fabrication of MDF board from bamboo. This procedure is most modern manufacturing practice but require huge capital investment.

Deshpande et al.[29] reported the fibre extraction of bamboo by compression or roller pressing of steamed & chemically treated bamboo strips. The extracted fibre was used for fabrication of bamboo polymer composite.

Review of works on bamboo used as substrate for composite materials is presented in section 3.

2.1.2a Chemical Composition of Bamboo

The chemical composition of bamboo fibre[7, 8] is shown in the following Table 12. The presence of cellulose is 26 to 43% whereas hemicellulose is present in the range of 15-26%. Presence of lignin is very dominant in bamboo fibre at around 21-31%. Bamboo contains around 0.7% silica.

Proximate & Elemental analysis[14] of different parts of bamboo is given in Table-15 & 16. Heat of combustion[14] is given in Table 17 and ash analysis[14] in Table 18.

2.1.2b Physical Properties of Bamboo Fibre

Some physical properties of bamboo fibre[8, 10,11,12,52] are given in Table 13. Range of length of bamboo fibre is 1.5 to 4.4 mm. The average length is 2.7 mm. Diameter of the fibre is 7 to 27 μm with average diameter of 15 μm. The aspect ratio has wider range of 150 to 250. Tenacity of the fibre is 23.8 g/tex with high extension at break (23%).

GRADING OF BAMBOOS

Primarily bamboos are sorted or graded on the several characteristics important for utilization. The main characteristics are (1) dimension of culm, (2) taper of culm, (3) straightness of culm, (4) internode length, (5) wall thickness, (6) density, (7) durability & seasoning. Individual characteristic or sometimes combination of two to three characteristics forms the basis of grading. However the method of identification of bamboos through anatomical or morphological characters has not been perfect & satisfactory. Experienced sorters can identify the bamboo in any locality[13].

CLASSIFICATION OF BAMBOO FOR STRUCTURAL PURPOSES

Classification of bamboo for structural purposes attempted on the basis of MOR (modulus of rupture), MOE (modulus of elasticity) & MCS (Mean compressive strength) of bamboo tested in green condition. In the following Table 14 the ranges of the above three properties are stated in respective of classified groups. The limits have been fixed keeping in view the corresponding limits for wood[13].

2.1.2c Available Physical Forms of Bamboo

Bamboo as a substrate is available in the following physical forms:

***** Culms

***** Sliver

***** Strip / lath

***** Particle

***** Mat

Table 11: The State-wise Distribution of Bamboo Genera

States	Genera
Andhra Pradesh	*Bambusa, Dendrocalamus, Pseudoxytenathera* and *Schizostachyum*
Arunachal Pradesh	*Arundinaria, Bambusa, Chimonobambusa, Dendrocalamus,Gigantochloa,Phyllostachys, Pleioblastus, Schizostachyum, Sinarundinaria, Thamnocalamus* and *Thyrsostachys*
Assam	*Bambusa, Dendrocalamus, Dinochloa, Gigantochloa, Melocanna, Oxtenanthera, Phyllostachys, Racemobambos* and *Schizostachyum*
Bihar	*Bambusa, Dendrocalamus, Gigantochloa* and *Schizostachyum*
Goa	*Pseudoxytenathera*
Gujarat	*Bambusa* and *Dendrocalamus*
Haryana	*Dendrocalamus*
Himachal Pradesh	*Dendrocalamus, Phyllostachys* and *Sinarundinaria*

States	Genera
Karnataka	*Bambusa, Dendrocalamus, Thamnocalamus, Melocanna, Ochlandra, Schizostachyum, Thyrsostachys* and *Pseudoxytenanthera*
Kerala	*Bambusa, Dendrocalamus, Ochlandra, Pseudoxytenanthera, Schizostachyum, Sinarundinaria* and *Thyrsostachys*
Madhya Pradesh	*Bambusa, Dendrocalamus, Gigantochloa* and *Schizostachyum*
Maharashtra	*Bambusa, Dendrocalamus, Gigantochloa* and *Pseudoxytenanthera*
Manipur	*Bambusa, Chimonobambusa, Dendrocalamus, Dinochloa, Melocanna, Racemobambos, Schizostachyum* and *Sinarundinaria*
Meghalaya	*Bambusa, Chimonobambusa, Dendrocalamus, Gigantochloa, Melocanna, Racemobambos, Phyllostachys, Schizostachyum* and *Sinarundinaria*
Mizoram	*Bambusa, Chimonobambusa, Dendrocalamus, Gigantochloa, Melocanna, Oxytenanthera, Schizostachyum* and *Sinarundinaria*
Nagaland	*Bambusa, Chimonobambusa, Dendrocalamus, Racemobambos, Schizostachyum* and *Sinarundinaria*
Orissa	*Bambusa, Dendrocalamus, Gigantochloa* and *Schizostachyum*
Punjab	*Dendrocalamus*
Rajasthan	*Dendrocalamus*
Sikkim	*Arundinaria, Bambusa, Dendrocalamus, Melocanna, Phyllostachys, Racemobambos, Schizostachyum, Sinarundinaria* and *Thamnocalamus*
Tamil Nadu	*Bambusa, Dendrocalamus, Ochlandra, Pseudoxytenanthera, Schizostachyum* and *Sinarundinaria*
Tripura	*Bambusa, Dendrocalamus, Gigantochloa, Melocanna* and *Schizostachyum*
Uttar Pradesh	*Bambusa, Dendrocalamus, Dinochloa, Gigantochloa, Oxytenanthera, Phyllostachys, Pseudosasa, Schizostachyum, Sinarundinaria, Thamnocalamus* and *Thyrsostachys*
West Bengal	*Arundinaria, Bambusa, Dendrocalamus, Dinochloa, Gigantochloa, Melocanna, Pseudosasa, Schizostachyum, Sinarundinaria, Thamnocalamus* and *Thyrsostachys*

Table 12: Chemical Constituents of Bamboo

Constituents	Quantity (%)
Cellulose	26 – 43
Hemicellulose	15 – 26
Lignin	21 – 31
Fats	2 – 4
Silica	0.7
Protein	0.8 – 2.5

Table 13: Physical Properties of Bamboo Fibre

Properties	Bamboo
Fibre Length (mm)	1.5 – 4.4 (2.7)
Diameter (μm) Length / Breadth Ratio	7 – 27 (15) 250 – 150
Fibre Tenacity (g/tex) Extension at Break (%) Mod. Of elasticity (Gpa)	23.8 23.8 27

Table 14: Classification of Bamboo for Structural Purposes

Groups	MOR (kg/sq.cm)	MOE (kg/sq.cm)	MCS (kg/sq.cm)
I	700	90	350
II	500-700	60	300
II	300-500	30	250

Table 15: Proximate Analysis of Different Parts Bamboo

Location in the culm	Moisture (%)	Volatiles (%) (dry basis)	Fixed Carbon (%) (dry basis)	Ash (%) (dry basis)
Top	13.7	79.6	15.6	5.2
Middle	13.5	80.5	15.6	3.9
Bottom	13.0	80.6	14.9	4.5
Bamboo Dust	11.1	79.8	15.9	4.3

Table 16: Elemental Analysis of Different Parts Bamboo

Location in the culm	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Sulphur (%)
A	42.9	6.7	0.5	Nil
B	55.8	4.8	1.3	Nil
A	43.8	6.6	0.4	Nil
B	55.8	4.8	1.2	Nil
A - analysis done at RSIC, IIT Bombay **B** - Analysis done at Italab Pvt. Ltd. Mumbai				

Table 17: Heating Value of Different Parts Bamboo

Location in the Culm	Heating Value (MJ/kg)
Top	16.2
Middle	15.2
Bottom	15.8

Table 18: Ash analysis of Bamboo

Location	Si (%)	Fe (%)	Mg (%)	Na (%)	Ca (%)	K (%)
Top	1.05	0.05	0.15	0.003	0.12	0.11
Middle	0.86	0.04	0.13	0.01	0.07	0.15
Bottom	1.13	0.04	0.23	0.02	0.09	0.26

2.2 Matrix

The main function of the matrix is to bind reinforcing medium together and protect the composite product from environmental attacks. The matrix may be of synthetic or natural. Developments of synthetic matrices (resin or polymer) were tremendous for several decades due to need for superior technology. Selected matrix should resist the dislocation of fibre when composite is in stress.

The choice of matrix, i.e. polymers, depends on the targeted end uses. Here both jute and bamboo are polar & lignocellulosic in nature.

Polymers, used for the development of lignocellulose based composite materials are mainly urea formaldehyde, phenol formaldehyde, modified phenol formaldehyde, methyl diphenyl diisocyanate etc. These matrices are used for development of products targeting the replacement of wood.

Polyester and Epoxy resin are used for high end uses (i.e. auto trim etc) though they are non polar in character. Due to this property lignocellulosic materials are required modification for better ultimate properties of composite products.

All the above mentioned matrices are thermosetting polymers. Thermosetting polymers which are particularly convenient because they can be applied in a fluid state, which facilitates penetration and wetting in the unpolymerised state, followed by hardening of the system at times and conditions largely controlled by the operator. Exothermicity, shrinkage and the evolution of volatiles, if the polymerization is of the condensation type, are among the difficulties encountered using such resins.

Now polypropylene (PP) is the favourite resin for natural fibre reinforcement to target auto & machine components. Here maleated PP is used with virgin PP granules for better bonding with lignocellulosic fibres.

Advantages and disadvantages of thermoset and thermoplastic resins[15] are given in Table 19. Recent trends are to replace partially or totally the synthetic resin with natural polymers.

Table 19: Summary of Advantages and Disadvantages of Thermosets and Thermoplastics as Composite Matrix Resins

PROPERTY	THERMOSETS	THERMOPLASTICS
Formulations	Complex	Simple
Melt viscosity	Very low	High
Fibre impregnation	Easy	Difficult
Prepeg tac	Good	None
Prepreg drape	Good	None to fair
Prepeg stability	Poor	Excellent
Processing cycle	Long	Short to long
Processing temperature / pressure	Low to moderate high	High
Fabrication cost	High	Low (potentially)
Mechanical properties, -54 to 93°C, hot/wet	Fair to good	Fair to good
Environmental durability	Good	Unknown
Solvent resistance	Excellent	Poor to good
Damage tolerance	Poor to excellent	Fair to good
Database	Very large	Small

2.3 Preservative

2.3.1 for Jute:

Jute is prone to microbial attack under humid condition. Fungi begin to multiply rapidly with increase in moisture regain above 17%, while bacteria need much higher regain (above 35%) for substantial growth[16]. Fungi play a dominant role in the microbiological deterioration of the jute during storage, transit and normal indoor uses and the “mildew” growth on jute is mainly due to fungi. A comparative study of the microbiological decomposition of various cellulosic fibres as adapted from Bose[17] is given in Table 20. Rot proofing of jute are done approaching the following guidelines:

i) Developing a physical barrier between the micro-organisms and the fibre material by applying resin solution.

ii) Application of chemicals toxic to micro-organisms.

iii) Chemical modification of the fibre to make it immune to micro-biological attack, viz. acetylation, cyanoethylation.

Treatments of second category and to a lesser extent also first, are used in industries. The third category of process is not economical.

Copper is the single element favoured as textile rot proofing agent because it is cheap, easily available and highly rot-resistance. W. G. Macmillan et al[18] studied the effect of large number of copper compounds, e.g. naphthenate, cuprammonium, borate, basic carbonate, basic chromate, 8-hydroxyquinolinate, pentachlorophenate, silicate, cupferron etc. for imparting rot proofing to jute. Copper compounds mentioned above when applied to jute to deposit the metal in the range of 1 to 1.5% are found to protect the fibre from both rotting and mildewing with satisfactory leach resistance property. Copper naphthenate is most commonly recommended for rot proofing jute materials. Since copper naphthenate is insoluble in water and requires to be applied in solution of a suitable organic solvent or as emulsion, the next choice of copper based compound is cuprammonium which is not only water soluble but easy to apply, efficient and economical[19-21]. This cuprammonium solutions used for rot proofing were prepared by the action of ammonia liberated from ammonium sulphate and caustic soda on copper sulphate solution, which resulted in the deposition of sodium and ammonium sulphates as by-product on the fibre. But treated jute was deteriorating during prolonged storage due to the liberation of acid from deposited ammonium sulphate. This formulation was subsequently modified by Macmillan et al[22] to counteract the harmful effect of acid by addition of sodium carbonate in suitable amount. Outdoors uses of jute involve the frequent prolonged exposure to sunlight, rain, dew, wind, etc with widely varying temperature range. Jute fibres in particulars are more prone to damage due to sunlight than micro-organism. To obtain a high degree of rot and weather resistance properties in jute, various combinations[22-23] of toxic copper compounds with those of light resisting heavy metals like chromium, manganese and cobalt have been investigated. The best performing mixed formulations for both rot and weather proofing of jute are given below in the decreasing order of effectiveness:

i) Lead-copper chromate-cum-cobalt-manganese pyroborate
ii) Lead-copper chromate-cum-cobalt-manganese oxide / hydroxide
iii) Basic copper chromate
iv) Cutch-cuprammonium

Majumdar et al[24] studied the effect of two colourless bactericidal cationic surfactants of the quaternary ammonium group viz., Benzalkonium chloride and Cetyl trimethyl ammonium bromide on bleached and dyed jute. The anti-microbial finish afforded by the compounds on jute was found to be relatively durable as compared to that on cotton[25].

2.3.2 for Bamboo:

Bamboo is one of the strongest structural materials, but its natural durability is very low varying from 1 to 36 months depending on species[31]. Specially in tropical countries the biodeterioration is very fast and severe due to stain fungi, rotting fungi and insects. Split bamboo is more susceptible to degradation due to micro-organisam than round bamboo[32].

Review on methods of treatment and preservatives for bamboo made by Jain[13], it was found that bamboo can be treated by brushing (B), dipping (D), modified boucherie (MB), diffusion (Df), open tank / hot and cold (HC) and pressure (P) methods. Hot and cold and pressure methods of treatment of any lignocellulosic material are most versatile and well known. Brushing and dipping have limited efficiency but are useful in many cases. For treatment of green bamboo diffusion or modified boucherie – where treating liquid forces, (under air pressure of 1 to 1.4 mg/sq.cm) developed with ordinary foot pump, the sap out of walls and septa of the bamboo through the open end and takes its (sap) place in course of time – methods are most suited (IS: 1902-1961), (IS: 9096-1979). Choice of method depends on type of preservative and condition and end use of bamboo.

Choice of preservative depends on the targeted end use of bamboo. Recommended preservatives under Indian Standards are Coal tar creosote (CTC), copper chrome arsenic (CCA), acid cupric chromate (ACC), chromated zinc chloride (CZC), copper chrome boric (CCB), copper chrome zinc arsenic (CCZA), boric acid borax (BAB), copper naphthenate (CN), zinc naphthenate (ZN), benzene hexachloride (BHC). Another very effective soaking method for preservation of round bamboo with ammoniacal copper arsenate has been developed[33]. The details of treatment methods and preservative chemicals for different uses of bamboo are given in Table 21.

Table 20: Relative Resistance of Various Fibres to Microbiological Decomposition (Fibres Arranged in Groups According to Decreasing Order of Resistance)

Group	Fibres	
	Resistance to Fungal Decomposition	**Resistance to Bacterial Decomposition**
I	Coir	Coir
II	Tossa jute and raw cotton	Manila and sisal
III	Hemp, manila, viscose, rayon, mestha, white jute, aloe	Hemp, green hemp and ramie
IV	Ramie and sisal	Flax, New Zealand hemp, aloe, tossa jute, white jute
V	Geen hemp, New Zealand hemp and flax	Mestha, viscose rayon and raw cotton

Table 21: Treatment Methods and Preservative Chemicals for Different Uses of Bamboo

Sl. No	End Use	Preservative Chemical	Treatment
1.	Post, pole, fencing etc, exposed to weather and in contact with ground:		
	a) Dry bamboo	CTC	P, HC
		CCA & ACC	P
	b) Green round bamboo	CCA & ACC	Df
2.	Bridges, ladders, scaffolding exposed to weather but not in contact with ground:		
	a) Dry bamboo	CTC	D, HC, P
		CCA & ACC	P
	b) Green round bamboo	CCA & ACC	MB(4-6 hrs), Df (20-25 days)
3.	House components (wall, trusses, purlins, rafters, tent poles) etc. under cover		
	a) Dry bamboo	CTC	D, HC, P
		CCA, ACC, CZC, CCB, CCZA	P
	b) Green round bamboo	CCA & ACC	MB (4 hrs), Df (15-20 days)
4.	House components (ceiling, door and window shutters)		
	a) Dry bamboo	CCA, ACC, CCB, CCZA and BAB	P
	b) Green round bamboo	CCA, ACC, CCB, CCZA and CZC	MB (2-3 hrs), Df (8-10 days)
5.	Furniture, chicks, zafri and mats exposed to weather		
	a) Green round bamboo	CCA, ACC, CCB, CCZA and CZC	MB (2-3 hrs)
	b) Green split bamboo	CCA, ACC, CCB, CCB and CCZA	Df (10 days)
	c) Dry split bamboo	CN, ZN, BHC	B (two coats) D (5 min)

Sl. No	End Use	Preservative Chemical	Treatment
6.	Furniture, chicks, zafri, mats and other household articles under cover	BAB, CZC	
7.	Basket ware, etc. for packing fruits, vegetables, and other edible materials	BAB	
8.	Basket ware for agriculture use other than for edible materials	CCA, ACC, CZC, CCB, CTC	Df (3 weeks) HC

3. Composites

2.1 Jute Reinforced Composite

The first reported work on jute as reinforcement appears to be carried out by Bhatnagar[34] who filed several patents on jute-shellac composites. An attempt was made to manufacture several items like tea chest, box, paneling and sliver cans etc.[35]. Though at present, natural resin is not getting commercial importance, it may be important in near future because of biodegradability of composites.

The second phase of development of jute reinforced composite using matrices other than shellac started in 1960 by Bhattacharya et.al[36-39] using phenol formaldehyde (P.F.) resin to produce Jute-PF laminates. Here they studied the effect of various physical conditions of jute fabric and molecular size of phenol formaldehyde on the jute composite (Tables 22 & 23). Several patents were filed on the extended work on these process[46, 47]

Table 22: Tensile Strength and Specific Gravity of Jute Laminates

	Condition of Fabric/ Resin	Resin content (laminate basis) %	Tensile strength lb/sq.in.	Sp. Gr.
1.	Loom state fabric (containing 4-5% oil)	32.3	4980	1.275
2.	De-oiling of fabric and use of wetting agents (series 1)	30.0	5250	1.325
3.	Drying the fabric prior to impregnation (series 2)	--	5375	1.230
4.	Use of resins of increasing molecular size complexity (series 3)			
	Resin solution obtained after:			
	(a)0-0.5 hr reflux	33.7	4310	1.381
	(b) 0-1 hr reflux	32.4	4150	1.370
	(c) 0.5-1 hr reflux	29.4	4090	1.380
	(d) Resin type(b) topped with a heavier resin	29.5	4540	1.305
Pressure used 4000 – 5000 lb/sq.in				

Table 23: Effect of Yarn and Fabric Characteristics on the Tensile Properties of Jute Laminates

Fabric	Nominal Specification	Wt/yd per 40 in. width	No. of threads / in.		Twist / in (warp yarn)	Elongation of fabric %	Crimpness %		Direction of test	Tensile strength of laminates lb/sq. in.	Sp. Gr.
			Warp	Weft			Warp	Weft			
Jute Canvas I	35 in, 16x18, 18.92 oz/yd	21.62 oz	34.6	19.5	4.5 4.4 (weft yarn)	13.0	10.52	--	Warp	4936	1.246
Jute Canvas I	35 in, 16x18, 18.92 oz/yd	21.62 oz	34.6	19.5	4.5 4.4 (weft yarn)	13.0	--	4.85	Weft	6961	1.288
Jute Canvas I	35 in, 16x18, 18.92 oz/yd	21.62 oz	34.6	19.5	4.5 4.4 (weft yarn)	13.0	10.52	4.85	Warp and weft crosswise	4442	1.222
Jute Canvas II	17x18	--	36.8	19.5	4.0	11.4	9.91	--	Warp	5117	1.237
Tarpaulin	30 in., 1x13, 12.33 oz/yd	16.44 oz	23.8	14.0	4.3	3.5	4.14	--	do	5816	1.295
Ordinary Hessian	40 in., 11x12, 10 oz/yd	10.00 oz	11.9	12.8	--	--	--	--	do	3286	1.232
Fine Hessian	51 in., 19x19, 9 oz/yd	7.06 oz	20.5	20.5	5.2	4.5	3.67	--	do	4864	1.262
Jute yarn	--	8 lb / 14,400 yd	--	--	--	--	--	--	Yarn	7695	1.250
Jute sliver	2 oz/yd	--	--	--	--	--	--	--	Fibre	8482	1.315
Raw jute	--	--	--	--	--	--	--	--	do	11860	1.280

Further work in this range was done by B.C.Mitra et al[40] on pretreatment of substrate for fabrication of jute composite using P.F resin. It were observed that the flexural strength and modulus were higher for PF based jute composites when the substrate (jute non woven) were pretreated with low molecular weight phenol formaldehyde / melamine formaldehyde resin than the untreated substrate (Table 24). These work were extended using PF, MF & CNSL precondensate to reduce moisture and water intake of jute composite and reported by B.C.Mitra et al[41] (Table 25).

Table 24: Flexural Properties of Different Jute Composite Samples

Sl. No.	Samples	Flexural Strength (Dry) (N/m^2)	Flexural Strength (After 2 hrs. boiling in water) (N/m^2)
1.	Untreated non-woven* + PF resin	91×10^4	79×10^6
2.	MF pretreated non-woven + PF resin	105×10^4	88×10^6
3.	PF pretreated non-woven + PF resin	112×10^4	100×10^6
*Non-woven was unidirectionaly laid			

Table 25: Physical Properties of the Jute Composite with Treated Jute Non-woven

Physical Properties	PF-5%	MF-5%	CNSL – PF-5% (water soluble)	CNSL – PF-5% (methanol soluble)	CNSL – Formaldehyde– 5%	CNSL-Polymerised – 5%	Control (Laminated with 15% PF)
Density (g/mL)	1.13	1.13	1.12	1.20	1.16	1.14	1.16
Tensile Strength (Mpa)	47.70	49.99	62.21	77.37	40.83	38.12	42.10
Flexural Strength (Mpa)	72.32	73.97	90.03	100.03	59.98	49.73	68.24
Water absorption (%) Soaking time 2 h 24 h	 19.39 26.98	 18.98 25.93	 12.08 20.72	 13.23 21.13	 13.95 22.00	 18.95 26.11	 19.13 25.71
Thickness swelling (%) Soaking time 2 h 24 h	 11.08 14.89	 10.98 14.00	 7.32 11.97	 8.09 12.01	 9.02 13.72	 11.92 15.13	 10.89 14.12
After 2 h boiling with water Flexural Strength (Mpa) Thickness swelling (%)	26.13 27.03	27.50 26.91	58.27 16.96	62.33 17.00	22.70 26.63	Delaminated	22.17 25.62

Due to presence of reactive group (-OH), jute by nature absorbs moisture and water. This hinders the performance of composites fabricated with jute. Several attempts were made to modify jute using chemicals and hygrothermal pretreatment. Jute slivers were acetylated and composites were fabricated using U.F. resin with different types of salt and melamine powder. The dimensional and mechanical properties of composite were improved due to acetylation of jute[42]. Functional properties of jute composite fabricated from cyanoethylated jute with polyester resin were improved and these were reported in the study of A. K. Saha et al[43,44] and some of its properties are reported in Table 26 & 27. Lot of works were done on jute polyester system, unsaturated polyester was used as a matrix. As polyester resin is hydrophobic in nature, the products are less susceptible to moisture or water. A comparative study was done by Pal[30] on glass and jute substrate using unsaturated polyester and phenolic resin and the result is shown in Table 28.

Table 26: Water Absorption & Thickness Swelling of Composites at Boiling Condition

Sample	Water absorption (%)		Thickness swelling (%)	
	0.5 h	2 h	0.5 h	2 h
Control	42.37	48.09	62.31	66.67
MJC-1	9.58	14.06	16.34	23.32
MJC-2	8.26	13.59	14.21	21.76
MJC-3	8.01	13.07	13.56	19.47
MJC-4	7.39	12.46	12.97	18.35
MJC-5	7.11	11.08	11.25	16.89
MJC-1 denotes composite made from jute non woven (unidirectional), cyanoethylated at 1 h.				

Table 27: Mechanical Properties of Composites

Sample	Dry Tensile Str. (Mpa)	Wet Tensile Str. (Mpa)	Dry Flex. Str. (Mpa)	Wet Flex. Str. (Mpa)	Dry Flex. Mod. (Mpa)	Wet Flex. Mod. (Mpa)
Control	74.24	25.89	84.81	40.21	12,970	6750
MJC-1	89.96	48.83	121.39	76.99	16,050	14,840
MJC-2	99.59	56.65	129.73	88.61	17,630	15,250
MJC-3	104.76	60.38	134.36	95.93	17,980	16,740
MJC-4	108.60	63.03	136.90	100.6	18,050	17,260
MJC-5	109.32	67.33	137.87	101.76	18,080	17,430

Table 28: Comparative Properties & Costs of GRP and JRP

Materials	Fibre content[a] (%)	10^{-3} x Density d (kg m^{-3})	E^b (Gpa)	10^3 x E/d (Gpa m^{-3} kg^{-1})	σc (Mpa)	10^3 x σ/d (Mpa m^3 kg^{-1})	Cost / m^{3d}		Cost / m^3 E/d		Cost / m^3 σ/d	
							Rs.	£	Rs	£	Rs	£
GRP ; Hand lay up or spray up (chopped strandmat PE[e])	35 w/o	1.5	10	6.7	200	133.3	65000	1600	9750	240	487	12
JRP: Felt (Pressure moulding PE)	60 v/o	1.2	8	6.7	100	83.3	25000	600	3750	90	300	7.2
GRP: Woven roving (hand lay up PE)	35 w/o	1.5	12.5	8.3	250	166.7	80000	2000	9600	240	480	12
JRP: Hessian (hand lay up PE)	30 v/o	1.2	6	5	75	62.5	35000	750	7000	150	560	12
GRP: Roving (filament wound or pultruded PE)	60 w/o	1.7	45	26.5	800	470.6	72000	1800	2720	68	153	3.8
JRP: Unidirectional fabric (low pressure PE)	50 v/o	1.2	15	12.5	210	175	30000	750	2400	60	171	4.3
JRP: Yarns (Pressure PE)	60 v/o	1.2	24.5	20.4	300	250	24000	600	1175	29	96	2.4
JRP: Unidirectional fabric (low pressure PF[f])	50 v/o	1.2	12.5	10.4	125	104.2	20000	600	1920	58	192	5.8
JRP: Jute felt-PF resin	60 v/o	1.2	8	6.7	100	83.3	16000	500	2400	75	192	6
JRP: Jute felt-PF resin- fly ash[g]	40 v/o	0.9	7	7.8	80	88.9	12000	350	1543	45	135	3.9

[a] w/o = % by weight; v/o = by volume, [b]E = Flexural modulus, [c]σ = Flexural strength

[d]Cost of materials only: Rs, based on materials cost in India; £, based on materials cost in Great Britain

[e]PE = Polyester resin, [f]PF = Phenol-formaldehyde resin, [g]Jute: resin: fly ash, 40:30:30

Hygrothermal pretreatment of jute fibre for dimensional stability was attempted, where jute fibre was pretreated with inbuilt steam at 200 °C & 250 psi for 4 minutes (optimized time) to minimize the irreversible swelling of board. Though the fibre lost its strength for thermal degradation and reported by S. Das et al[45].

Effect of bleaching of jute fibre on jute – polyester composite was by B. N. Dash et al[48]. The flexural properties and interlaminar strength of composite were improved on bleaching of jute but simultaneously of reduced tensile strength and reported in Table 29 & 30.

Table 29: Tensile Properties of JPH-60 Using Low Viscosity Resin

Specimen	Spc.	Ult. Str. (Mpa)	Ult. Stn. (%)	Toughness (Mpa)	TEA (N/mm)	Tensile Modulus, (Mpa)
JPH-60 I	Avg	132.40	5.834	3.608	9.767	2956
	Sdv.	6.33	0.683	0.312	1.234	774
JPH-60 (B)	Avg	117.00	6.677	3.764	10.600	2106
	Sdv.	21.32	0.821	0.878	1.981	229
JPH-60- jute polyester hot cured, I- control, (B)- bleached, 60% fibre content.						

Table 30: Flexural Properties of JPH-60 Using Low Viscosity Resin

Specimen	Spc.	Flex. Yield Str. (Mpa)	Flex. Modulus, (Mpa)	Energy at Break (J)	Toughness (Mpa)	ILSS (Mpa)
JPH-60 I	Avg	140.4	13850	0.4008	0.1157	3.865
	Sdv.	12.3	2058	0.0213	0.0084	0.306
JPH-60 (B)	Avg	171.8	18440	0.3828	0.1263	4.032
	Sdv.	19.1	2977	0.039	0.0217	0.355
JPH-60- jute polyester hot cured, I- control, (B)- bleached, 60% fibre content.						

P. Ghosh et al[49] studied the behaviour of hybrid composites of glass chop strand mat (CSM) & jute woven fabric with epoxy as matrix for dynamic mechanical properties under various thermal conditions. Addition of glass fibre improved the properties of the hybrid composite and shown in Table 31.

The use of thermoplastic resins as matrices with natural fibres was reported in many literatures. A. K. Rana et al[50] reported the use of polypropylene (PP) granules with stapled jute fibre and simultaneous use of maleated PP as compatibiliser for better bonding with jute fibre. They used the melt blend technique and there were remarkable improvement in properties of composite using jute-pp-compatibiliser combination.

Table 31: Composite Code for 3-Ply Laminates Showing Volume Fraction of Fibre Used, Flexural Properties and Temperatures Corresponding to E”$_{max}$ and tan δ_{max}

Composite number and Code[a]	Volume Fraction (x 100) of Fibre in Composite			Flexural Data[b]		Temperature (°C)		
	Glass	Jute	Total	FS (Mpa)	FM (Gpa)	E''_{max}	$\tan\delta_{max}$	ΔT^{c}
1 Cured epoxy resin (unreinforced)	--	--	--	80.8	2.6	128	135	7
2. E E E	25.5		25.5	178.7	7.6	115	118	3
3. N N N	25.8		25.8	167.5	6.6	118	123	5
4. J J J	--	23.5	23.5	82.4	3.6	128	135	7
5. E J E	11.80	9.4	21.2	161.6	5.7	128	130	2
6. N J N	12.0	9.4	21.4	144.7	5.4	118	122	4
7. J E J	6.7	15.0	21.7	84.8	3.9	128	132	4
8. J N J	6.8	15.0	21.8	88.9	4.3	115	118	3

[a] E= E glass CSM, N= N glass CSM and J= jute fibre.
[b] FS= flexural strength, FM= flexural modulus.
[c] Difference between temperature under columns 7 and 8.

3.2 Bamboo Reinforced Composite

Bamboo as reinforcement was used for construction of mud house by our predecessors. It is found that in 1940 China was the first country to produce bamboo based panel using bamboo mat[54]. Based on the culm derivatives, bamboo boards may be grouped in the following categories:

- Culms converted into slivers, strips or laths by flattening and / or cutting, and further processed;
- Culms peeled into veneers and further processed;
- Culms converted into particles, fibres, wafers or strands and reconstituted;
- Combination of one or more of above products among themselves or with other materials and further processed. Such as different bamboo panels; wood or other lignocellulosic materials; and inorganic substances.

BOARDS FROM SLIVERS, STRIPS OR LATHS

Slivers of uniform thickness and width are woven into mats and BMB (bamboo mat board) is produced by pressing of multi layers of mat in presence binder (matrix) with or without addition of heat. The properties of this product whether physical or mechanical are at per with waterproof plywood. However, the properties of the BMB can be altered by changing the weaving pattern of bamboo slivers used in mat to get the required values for modulus of elasticity (MOE), modulus of rigidity (MOR), tensile strength etc[31, 58]. MOR or shear modulus of BMB in the plane of the board is very high and is comparable[53] to the required values for structural plywood as per IS: 10701. This is attributable to the herringbone weave of mat. Clearly, BMB has high in-plane rigidity and high racking strength and is more flexible than equivalent plywood[59-62]. Due to these properties, BMB can be used in many engineering applications. BMB has been found to be especially useful as sheathing material in structural and semi structural uses such as walling, partitions, roof sheeting[63], door skins, box furniture, built up hollow beams, gussets, containers[51]. Usually phenol formaldehyde (PF) is the binder used in most cases but urea formaldehyde (UF) is used for lower end uses. Melamine urea formaldehyde is used to improve the properties of bamboo composite made of UF matrix. Physical and mechanical properties of BMB bonded with PF resin (India) was reported by INBAR[54] in Table 32

For roofing application the bamboo mat is moulded to corrugated sheet (Bamboo mat corrugated sheet- BMCS) same as asbestos cement corrugated sheet (ACCS) and a comparative strength properties[53] with other existing roofing sheets are given in Table- 33.

Matrix or binder treated bamboo strips / slivers assembled in layers in parallel to each other or a few are placed in criss-cross direction to produce parallel gluelam. This process is used in limited extent in China. Physical and mechanical properties[54] of bamboo parallel gluelam (China) are shown in Table- 34.

Table 32: Strength Properties of BMB Bonded with PF Resin (India)

Properties	**No. of mats used for making board**			
	2	**3**	**5**	**7**
Density (kg/m^3)	751	766	771	790
Internal bond strength (Mpa)				
• Dry state	2.23	2.18	2.42	1.97
• Wet state	1.79	1.98	2.14	1.73
Surface strength by torque wrench (Mpa)				
• Dry state	12.14	11.42	11.23	9.47
• Wet state	11.01	1.42	10.47	9.10
Tensile strength (Mpa)	-	22.69	26.59	29.54
Compressive strength (Mpa)	-	16.77	30.35	35.30
Modulus of rupture (Mpa)	-	50.74	56.31	59.35
Modulus of elasticity (Mpa)	-	3678	3220	3114
Modulus of rigidity (Mpa)	5401	5881	6050	6066

Table 33: Strength Properties of BMCS in Comparison with Other Existing Roofing Sheets

Items	Thickness (mm)	Width (mm)	Max. load (N)	Load bearing capacity (N/mm)	Weight of sheet (2.44m x 1.05 m) kg
BMCS(4 layers)	3.7	400	1907	4.77	9.78
GI Sheet	0.6	400	1937	4.84	10.43
Aluminium Sheet	0.6	405	669	1.67	3.92
ACCS	8.0	330	1880	5.45	21.50

Table 34: Important Physical and Mechanical Properties of Bamboo Parallel Gluelam

Properties	Variety of product	
	Single direction panel	Non-single direction panel
Density (kg/m3)	850 – 1050	840 – 1050
Moisture content (%)	3.6 – 8.7	4.0 – 9.3
MOR longitudinal (Mpa)	167 – 201	128 – 223
MOR transverse (Mpa)	10.3 – 13.8	30.4 – 72.0
MOE longitudinal (x 10 Mpa)	11.5 – 14.8	10.1 – 15.9
MOE transverse (x 10 Mpa)	3.0 – 4.4	2.3 – 4.1

The main applications for this panel are for truck floors, gang planks and less commonly in building construction. But it requires large quantity of resin, thereby pushing up the cost and pressing time.

BOARDS FROM VENEER (PLYBAMBOO)

Veneers from bamboo are prepared by rotary cut. Boards are prepared using bamboo veneer as face and wood veneer or block as core. This is produced at present in small quantity in china. Bamboo veneer is also used as face layer for BMB board as decorative appearance.

BOARDS FROM RECONSTITUTED PARTICLES, STRANDS OR FIBRES

Following technology of wood particleboard, bamboo particleboard has been developed in Canada, China, India and Vietnam. Studies carried out at the Queen's University in Canada have clearly indicated that it is feasible to economically produce high-quality, durable bamboo particleboards. The bamboo particleboards can be used as an alternative to wood particleboard and structural panels like wafer board for use in construction, furniture, packaging etc. Properties of bamboo particleboards made in different countries are given in Tables 35, 36 & 37.

Table 35: Properties of Bamboo Particleboard (China)

Property	Value
Density	730 – 800 kg/m^3
Moisture content	6.9%
Thickness swelling	1.6%
Internal bond strength	0.64 Mpa
Modulus of rupture	24.24 Mpa
Modulus of elasticity	2480 Mpa
* needle or flaked shaped particles, resin add on 8 – 12%	

Table 36: Properties of Bamboo (Bambus Vulgaris) Particleboard (Malaysia)

Resin (%)	Density (kg/m^3)	Modulus of Rupture (Mpa)	Internal Strength (Mpa)	Screw Withdrawal (N)	Thickness Swelling (%)
6	550	12.7	0.15	489	7.6
6	610	17.6	0.27	671	9.3
6	710	27.9	0.36	777	9.5
8	840	11.8	0.31	418	4.0
8	610	16.9	0.49	528	5.2
8	690	21.3	0.74	697	4.4
10	610	20.7	0.52	650	5.7
10	660	27.3	0.62	670	6.3
10	720	27.4	0.85	881	7.6
B.S. for Type 1		Min. 13.8	Min. 0.34	Min. 360	< 12.0
67. Beating of culm into particles, UF resin add on by spraying, follows British standard BS:5906-1989					

Table 37: Test Results Obtained for Bamboard (Canada)

Properties	Values
Density	750 kg/m^3
Modulus of elasticity (longitudinal)	3100 Mpa
Modulus of rupture (longitudinal)	17.2 Mpa
Internal bond strength	345 kPa
Water absorption (after 24 h soaking)	57%
Thickness swelling	14%
* bamboo is refined using hammer mill, PF resin and wax add on 4% and 1% respectively	

Fibre board from bamboo is newer in concept. Now researches are going on in different countries and some works also reported in peer reviewed journals. One of the major tasks is to extract bamboo fibre from its culm. There are different approaches in laboratory scale to extract bamboo fibre. Deshpande et al.[29] reported one of the easiest process of bamboo fibre extraction from commercially available bamboo strips. They used a combination of chemical and mechanical methods for extraction of fibre. 0.1 (N) NaOH solutions were used for delignification of the fibres. Then the treated strips were undergone separate processing path through compression moulding technique (CMT) and rolling mill technique (RMT) for separation of fibres. Distribution of fibre diameter and tensile strength obtained by each process was reported in Table-38 and 39. Then these fibres were used to make unidirectional preformed mat for moulding with unsaturated polyester resin. The finer fibre was produced by RMT than CMT as per Table 38. But the tensile strength of fibre was lower for RMT than CMT reported in Table 39.

Table 38: Distribution of Fibre Diameters & Their Statistics

Fibre source	**Statistics of fibre diameters (mm)**	
	Mean	**Standard Deviation**
CMT	0.14915	0.07052
RMT (initial strip length, 12 cm)	0.08987	0.04149
RMT (initial strip length, 17 cm)	0.09685	0.04385
Fibre source	Parameters from Gaussian Distribution Fit	
	Centre	Width
CMT	0.17577	0.17227
RMT (initial strip length, 12 cm)	0.10887	0.11183
RMT (initial strip length, 17 cm)	0.11393	0.10199

Table 39: Statistics of Tensile Strength Distribution for Fibres with Different Techniques

Fibre source	**Statistics of Tensile Strength (MPa)**	
	Mean	**Standard Deviation**
CMT	644.8	145.5
RMT	370.1	71.8
Fibre source	Parameters from Gaussian Distribution Fit	
	Centre	Width
CMT		
RMT (initial strip length, 12 cm)	649.0	299.6
RMT (initial strip length, 17 cm)	362.5	145.8

More elaborate work was done by Xiaobo Li[(8)] on physical, chemical, mechanical properties and utilization of bamboo fibre board manufacturing. He experimented with bamboo species (Phyllostachys pubescens) of one, three and five years age. Bamboo chips were steamed before atmospheric refining using Sprout-Waldron model 105-A. The dried fibre bundles were separated through second time refining. Furnish was loaded in a rotating drum type blender and urea formaldehyde sprayed on the Furnish to control the resin add on up to 8%. Treated furnish was formed as mat for compression moulding. Some of the properties of the composite are given in Table 40

Table 40: Physical & Mechanical Properties of Bamboo Fibre Board

Composite Source		**SG**	**CR**	**MOR MPa**	**MOE GPa**	**IB MPa**	**WA %**	**TS %**
Fibre tree/ age(years)	**Resin content %**							
Bamboo/ one	6	0.718	1.44	19.0	2.18	0.38	101	43
	7	0.705	1.41	23.9	2.72	0.85	83	32
	8	0.714	1.43	27.6	3.07	1.06	77	23
Bamboo/ three	6	0.71	1.02	10.7	1.63	0.48	110	47
	7	0.727	1.04	17.1	2.50	0.90	78	37
	8	0.715	1.02	20.0	2.64	1.20	68	29
Bamboo/ five	6	0.731	1.04	21.6	2.19	0.70	105	37
	7	0.730	1.04	23.6	2.47	1.07	79	30
	8	0.734	1.05	26.1	2.76	1.16	72	25

SG= specific gravity, CR= compression ratio (i.e. panel density/material density),
WA= water absorption, TS= thickness swelling;
Board pressed during closing at 2.76 MPa and increased to 3.45 MPa after attaining the target thickness.

3.3 Hybrid Reinforced Composite

Several publications were available on glass fibre and natural fibre combination for reinforcement in composites. This was simply used for enhancement of physical and mechanical properties of natural composites exploiting the better properties of glass fibre. There is no significant reference on hybrid reinforcement only using natural fibres.

4. End Product:

The development of hybrid composite from jute-bamboo combination will replace mainly the products made from wood or ply wood. Preliminary indication from laboratory trials, inclusion of bamboo substrate with jute substrate increases mechanical properties.

In rural area especially in North Bengal and North Eastern States wood or wood products are used for building materials. These components of building can be replaced by developing jute-bamboo hybrid composite. Thus utilizing the abundant natural resources (bamboo & jute) of these regions, the socio economic condition of people will be improved. The developed materials can be used for building components for low cost housing, temporary or emergency shelter, village school building, market kiosk and components for furniture & transport sector also.

TARGETED END PRODUCTS	
a) building components: ceiling partition wall door window shutter wall of toilets above plinth	b) furniture components Table book shelf almirah seat & backrest for chair
c) transport sector body building of bus, truck etc (replacement of wood components) seat & back rest of rickshaw base platform & side cover of hand pull cart etc.	

5. Conclusion:

There are plenty of publications, literature reviews on both jute composite and bamboo composite. So it is possible to develop new hybrid reinforcement system using jute with bamboo. Bamboo has high strength with higher elongation properties than jute. Higher elongation property will confer the ductility (i.e. reduce the chances of sudden failure under load) to the composite. It enhances the selection of jute-bamboo composite as engineering material.

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7. List of Some Entrepreneurs:

BAMBOO COMPOSITE

1.	Emmbee Forest Products Pvt. Ltd.	Address- 25/4 Rustomjee Street, (Ground Floor) Kolkata-700019 Factory: P.O. Manabari, Oodlabari, Dist. Jalpaiguri 735222 West Bengal
2.	Zonum Matply Pvt. Ltd.	Address- A- 20, Lower Zarkawt, Aizwal, Mizoram Works: Lengpui, Near Airport, Aizwal, Mizoram
3.	Kosons Forest Products Pvt. Ltd.	Address- 107, Stephen House, 4E, B. B. D. Bag Kolkata, West Bengal
4.	Timpack Pvt. Ltd	Address- 15th Mile G. S. Road, Byrnihat, Meghalaya-793010
5.	Srivari Metal Works Pvt. Ltd.	Address E-14, Phase V, SIDCO Industrial Estate Hosur-635 126, Tamil Nadu
6.	Ply-bamboo Industries	Address P.O. Mohuda Village, via Berhampur Orissa

JUTE COMPOSITE

1.	APL Polyfab (P) Ltd.	Address- 5, Dr. Rajendra Prasad Sarani Kolkata- 700001
2.	A. B. Composites Pvt. Ltd.	Address- 1/1B/18, Ramkrishna Naskar Lane Kolkata- 700010
3.	Excel Composites Pvt. Ltd.	Address- 37 A/1, B. T. Road, Kolkata- 700002
4.	Micaply	Address- 23-24, New Sector, Phase-II, Industrial Area, Bhopal-462046, M.P.

8. List of Standards:

1.	IS: 14588- 1999	Specification for Bamboo Mat Veneer Composite for general purpose.
2.	IS: 13958- 1994	Bamboo Mat Board to General Purposes- Specification.
3.	IS: 2380 (Parts I to XXI)- 1977	Methods of test for wood particle boards and boards from other lignocellulosic materials (first revision).
4.	IS: 3087- 1985	Specification for Wood particle boards (medium density) for general purpose (first revision).
5.	IS: 1658- 1977	Specification for Fibre Hardboards (second revision).
6.	IS: 2036- 1974	Specification for Phenolic Laminated Sheets (first revision).
7.	IS: 3513 (Part 1)- 1989	Specification for Resin treated compressed wood laminates (compregs) (first revision).
8.	IS: 3478- 1966	Specification for Particle Boards of Wood and other Lignocellulosic Materials (High Density) for General Purposes.
9.	IS: 4990: 1993	Plywood for Concrete Shuttering Work- Specification (second revision)
10.	IS: 12406- 1988	Specification for Medium density fibreboards for general purposes.
11.	ASTM: D 256- 84	Standard Test methods for Impact Resistance of Plastics and Electrical Insulating Materials.
12.	ASTM D 570- 81	Standard Test method for Water Absorption of Plastics.
13.	ASTM: D 638M- 84	Standard Test methods for Tensile Properties of Plastics (Metric).
14.	ASTM: D 790M- 84	Standard Test methods for Flexural Properties of Un-reinforced and Reinforced Plastics and Electrical insulating materials (Metric).
15.	ASTM D1037-96a	Standard Test Methods for Evaluating properties of wood- base fibre & particle panal materials.
16.	ASTM: D 2344- 84	Standard Test method for Apparent Interlaminar Shear Strength of Parallel Fibre Composites by Short-Beam Method.

17.	ASTM: D 3039/ D D3039M/ 93	Standard Test method for Tensile Properties of Polymer Matrix Composite Materials.
18.	ASTM: D 6002 (2002)e1	Standard Guide for Assessing the Compostability of Environmentally Degradable Plastics.
19.	ASTM: D 6400- 04	Standard specification for Compostable Plastics.
20.	ASTM: D 6868- 03	Standard Specification for Biodegradable Plastics used as Coating on Paper and other Compostable substrate.
21.	ASTM: D 6954- 04	Standard Guide for Exposing and Testing Plastics that Degrade in the Environment by a combination of Oxidation and Biodegradation.
22.	BS 1142: 1989 (BSI)	British Standard Specification for Fibre building boards

Chapter 2

Need Assessment

Introduction:

Renewable resources from agricultural or forestry products form a basis for new industrial products or new alternative energy sources. Plant based fibers are already used in a wide range of products. Plant fibers find applications as textiles and geo-textiles, twines and ropes, special pulps, insulating and padding materials, fleece, felt and non-woven materials and increasing as reinforcement for polymers to develop composites.

Trend for exploration on application of natural resources is tremendously increased for sustainable technology development. Environmental issues and decreasing stock of mineral resources are the prime concern for this objective. Natural fibre is emerging as an important ingredient for new technologies. India has biodiversity on natural fibre i.e. jute, kenaf (mesta), bamboo, coir, sisal, pineapple, banana, bagasse etc. All these natural fibres are now used in the area of low value end product. Among these natural fibers, jute and bamboo specially have been concentrated for need assessment for their abundant availability in India. At present jute, which is a yearly renewable crop, is mainly used for making sacks and hessians. Bamboo is also found for making low cost housing and packaging. Thus reflects it's under utilisation of potential properties.

Jute and Its Present Status:

Jute fibers are the most important plant fibers alongside cotton. Jute was used by humans since pre-historic times. Jute is the most versatile, eco-friendly, natural, durable fiber available in India. Maximum quantity of jute is produced in India and Bangladesh. Farmers might benefit from their crops because of their quick turnaround times with various alternative uses.

Jute is one of the major annual cash crops in the eastern part of India. Total supply of raw jute[1] for the period of 2008-09 was 106 lakh bales, within which 2 lakh bales were imported whereas the consumption was 98 lakh bales (Table-1). Productions of various jute goods[1] are also shown in Table-2.

Table 1: Consumption of Raw Jute from 1998 to 2009

Raw Jute (Qty: in lakh bales)											
	1998 -99	1999 – 00	2000 - 01	2001 - 02	2002 - 03	2003 - 04	2004 - 05	2005 - 06	2006 - 07	2007 - 08	2008 - 09
Carry over	27.00	22.00	10.50	7.00	16.00	34.00	33.00	14.00	8.00	23.00	22.00
Production	83.00	78.00	90.00	105.00	110.00	90.00	75.00	85.00	100.00	99.00	82.00
Import	*9.00*	*8.00*	*4.00*	*4.00*	*9.00*	*5.00*	*3.00*	*7.00*	*4.00*	*8.00*	*2.00*
Total Supply	**119.0**	**108.0**	**104.5**	**116.0**	**135.0**	**129.0**	**111.0**	**106.0**	**112.0**	**130.0**	**106.0**
Domestic Consumption	7.00	7.00	7.00	8.00	8.00	8.00	8.00	8.00	9.00	9.00	9.00
Mill Consumption	90.00	90.50	90.50	92.00	93.00	88.00	90.00	90.00	80.00	99.00	89.00
Total Demand	**97.00**	**97.50**	**97.50**	**100.0**	**101.0**	**96.00**	**98.00**	**98.00**	**89.00**	**108.0**	**98.00**
Carry over	22.00	10.50	7.00	16.00	34.00	33.00	14.00	8.00	23.00	22.00	8.00

Table 2: Production of Jute Goods from 1999 to 2009

(In '000' M. Ton)

Period (Apr-Mar)	Hessian	Sacking	CBC	Others	Total
1999 – 2000	344.5	909.2	8.0	328.5	1590.2
2000 – 2001	337.9	952.9	6.6	327.5	1624.9
2001 – 2002	275.3	1034.6	5.0	286.2	1601.1
2002 – 2003	338.3	1000.0	5.4	278.1	1,621.8
2003 – 2004	305.2	979.3	4.7	282.1	1,571.3
2004 – 2005	310.3	992.0	4.0	306.8	1613.1
2005-2006	320.1	1007.8	6.1	248.5	1582.5
2006-2007	250.3	874.7	2.8	228.5	1356.3
2007-2008	350.3	1143.0	6.0	275.7	1775.0
2008-2009	297.8	1071.4	4.5	260.0	1633.7

Domestic consumption[1] of jute goods was 1435.6x10^3 Ton for the period of 2008-09 mainly in the form of Hessian, sacking, CBC etc (Table-3). Exports of the jute goods[1] were declining from 2005-06 & to 199.8 x 10^3 Ton during 2008-09 (Table-4). Where as the domestic consumption and exports of jute diversified products (JDP) were stagnant and declined for the period of 2008-09.

Table 3: Domestic Consumption of Jute Goods

Jute goods (Qty: In 000' Ton)					
(April–March)	Hessian	Sacking	CBC	Others	Total
1996 – 97	259.8	652.0	1.7	222.5	1336.0
1997 – 98	285.8	842.4	1.5	257.5	1387.2
1998 – 99	286.2	886.3	1.3	230.5	1404.3
1999 – 2000	287.0	907.4	1.4	230.9	1426.7
2000 – 2001	269.7	935.2	0.8	229.4	1435.1
2001 – 2002	243.0	1021.4	0.9	195.5	1460.8
2002 – 03	251.3	954.5	1.9	167.7	1375.7
2003 – 04	253.3	910.00	0.3	179.3	1342.9
2004 - 05	244.8	972.4	0.5	176.5	1394.2
2005 – 06	237.6	974.2	0.7	165.3	1378.8
2006 - 07	209.1	854.4	0.5	152.7	1216.2
2007 - 08	271.4	1102.0	1.2	168.2	1542.7
2008 - 09	249.8	1043.0	0.3	142.5	**1435.6**

Table 4: Exports of Jute Goods

Jute goods (Qty: In 000' Ton, Value : Rs / Crore)						
(April–March)	Hessian	Sacking	CBC	Others	Total	Value
1996 – 97	76.3	6.7	15.4	5.6	155.0	572.3
1997 – 98	103.5	17.9	13.5	9.7	240.0	694.7
1998 – 99	65.3	8.0	15.3	12.9	171.0	582.3
1999 – 2000	57.4	5.6	6.3	15.8	169.0	571.5
2000 – 2001	61.4	17.3	5.9	11.5	181.4	646.3
2001 – 2002	36.8	12.2	4.4	13.7	146.1	567.5
2002 – 03	77.4	37.5	3.8	22.5	229.2	916.6
2003 – 04	157.1	33.4	5.2	24.1	310.4	1051.88
2004 - 05	153.7	31.2	1.5	15.0	321.8	1146.9
2005 – 06	171.6	33.2	0.9	11.0	285.8	1186.24
2006 - 07	122.2	31.6	0.1	10.6	242.8	1055.16
2007 - 08	67.8	30.0	N.A.	14.4	204.3	1143.57
2008 - 09	53.0	53.2	N.A.	10.7	**199.8**	**1066.08**

Bamboo and Its Present Status:

Among many natural fibrous plants, bamboo is the one of the fastest growing grass plants and it is abundantly available in many countries. Unfortunately, in spite of its remarkable tensile and impact strength, bamboo fiber has been utilized only for making low grade structural materials that to, for short term applications.

India has the second largest reserve of bamboos[2] after China and $9607x10^3$ hectares of forest land is covered by bamboo (Table-5). The area[2] is divided into natural forest area of $8434x10^3$ hectares and plantation forest area of 2927×10^3 hectares (Table-6).

Table 5: Extent of Bamboo Forests in INDIA

Description	Area (1000 hectares)		
	1990	**2000**	**2005**
Bamboo on forest land	8957	9109	9607

Table 6: Characteristics of Bamboo Forests in INDIA

Description	Area (1000 hectares)		
	1990	**2000**	**2005**
Natural bamboo forests	7844	7996	8434
Plantations	2867	2867	2927
TOTAL	10711	10863	11361

Table 7: Diversity of Bamboo Tree Species

Description	Number of species (Year 2000)
Native bamboo species	119 (exact status yet to be explored)
Introduced bamboo species	25

Table 8: Bamboo Growing Stock in INDIA

Description	Volume (million tones)					
	Bamboo on forest land			**Bamboo on other land**		
	1990	**2000**	**2005**	**1990**	**2000**	**2005**
Bamboo growing stock (total culms)	96.16	97.8	103.1	18.83	18.83	18.83
Commercial bamboo growing stock (total culms)	13.25	13.48	14.21	2.56	2.56	2.56

Diversity of Indian bamboo[2] (Table-7) is around 119 native species & 25 as introduced species. Growing bamboo stock (culm) was 121.93 million ton within which the commercially important stock[2] was merely 16.77 million ton on 2005 (Table-8). Total Bamboo removal[2] from bamboo forest during 2005 was 14.615 million ton within which 13.470 million ton was used for various purposes other than wood fuel (Table-9). Only 1.145 million ton was used as wood fuel. Bamboo, as a major constructional material is used for almost all parts of houses, including walls, floors, posts, roofs, beams, trusses, fences etc. Other uses are as fuel, weaving products & crafts, production of charcoal, paper & pulp, etc. Recently bamboo reconstituted panels are produced as replacement of plywood / wood based product. But major portion of the resources are still left for utilization.

Table 9: Bamboo Removal in INDIA

Description	Bamboo removal (million ton)
	2005
Bamboo wood removal	13.470
Bamboo wood-fuel removal	1.145
Total	14.615

Present Situation of Wood:

The building industry is under tremendous pressure and unable to cope with the new demands from different construction sectors. For example wood is in very short supply and good quality, seasoned timber is not readily available. Anticipating the need to combat wood scarcity, substitute materials are continuously being looked into and developed. The existing wood substitute materials such as reconstituted panel (particle board / fibre board), plywood can not meet the increasing demand for wood without new efforts.

If we look at the world demand for wood and wood based products, there is enormous scope for use of jute-bamboo hybrid composite as it will help us to protect our precious forest resources. As per FAO[3] documentation, the main factors affecting long-term global demand for wood products include:

- Demographic change: the world's population is projected to 7.5 billion in 2020 and 8.2 billion in 2030.
- Economic growth: global GDP is projected to grow US $100 trillion by 2030.
- Regional shift: developed economics accounted for most of the GDP in the period 1970-2005. The rapid growth of developing economies, especially in Asia, will swing the balance significantly in the nest 25 years.
- Environmental policies and regulations: more forests will be excluded from wood production.
- Energy policies: the use of biomass, including wood, is increasingly encouraged.

From Table-10, it is found that global production[3] of Industrial round wood (log) on 2005 was 1668 million m^3 and projected to 2166 million m^3 for 2020 & 2457 million m^3 for 2030. Thus the annual change of 1.8% for the period of 2005-2020 and 1.3% for the period of 2020-2030 were projected. Also global consumption of the same product in 2005 was 1682 and projected to 2165 million m^3 for 2020 and 2436 million m^3 for 2030. There would be little gap between projected demand & production for 2020 but this would increase during 2030.

Table 10: Production and Consumption of Industrial Round Wood

Region	Amount (million m^3)					Average annual change %			
	Actual			Projected		Actual		Projected	
	1965	1990	2005	2020	2030	1965-1990	1990-2005	2005-2020	2020-2030
Production									
Africa	31	55	72	93	114	2.4	1.8	1.8	2.0
Asia and the Pacific	155	282	273	439	500	2.4	-0.2	3.2	1.3
Europe	505	640	513	707	834	0.9	-1.5	2.2	1.7
Latin America and the Caribbean	34	114	168	184	192	5.0	2.6	0.6	0.4
North America	394	591	625	728	806	1.6	0.4	1.0	1.0
Western and Central Asia	10	9	17	15	11	-0.6	4.5	-0.8	-3.0
WORLD	**1128**	**1690**	**1668**	**2166**	**2457**	**1.6**	**-0.1**	**1.8**	**1.3**
Consumption									
Africa	25	51	68	88	109	2.9	1.9	1.8	2.1
Asia and the Pacific	162	315	316	498	563	2.7	0.0	3.1	1.2
Europe	519	650	494	647	749	0.9	-1.8	1.8	1.5
Latin America and the Caribbean	33	111	166	181	189	4.9	2.7	0.6	0.4
North America	389	570	620	728	808	1.5	0.6	1.1	1.0
Western and Central Asia	10	10	19	22	19	-0.2	4.4	1.1	-1.3
WORLD	**1138**	**1707**	**1682**	**2165**	**2436**	**1.6**	**-0.1**	**1.7**	**1.2**

Table 11: Production and Consumption of Sawn-wood

Region	Amount (million m^3)					Average annual change %			
	Actual			Projected		Actual		Projected	
	1965	1990	2005	2020	2030	1965-1990	1990-2005	2005-2020	2020-2030
Production									
Africa	3	8	9	11	14	3.7	0.5	1.6	1.9
Asia and the Pacific	64	105	71	83	97	2.0	-2.6	1.1	1.6
Europe	189	192	136	175	201	0.1	-2.2	1.7	1.4
Latin America and the Caribbean	12	27	39	50	60	3.3	2.5	1.7	2.0
North America	88	128	156	191	219	1.5	1.3	1.4	1.4
Western and Central Asia	2	6	7	10	13	4.6	1.5	2.6	2.2
WORLD	**358**	**465**	**417**	**520**	**603**	**1.1**	**-0.7**	**1.5**	**1.5**
Consumption									
Africa	4	10	12	19	26	3.6	1.2	2.8	3.5
Asia and the Pacific	64	112	84	97	113	2.3	-1.9	1.0	1.6
Europe	191	199	121	151	171	0.2	-3.3	1.5	1.2
Latin America and the Caribbean	11	26	32	42	50	3.3	1.5	1.7	1.8
North America	84	117	158	188	211	1.3	2.0	1.2	1.2
Western and Central Asia	3	7	13	18	23	4.0	3.7	2.5	2.2

The statistics[3] on global production and consumption of sawn wood is given in Table 11. Here we find the projection of production of sawn wood would be greater than consumption both during year 2020 & 2030.

Global production and consumption of wood[3] based panel (plywood, veneer & the secondary wood products) is given in Table-12. The demand and production of panel during 2020 and 2030 is projected more or less equal to each other.

Table 12: Production and Consumption of Wood-based Panels

Region	Amount (million m^3)					Average annual change %			
	Actual			Projected		Actual		Projected	
	1965	1990	2005	2020	2030	1965-1990	1990-2005	2005-2020	2020-2030
Production									
Africa	1	2	3	4	5	4.6	3.8	2.1	2.4
Asia and the Pacific	5	27	81	160	231	6.9	7.5	4.6	3.7
Europe	16	48	73	104	129	4.5	2.8	2.4	2.2
Latin America and the Caribbean	1	4	13	21	29	7.4	7.6	3.3	3.2
North America	19	44	59	88	110	3.4	2.0	2.7	2.2
Western and Central Asia	0	1	5	11	17	6.8	8.9	5.4	4.7
WORLD	**41**	**127**	**234**	**388**	**521**	**4.6**	**4.2**	**3.4**	**3.0**
Africa	0	1	3	4	5	4.8	5.3	1.9	2.4
Asia and the Pacific	4	24	79	161	236	7.4	8.2	4.8	3.9
Europe	16	53	70	99	122	4.9	1.9	2.4	2.1
Latin America and the Caribbean	1	4	9	12	15	7.0	5.7	2.2	2.3
North America	20	43	70	96	115	3.1	3.3	2.1	1.8
Western and Central Asia	0	2	9	18	28	8.1	10.6	4.5	4.5
WORLD	**42**	**128**	**241**	**391**	**521**	**4.6**	**4.3**	**3.3**	**2.9**

Trade of primary wood products[4] in India (period 2004 to 2008) is shown in Table-13. Production of logs was increased to 23.191 million m^3 in the year 2005 from 22.81 million m^3 in 2004 and was same till 2008. But the import of log was increased year by year from 2.597 million m^3 in 2004 to 4.951 million m^3 in 2008. The domestic consumption was also increased from 25.399 million m^3 in 2004 to 28.136 million m^3 in 2008. Export of the log was insignificant during this period.

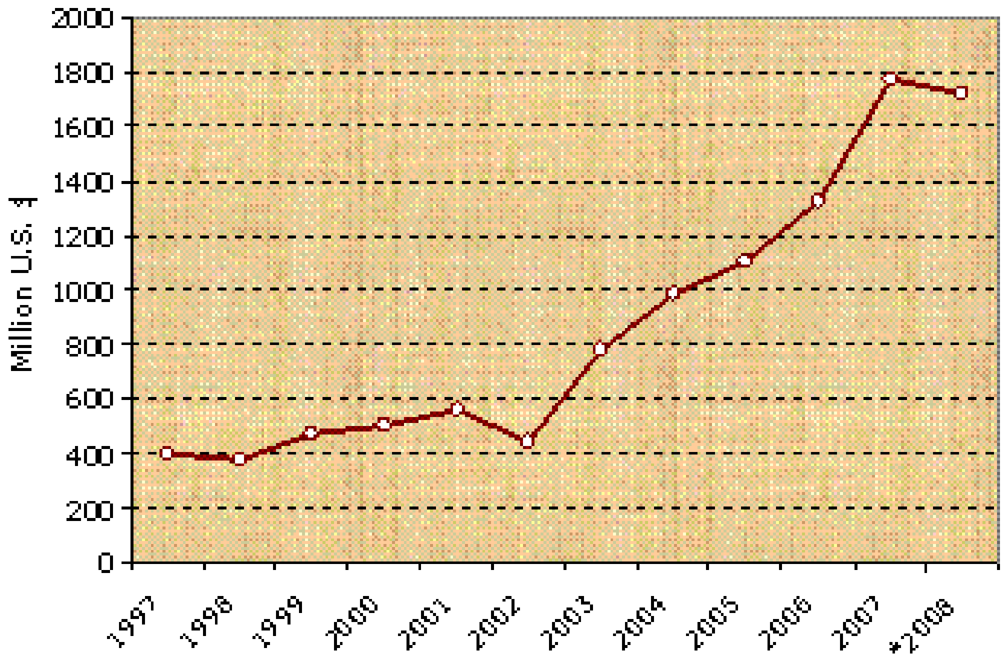
Production trend during this period for sawn wood and plywood was same as log; the initial increase in the year 2005 from 2004 it was stagnant during the rest of the period. But in the case of veneer production there was increase in 2005 from 2004 and again there was little increase in 2007 and 2008. Import and domestic consumption of sawn wood, plywood and veneer was increased during this period.

Import of wood and wood products by India in US $ was shown[5] in Chart-1 from year 1997/98 to estimated value for 2008/09. It was found the import increased manifold from US$ 400 million in

1997/98 to above US $ 1700 million in 2008/09. Significant upward trend was observed from 2002/03.

Category wise imports of wood products (in values) by India have been projected[5] in Table-14. India's import of secondary processed wood products in values has been reported[4] in Table-15 while the India's import of different types of secondary processed wood products in values for the year 2007 has been shown[4] in Table-16.

Chart 1: Import of Wood and Wood Products in India, 1997/98 through 2008/09



Note: 2008/09 estimated import (Indian financial year)

Table 13: Production, Trade and Consumption of all Timber by India (1000 m^3)

Product	Production					Imports					Exports					Domestic Consumption				
	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008
Logs	22810	23191	23192	23192	23192	2597	3697	3902	4652	4951	9	11	18	9	7	25399	26876	27076	27835	28136
Sawn wood	13661	14789	14789	14789	14789	94	76	216	368	337	14	15	19	21	32	13741	14850	14986	15137	15094
Veneer	267	280	280	285	290	4	9	15	17	24	17	19	22	27	38	254	270	273	275	276
Plywood	1957	2174	2154	2154	2154	20	39	31	54	65	49	109	106	118	71	1929	2104	2079	2089	2148

Table 14: India's Imports of Wood Products by Category (Million US $)

Item	1996/97	2003/04	2004/05	2005/06	2006/07	2007/08	*2008/09
Wood Logs	246.7	667.7	820.2	831.6	908.5	1171	1147.34
Sawn Lumber	4.8	12.3	13.2	20.9	22.8	25.5	30.51
Veneer	6.4	3.6	4.9	11.2	14.2	18.5	21.22
Plywood	4.2	4.2	5.1	8.2	12.8	28.5	34.47
MDF/HDF	0.7	13.1	17.5	27.9	35.3	57	50.94
Particle Board	3.6	13.3	16.8	26.5	32.2	46.5	41.85
Other Products	3.9	9.5	15.8	28.9	43.4	66	71
Total	270.4	723.7	893.5	955.1	1072.1	1413	1397.42
Wooden Furniture	0.5	57.3	90.7	150.3	250.5	358	324.29
Total Wood Products	270.8	781.0	984.2	1105.4	1322.6	1771	1721.71

Table 15: India's Import of Secondary Processed Wood Products (SPWP) (Million US $)

Year	2003	2004	2005	2006	2007
Value	40.067	62.906	119.709	197.680	248.692

Table 16: India's Import of Different Types of Secondary Processed Wood Products (SPWP), 2007 (Million US $)

Types of SPWP	Wooden Furniture and Parts	Builder's Woodwork	Other SPWP	Mouldings	Cane and Bamboo Furniture and Parts
Value	171.68	10.288	27.895	8.281	30.548

It is interesting to note that India is also exporting secondary processed wood products quite significant amount as depicted[4] in Table-17 & 18.

Table 17: India's Export of Secondary Processed Wood Products (SPWP) (Million US $)

Year	2003	2004	2005	2006	2007
Value	116.376	216.956	242.999	323.039	386.831

Table 18: India's Export of Different Types of Secondary Processed Wood Products, 2007 (Million US $)

Types of SPWP	Wooden Furniture and Parts	Builder's Woodwork	Other SPWP	Mouldings	Cane and Bamboo Furniture and Parts
Value	315.453	3.980	59.690	3.963	3.744

Table 19: Market Shares of Plywood, Particle Board and MDF

	India	China	World average
Plywood	90%	10%	20%
Particle board	6%	30%	55%
MDF	4%	60%	25%
Total	100	100	100

For economic growth major investment is made in construction field. It is found[6] from chart-2 that for doors, windows & woodwork is approximately 13% of total cost of construction stage wise and from chart-3 it is found the cost for doors & windows frame and shuttering/ framework[7] is within 8-12% of total cost of construction – item wise & activity wise. For example, building is one of the main fields of construction. Building consumes about 70% of global timber products.

Chart 2: Cost of Construction Stage wise

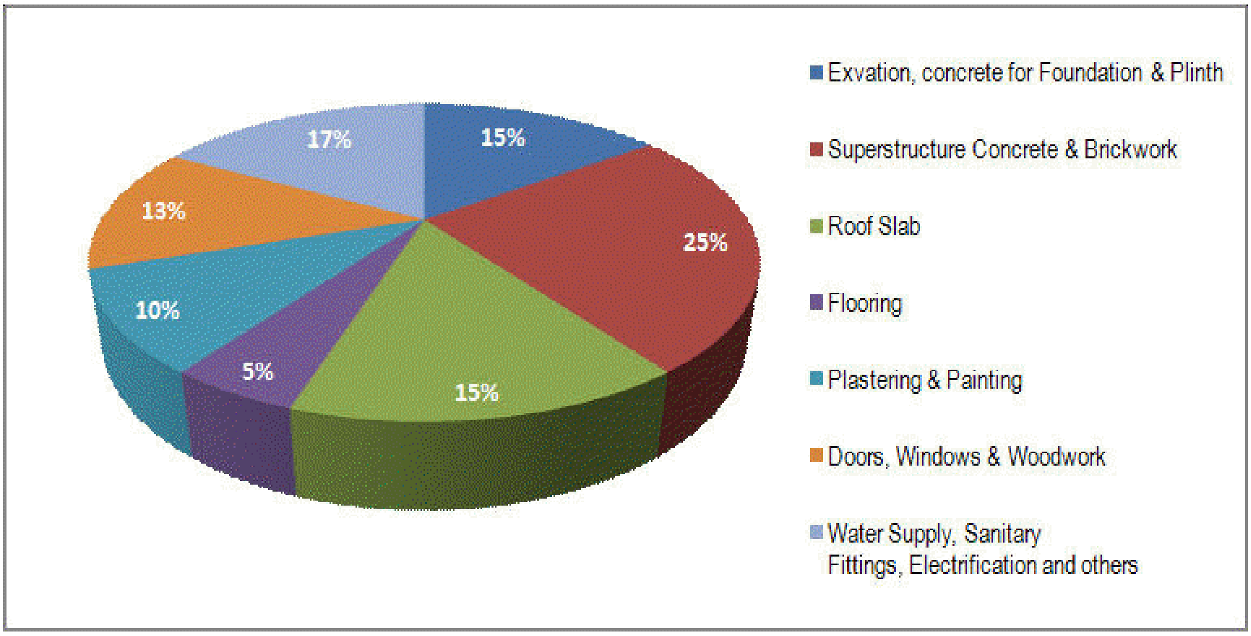
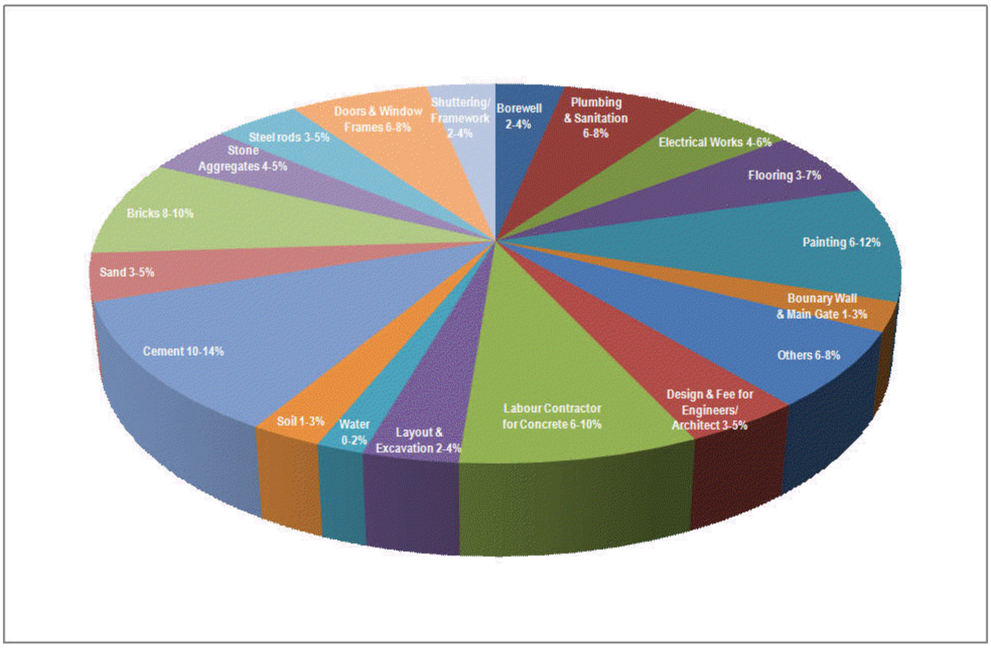


Chart 3: Approximate Cost of Construction - Item wise & Activity wise



If we look at India's growth in housing sector both in urban[7&12] & rural area[11], the shortage of housing stock is enormous. It is projected in 11th five year plan (2007-12) paper the shortage of house stock for urban & rural area during 2012 will be 26.53 million and 47.43 million respectively. The statistics[7,11&12] are shown in Table-20 to Table-23. It is obvious the demand of housing in rural area is greater than urban area as 71% of Indian population is residing in rural area. The demand of quality products is same as the urban area.

Table 20: India's Urban Housing Shortage as on 2007

Sl No	Description	Quantity in million
1	Households	66.30
2	Housing Stock	58.83
2.1	Pucca	47.49
2.2	Semi Pucca	9.15
2.3	Kutcha	2.18
3	Excess of HHs over HS (1-2)	7.47
4	Congestion factor (%)	19.11
4.1	Congestion HHs	12.67
5	Obsolescence factor (%)	3.60
5.1	Obsolescence in HHs	2.39
6	Up gradation of Kutcha (2.3)	2.18
7	**Total Housing Shortage (3+4.1+5.1+6)**	**24.71**

Table 21: Estimation of New Addition of Urban Housing during the Eleventh Plan Period

Sl No	Households	Quantity in million
1	Pucca	6.00
2	Semi Pucca	0.89
3	Kutcha	0.38
	Total Housing Stock	**7.27**

Table 22: Total Requirement of Urban Housing During the Eleventh Plan Period as on 2012

Sl No	Description	Quantity in million
1	Housing Shortage as on 2007	24.71
2	Households	75.01
3	Pucca Houses	53.49
4	Semi Pucca Houses	10.05
5	Kutcha Houses	2.56
6	Addition to Households	8.71
7	Addition to Housing Stock	7.27
8	Up gradation of Kutcha Houses	0.38
9	Additional Requirement (6-7+8)	1.82
	Total Requirement	**26.53**

Table-23 Total Requirement of Rural Housing during the Eleventh Plan Period as on 2012

Figures Used for Assessing Housing Shortage during 2007 & 2012

(In million)

	2007	2012
Housing Stock	153.03	169.79
Households	156.63	173.78
Pucca House	70.14	85.33
Semi-Pucca House	56.37	64.08

Assessing Rural Housing Shortage

S. No	Factors taken into account for assessing Housing shortage	Calculation	Shortage in million
1	No. of Households not having houses in 2007	No. of Households – No. of Housing Stock (156.63 million – 153.03 million)	3.60
2	No. of Temporary Houses in 2007	No. of Housing Stock – No. of Permanent Houses (Pucca + Semi Pucca) 153.03million – 126.51 million	26.52
3	Shortage due to Congestion in 2007	6.5% x No. of Households (6.5% x 156.63 million)	10.18
4	Shortage due to Obsolescence in 2007	4.3% x No. of Household (4.3% x 156.63 million)	6.74
5	Additional Housing Shortage arising between 2007 to 2012	No. of excess Households projected for 2012 over 2007 – No. of excess Housing Stock projected for 2012 over 2007 = (17.15 - 16.76)	0.39
Total Rural Housing Shortage 2007-2012			**47.43**

Composites as Wood Substitute

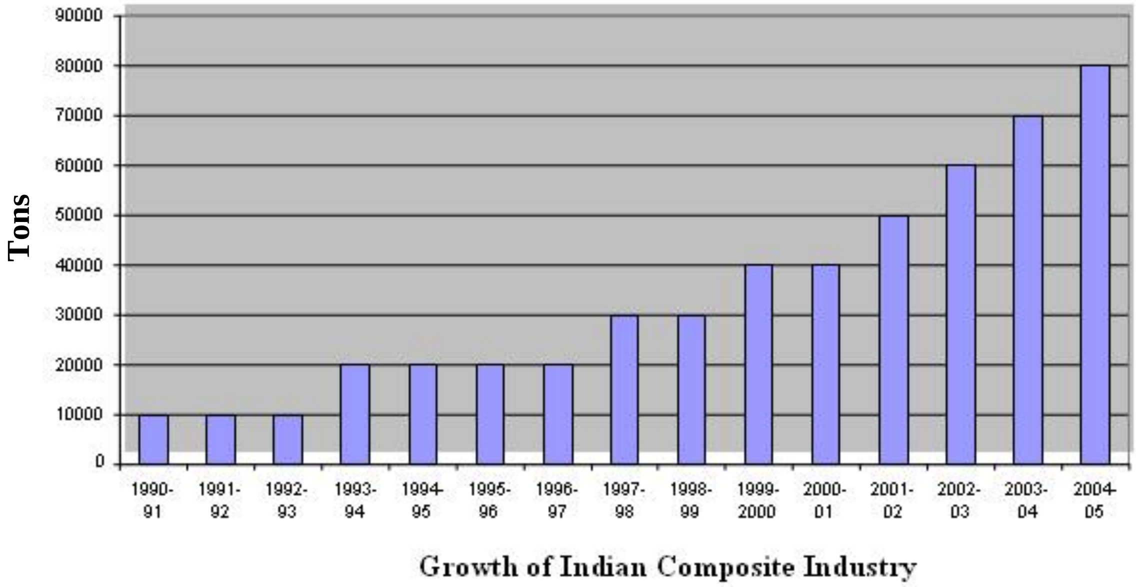
Composite materials are the most advanced and adaptable engineering materials. Composite materials are attractive because they combine material properties in ways not found in nature. The composite is a heterogeneous material created by the synthetic assembly of two or more components constituting reinforcing fibre and a compatible matrix in order to obtain specific characteristics and properties. Such materials often result in light weight structures having high stiffness and tailored properties for specific applications, thereby saving weight and reducing energy need. Fibre reinforced plastic composites began in 1908 and reaching commodity status in 1940s with glass fibre in unsaturated polyesters. Fibre reinforced composites are found in diverse fields. Glass fibre is the dominant fibre and is used in 95% of cases to reinforce thermoplastic and thermoset composites. The market for composite materials in India will continue to grow at a projected rate of about 25% during next 4 to 5 years.

Composite offers significant advantages of higher strength, lower weight, reduced maintenance and corrosion resistance compared to steel and other structural metals. Hence the growth is focused in such application areas as transportation, construction, wind energy, industrial and railways. The figures[8] in the Table-24 are released by Technology Information Forecasting and Assessment Council (TIFAC), Govt. of India. Thus, it is observed that the growth in glass reinforced composites is quite significant in India at this moment.

Table 24: Estimated Sector wise Overall Consumption of Composites in India

S. No	Sector	2006	2007	2008	2009	2010
1	Wind energy	15.79	20.27	25.96	33.20	42.46
2	Industrial	26	29.10	32.59	36.51	40.92
3	Railways	8	9.60	11.52	13.82	16.59
4	Automobile	20.69	22.67	24.9	26.3	28.1
5	Oil& Gas	1.5	1.6	1.7	1.8	1.9
6	Building & Construction	35.00	39.50	44.65	48.92	55.40
7	Marine	1	1.4	1.8	2.30	3
	Total	**107.98**	**124.14**	**143.12**	**162.85**	**188.37**

Chart 4: Growth of Indian Composite Industry



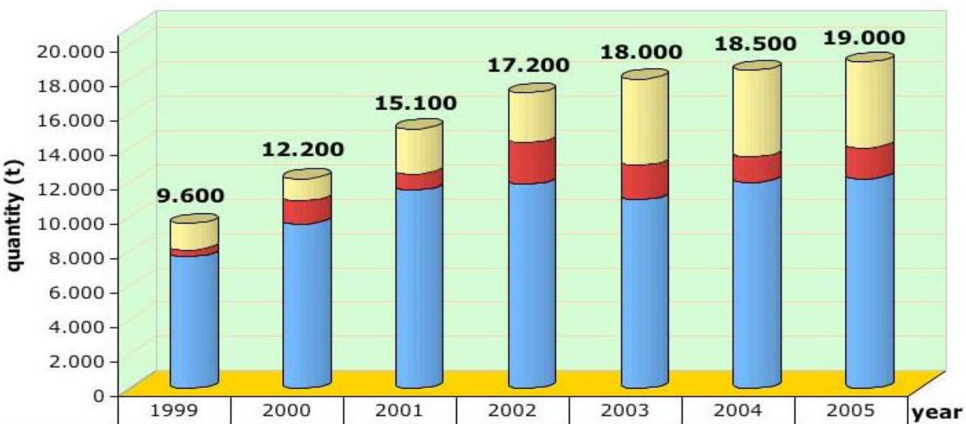
Natural fibre composites are attracting more attention as alternate building materials, especially as wood substitute in the developing countries. With the advent of surface modification, moisture resistant natural fibres are utilized low pressure moulding to over come their moisture absorption. As a result, dimensionally stable panel products, profiles, sheets and moulded items have been prepared as alternatives to boards/ plywood but these are not cost effective, till date. One strong option is to promote development and utilization of composites materials based on natural fibers. Manufacturing of natural fiber based panels as alternative to plywood has failed to possess desired properties as building materials due to their inadequate specific strength, stiffness and dimensional stability that conform to the existing specifications.

It is known that natural fibre without wood is being utilized for development of composites in different areas of applications. Out of those applications composites for automotive industries' has come in significant way particularly in German automotive industries. The growth[9] of such composite units in Germany has been clearly shown in Chart-5, 6 & 7. The quantity of composites for automotive industries using natural fibres has been more than doubled within six years span of time.

In India, automobile industry is also using the jute reinforced composite for auto trim products. M/S Birla Corporation Ltd. produced[10] 139,173 pieces of door trim during 2007-08 whereas declined to 43,073 pieces during 2008-09 on account of global recession in automotive sector. Production is operating at low level because of lack of orders.

We find from above facts and figures that the natural fibre reinforced composite will be an important factor for fabrication of innovative products for application in different areas, though this will depend on governmental legislation and increased people awareness.

Chart 5: Use of Natural Fibres (without Wood and cotton) for Composites in the German Automotive Industry 1999 – 2005)



	1999	2000	2001	2002	2003	2004	2005
Total	9.600	12.200	15.100	17.200	18.000	18.500	19.000
Exotic Fibres	1.548	1.279	2.618	2.895	4.995	5.000	5.000
Hemp	372	1.350	913	2.416	2.012	1.500	1.800
Flax	7.680	9.571	11.569	11.890	10.993	12.000	12.200

Chart 6: Use of Natural Fibres for Composites in the German Automotive Industry 2005 (Total: 19,000 Ton)

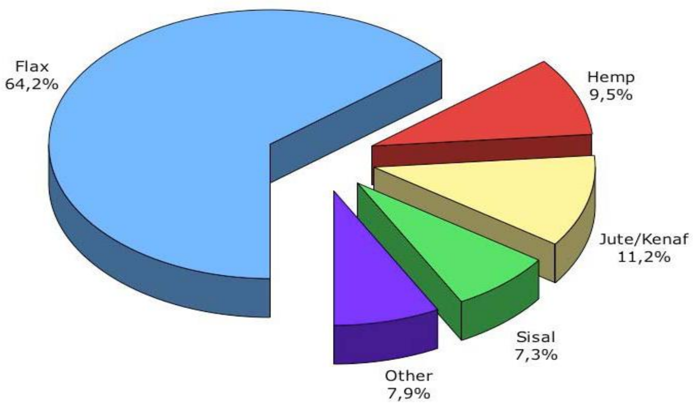
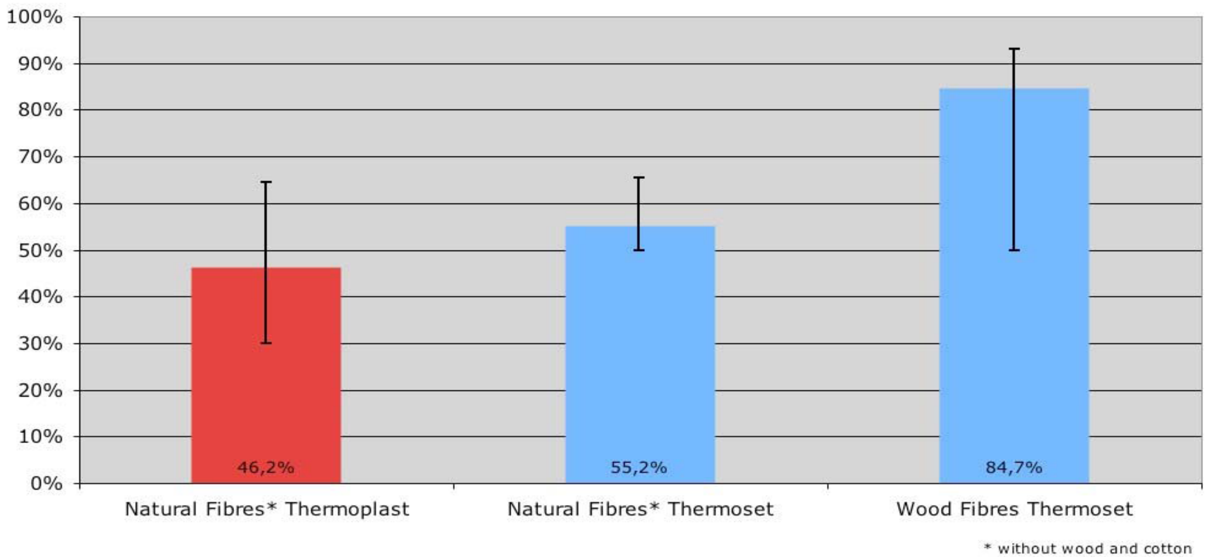


Chart 7: Natural Fiber (without wood and cotton) Reinforced Composites in Different Processing Technologies of Composites in the German Automotive Industry in 2005



One strong option is to promote the development and utilization of composite materials based on natural fibres. Manufacturing of natural fibre based panels as alternative to plywood has failed to possess desired properties as building materials due to their inadequate specific strength, stiffness and dimensional stability that conform to the existing specifications.

The natural fibre composites have been made as substitute of wood in the form of medium density fibre board (MDF) & high density fibre board (HDF). As shown[13] in Table-19, the comparative study has been made regarding the production of MDF board in comparison to plywood & particle board. It is shown that India is still dependent on reconstituted wood i.e. plywood, while China has come out successfully replacing wood by MDF to the extent of 60% of their total requirement. With respect to World average, natural fibre composite in the form of MDF is being mainly utilized as wood substitute.

Indian railway has shown interest to introduce natural fibre reinforced thermoset composite for replacement of conventional ceiling in EMU coach and floated tender of value around Rs3.3 crore in 2011-2012 (Doc:1). The fabricators are i) M/S A. B. Composites Pvt. Ltd. & General Industries, Kolkata, W.B, ii) M/S Excel Composites Pvt. Ltd. 24- Parganas (N), W.B. & iii) M/S Micaply, Bhopal, M.P.

Some major findings were reported in a market research document[14] on influencing factors of purchasing decisions in India for different purchasing segments are given in Table-25.

Doc: 1

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Table 25: Influencing Factors on Purchasing Decisions in India

S. No	Purchase Segments	% internal rating of Influencing Factors											Total
		Past experience with the Product	Recommendations by architects/ interior decorators /different agencies	Price of the products	Availability of dimensions /thickness	Choice for colours /shapes /textures	Trader's advice	Technical specifications	Operational ease	Others	Environmental consideration	Advertisement	
1	**Construction**	18	20	23	12	16	6	2	-	3			100
	Interior Decoration	10	30	4	15	26	Negati-ve	4	10	1			100
	Furniture Makers	32	Negative	18	20	22	Negati-ve	2	-	6			100
	Railways	12	Own system	5	13	-	-	60	5	-	5		100
	Automobiles	25		Negative				42	10	3			
	Consumers	3	22	42		6	8					19	100

Conclusion:

Natural fiber composites offer immense opportunities for an increasing role as an alternate material as wood substitutes in the construction market. India is a vast country with a population of more than hundred Crore. Seventy per cent of such huge population resides in village. The demand for housing is considerably higher in rural sector (as shown above in Tables 20-23) for which the demand for wood substitute will be tremendous. Natural fiber composites will play a major role in construction of low cost houses in the form of wall panels, doors, windows and in the form of corrugated sheet for roofing etc. In cold climatic areas, the rural houses are totally made of wood. The incentive for producing these natural fiber based components originates from their low cost, light weight, and oriented employment compared to synthetic fiber based products. As a result, various items such as school buildings, food grain silos, prototypes of low- cost housing units, roofing, wood substitutes have been made. Application developments of natural fiber composites (for example jute composites) as alternate building materials must be thoroughly studied for their durability and cost effectiveness in order to obtain consistent product performance under service conditions.

The use of natural fibers in composite applications is being pursued extensively throughout the world. As a result, many components for the automotive sector are now being made from natural fiber composite materials. These materials are based largely on polypropylene or polyester matrices incorporating fibers such as flax (in our country jute). Till date, the motivation for use of these fibers has been price and marketing rather than technical demands. Therefore, the resultant products are limited mainly to low strength interior automotive components.

Overall, natural fiber composites are seen as potential for many engineering/structural or non-structural applications. However, there are still important issues that limit their future use, including long term performance and the ability to be able to predict performance during service.

As Government and people become more aware and concerned about the environmental hazards of petroleum based products, natural fiber polymer composites (NFPC) are gaining more importance and acceptance as viable alternatives. However NFPC products have to overcome some hurdles, specially the issue of durability, in order to successfully substitute conventional materials. For out-door applications, the change in weathering conditions such as temperature, humidity, and UV radiation reduce the useful service life of the product. There is an on-going effort to develop NFPC materials with improved performance for real world applications.

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Chapter 3

Experimental Process, Results and Discussions

Introduction:

Natural fibres are now emerging as viable alternatives to glass fibres either alone or combined in composite materials for various applications in automotive parts, building structures and rigid packing materials. The advantages of natural fibres over synthetic or man-made fibres such as glass are low cost, competitive specific mechanical properties, carbon sequestration, sustainability, recyclability and biodegradability.

Among natural fibres, jute is abundantly available and other than cotton, jute is processed in various forms like sliver, yarn, ropes, cordages, fabric and non-woven form. Jute, the versatile natural fibre, has enormous applications in the traditional textile market. Considerable emphasis is being paid to the production of several non-traditional products. One area of product development which is attracting attention is the use of jute fibres for manufacturing composites.

For the last two decades, IJIRA is engaged in developing rigid, semi rigid composites in the form of board. Some of the products have already been commercialized suited for railway coach ceiling and some other related uses. As substitute of plywood, the jute based composite board is very strong but it has faced some other technical problem like processing i.e. cutting, nailing and screwing problem due to higher density than conventional plywood.

It is reported that hybridization with other fibres provides a method to improve the mechanical properties of natural fibre composites. With that concept in mind, bamboo has been chosen as a component fibre for reinforcement with jute for hybridization since bamboo is a known strong fibre with its lower density in comparison with jute and it is abundantly grown in Eastern India.

Objectives:

* To develop composite materials for rural application (building components, transport sector, structural, packaging, furniture etc.).

* Optimisation of the properties of end products.

* To study and explore the extraction operation of bamboo fibre.

Experimental:

Raw Materials:

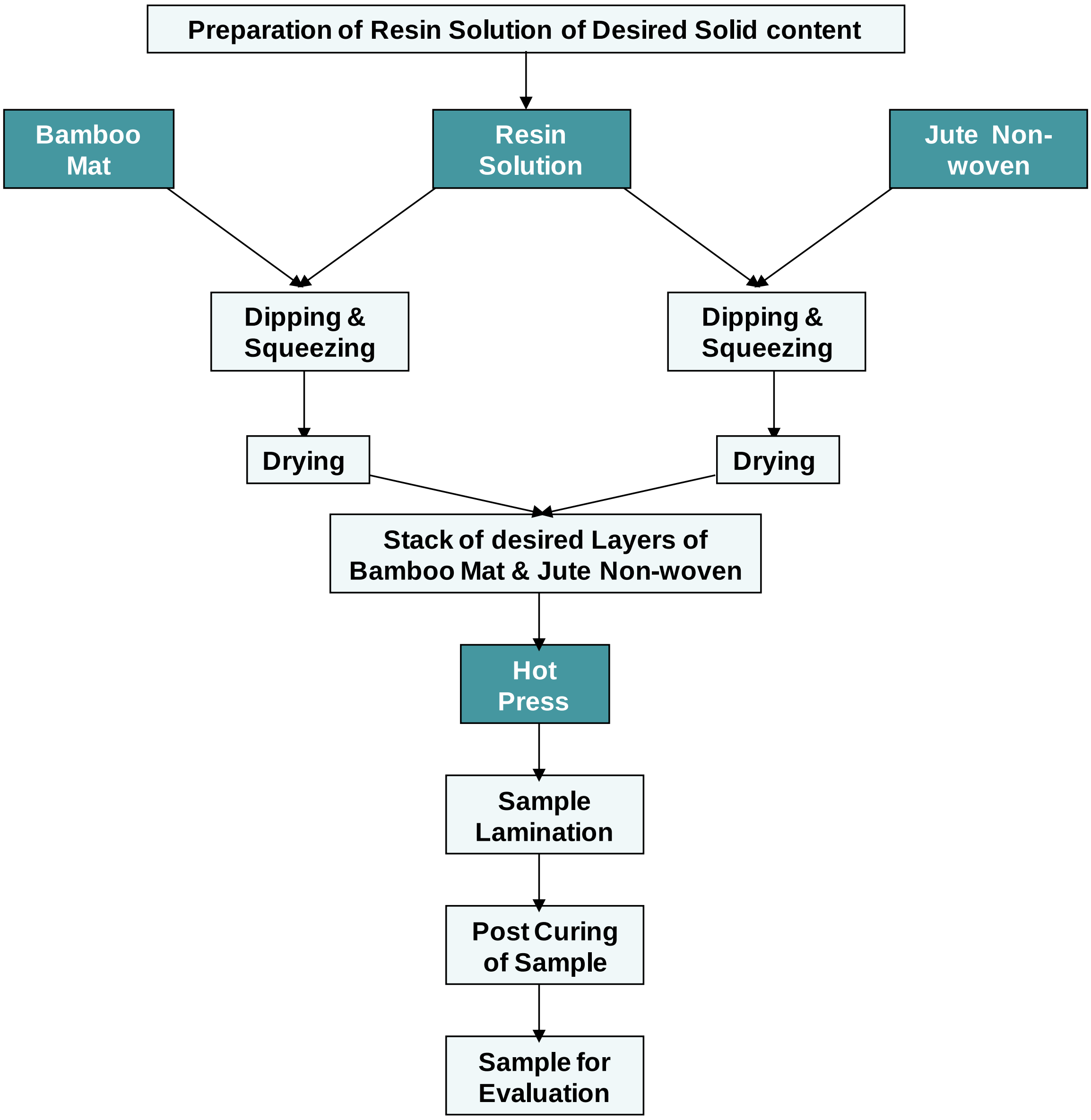
Substrate: According to our earlier experience, Jute non-woven (7mm thick) and 750 gsm is suitable for making composite board.

Bamboo mat has been chosen as a reinforcing material in combination with jute non-woven mat. Since it is available in market and it would be a market for local people. Bamboo plain weave mat of thickness (1-1.2 mm) made from sliver (10 mm x 0.6 mm) of common bamboo species (Bambusa Tulda).

Matrix resin: Water soluble phenol formaldehyde resin (50 % solid content) for hot-press procured from the market M/S Hindusthan Adhesives and Chemicals, 48, Dum Dum Road, Kolkata-700074, Phenoset-5001 grade.

Other materials like filler, specialty additives, and lubricants are procured from the market as and when required.

Methodology:



Process: Phenolic resin is suitably diluted with water in the range of 15 - 35% solid. Jute non-woven of suitable size is impregnated in the diluted resin bath, squeezed and then dried in an oven up to a desired level. Several such impregnated and dried mats are kept ready for pressing. Bamboo mat is separately dipped in the resin bath and slanted for a while and then dried. For making a board several pre-impregnated jute mat layers along with a single impregnated bamboo mat on top is assembled and then pressed in a hydraulic press as per experiments given in Table: 1. The material is then taken out from press, cooled and trimmed to size. Similarly, two layers of impregnated bamboo mat in two faces with jute non-woven in the core has also been tried out to make the composite. Another type was made where a single layer of the treated bamboo mat was kept in the middle layer and the treated jute mats as reinforcement on the two surfaces. Laminated board is then post cured at desired temperature and time. It is then trimmed and the board is subsequently tested as per ASTM and BIS standard.

Results and Discussions:

Composites made with a single layer of treated bamboo mat on the top and the required numbers of treated jute non-woven mats as reinforcement were evaluated to examine the effect of pressure, temperature and duration of pressing time keeping the matrix resin constant. The composite samples were made at variable pressures (i.e. 300, 500 and 800 psi), variable temperature (i.e. 145, 152.5 & 160 °C) and for a variable period of time (i.e. 10, 15 & 20 minutes). The mechanical properties for all such composites are reported in Figures 3 to 32.

Our major observations are:

1) Keeping the matrix resin content constant at 15%, the flexural strength is found to be maximum at a pressure of 550 psi, temperature 152.5 °C, for a pressing time of 10 minutes. Flexural strength is 117 MPa (Figure-3).

2) Keeping matrix resin content at 25%, flexural strength is found to be maximum at a pressure of 800 psi, temperature 145 °C, for a period of 15 minutes. The value comes around 126 MPa (Figure-5).

3) Keeping matrix resin content of 35%, the flexural strength is 137 MPa at 550 psi, temperature 152.5 °C (Figure-7).

4) Thus by variation of matrix resin for 15%, 25%, 35%, it is seen that the flexural strength is increased from 107 MPa to 137 MPa (Figures 3-5)

Another finding is that the flexural strength is enhanced in case of jute-bamboo hybrid composite than that of jute composite from 107 MPa to 117 MPa with same parameter (Figures 1&3).

Secondly, for flexural modulus, the modulus is found to be maximum at pressure of 550 psi, temperature 152.5 °C, for 10 minutes pressing time. The modulus is 15.85 GPa (Figure-4). Another interesting observation is that with the increase in matrix resin from 15% to 35%., the flexural modulus is decreased to 12.9 GPa from 15.85 GPa (figures 4, 6 & 8). Here again, alike flexural strength, the jute-bamboo hybrid composite shows higher flexural modulus than that of jute composite (Figures-2 & 4).

Our observation regarding the mechanical properties is as follows:

1) Keeping 15% matrix resin constant, the tensile strength is found to be maximum at a pressure of 300 psi, temperature 152.5 °C for a time period of 15 minutes. The value is 100 MPa. (Figure-11).

2) Keeping 25% matrix resin constant, the tensile strength is reduced to 91.4 MPa at 800 psi, temperature 152.5 °C, time for pressing 20 minutes. (Figure-13)

3) Keeping 35% matrix resin content, the tensile strength is more or less in the same range 92 MPa at pressure of 800 psi, temperature for a time period of 15 minutes.(Figure-15)

4) In contrast to flexural strength, tensile strength is reduced with increase in matrix resin content from 15% to 35% matrix resin. The value is reduced from 100 MPa to around 90 MPa (Figures 11, 13 &15)

5) It is interesting to note that the tensile strength of jute – bamboo hybrid composite (100 MPa) is also higher than that of 100% jute composite (67 MPa) at same matrix binder of 15% at 300 psi. At higher matrix resin content, this is not followed (Figures-13 & 15).

For tensile modulus, the maximum modulus of jute–bamboo hybrid composite is found to be 5.2 GPa at a pressure of 550 psi, temperature 152.5 °C for a time period of 20 minutes with matrix resin content of 15% (Figure-12).

Here again, the tensile modulus is decreased with increase in resin content (Figure-12,14,16) The tensile modulus of jute–bamboo hybrid composite is found to be higher than that of 100% jute composite at matrix resin content 15% (Figures10 &12).

One of the drawbacks of jute composite made with phenolic resin as matrix is that the water absorption and thickness swelling is higher than that of plywood as per our previous experience. For comparison, the experiments were done for water absorption and thickness swelling, for jute composites made at varying pressure, temperature and for different time of pressing as shown in figures 17 & 18. It is observed that the water absorption is decreased with increase in pressure which is logical because of less voids resulting higher density. The same is observed for thickness swelling (Figure- 25 & 26).

In case of jute–bamboo hybrid composite, the water absorption is found to be less than that of jute composite (Figures-17-20). Another interesting observation is that with increase in resin content from 15% to 35 %, the water absorption is further reduced from 12.9 % to 5.73 % (Figures 19 -24).

The same trend is observed for thickness swelling. As expected, the thickness swelling is found to be more for jute composites than that of jute-bamboo hybrid composites (Figures 25-28) with the same resin content. Here again, with increase in resin content from 15% to 35 %, the thickness swelling is reduced to 4.54 % from 10.08%. (Figures 27-32).

Our conclusion is, therefore, the incorporation of bamboo for hybridization helps to improve the properties of 100 % jute composites in every respect. The mechanical properties particularly, flexural strength, flexural modulus, tensile strength, tensile modulus are significantly improved. The water absorption and thickness swelling are also improved because of hybridization with bamboo along with jute fibre reinforcement.

One significant point is that there is no gain in properties when the proportion of bamboo is enhanced from 25% to 29%; rather modulus is reduced. A comparison has also been done among 100% jute composites, jute–bamboo hybrid composites (varying bamboo content) and 100% bamboo composites. The modulus is found to be least with 100% bamboo composite while it is maximum in case of 100 % jute composites. With the single layer of bamboo mat (60 % jute and 25 % bamboo as reinforcement), the flexural strength is maximum among 100 % jute composite, jute – bamboo hybrid composite and 100% bamboo composite.

Few of the samples were tested to evaluate some special properties such as reduction of noise level, abrasion resistance & resistance to surface flame propagation.

From Table-2, it is found that the % reduction of noise is higher when the bamboo side of the jute bamboo composite is exposed to source rather than the jute side. The damping effect of bamboo composite is little higher than jute composite for high frequency but it is lower than jute composite in case of low frequency. The damping of noise level is increased with the increase of resin content.

Abrasion rate of jute bamboo composite (coated bamboo top surface) was tested against jute composite (coated top surface) & Laminated wood flooring. It is observed from Table-3, the weight loss after 500 cycle of abrasion is less than the weight loss of jute composite but is little higher than that in case of laminated wood flooring.

Resistance of spread of flame is shown in Table-4, where the effect of bamboo surface on spread of flame is considered as positive rather than jute surface.

Fire resistance test was carried out as per Indian Railways RDSO specifications C-9601, January 1997. Each test conforms to the requirements.

Some mechanical properties were evaluated from other laboratories and shown in Annexure-I & II

It may be concluded that the optimum parameters for making jute – bamboo hybrid composites are as follows:

Jute non-woven-750 gm per sq. mtr (7 mm thick), bamboo (one and a half year old) mat (plain weave), phenolic resin – water soluble resole grade (50% solid content) are the raw materials.

Conditions for pressing – temperature:150 -155 °C, pressure 550 psi, duration of pressing time:10 - 15 minutes and matrix resin content:15%, bamboo mat (plain weave) single layer on one side. This condition is preferred for general purpose jute – bamboo hybrid composite. For better performance and according to end use requirements the process parameters are to be modified.

Pilot Scale Trials:

Pilot Scale Trials were conducted at two Institutes (1) Composite Technology Park, Bangaluru (2) Indian Plywood Industries Research & Training Institute, Bangalore.

Composite Technology Park, Bangalore: The trials were conducted at their hydraulic press, which is of higher platen size (3 ft x.3 ft) than that of IJIRA platen size (8" x 8"). Both jute non-woven and bamboo mat were impregnated and squeezed at IJIRA's pilot plant to maintain the secrecy of the process technology and sent them for pressing at their site. Several composite boards of different types (jute composites, jute-bamboo hybrid composites with varying jute-bamboo ratios) were made there in our presence. The optimum moisture content of the impregnated jute and bamboo could not be maintained as per our laboratory findings since the drying had to be carried out at room temperature and there was no proper drying system. The results of the composite board properties were shown in Table:5.

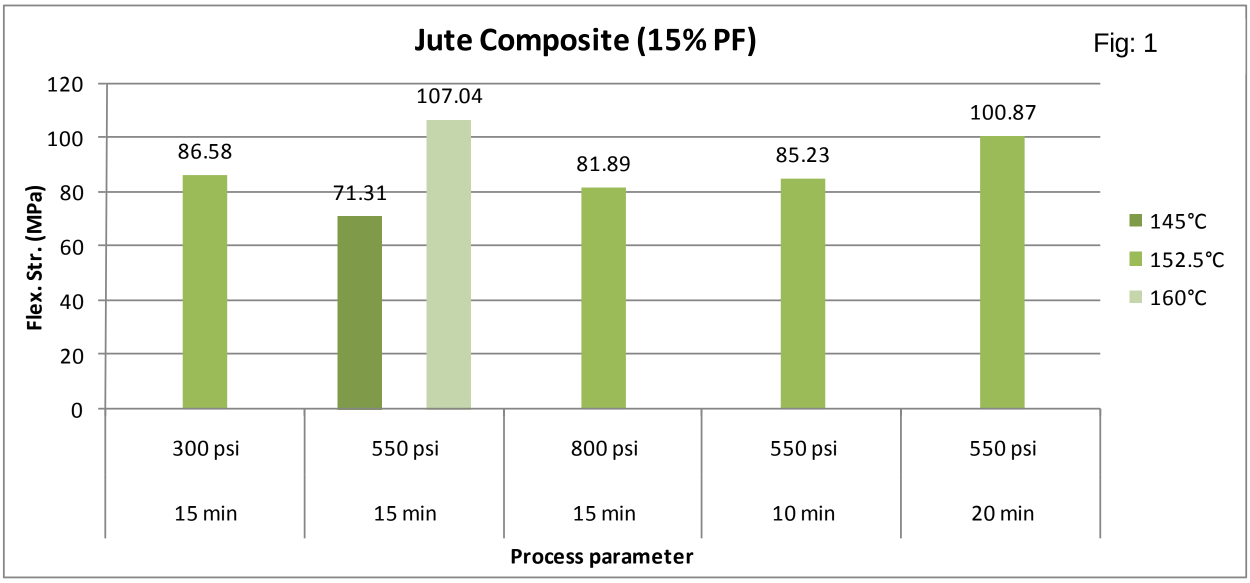
The results show the same trend of properties as observed in our laboratory scale trials. Both the tensile strength and the flexural strength are increased due to hybridization with bamboo along with jute fibre reinforcement using single layer bamboo mat (JBC-1) in comparison with jute composite (JC). It has been optimized earlier that with the increase of bamboo reinforcement, the strength is not enhanced. The same trend is followed here. The tensile and flexural strength is decreased when bamboo reinforcement is increased (JBC-4). As observed, the modulus of jute – bamboo hybrid composites is decreased in comparison to that of jute composites. It may be concluded that the same trend is followed in pilot experiments as studied in laboratory scale experiments. Only difference is that the strength (tensile & flexural) and modulus (tensile & flexural) values are lower than that of lab-scale trials because of the fact that proper processing conditions could not be followed.

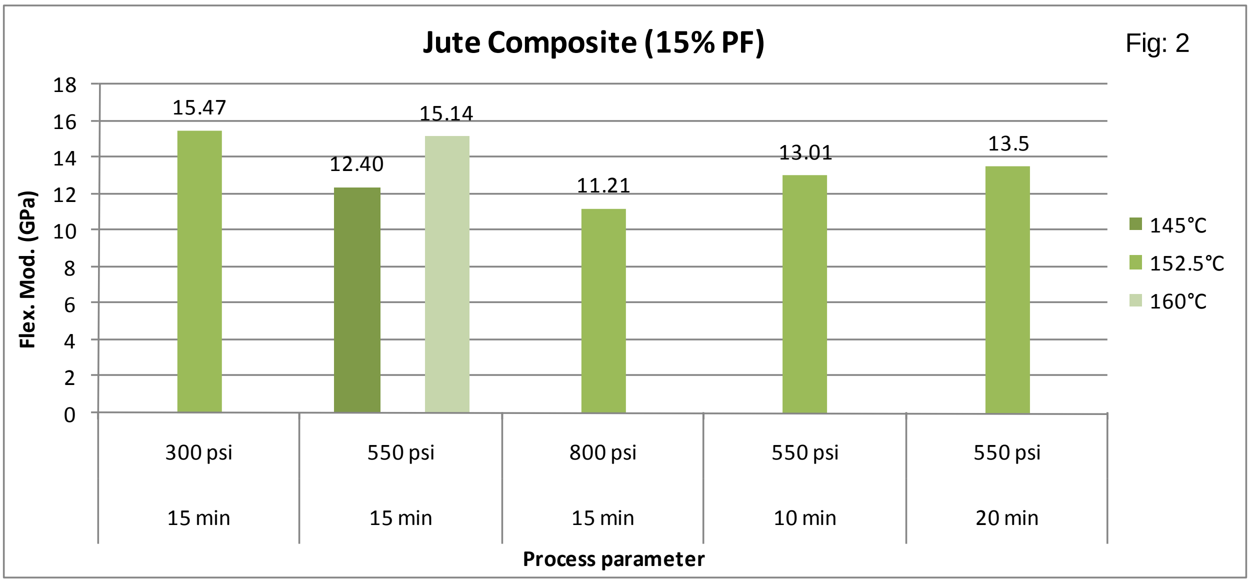
Pilot Scale Trial at Indian Plywood industries Research & Training Institute (IPIRTI): The second pilot scale trial was made where the process was done at IPIRTI, Bangalore. Only Jute non-woven and the phenolic resin was taken from IJIRA. Bamboo mat has been procured from there since it was available there as intimated by IPIRTI. Bamboo mat that was available there were of herringbone weave and not normal weaved mat (one up and one down) which was used at lab - scale trials. It is known from our earlier experience that the mechanical properties of the composites made from herringbone weaved mat are reduced in comparison to that made from plain weaved mat. Secondly, proper conditions for impregnation and drying could not be followed as drying have to be carried out at room temperature. However, the composite samples were made at their hydraulic press. The platen size was 4ft x 4ft. The jute composites using phenolic resin matrix requires higher pressure (tonnage). Hence, to attain required pressure, the size of the board was 4ftx 3ft. Different samples, jute composite, jute – bamboo hybrid (with variation of bamboo mat) composite were made. Those samples were evaluated for their mechanical strength. The results are shown in Table:6.

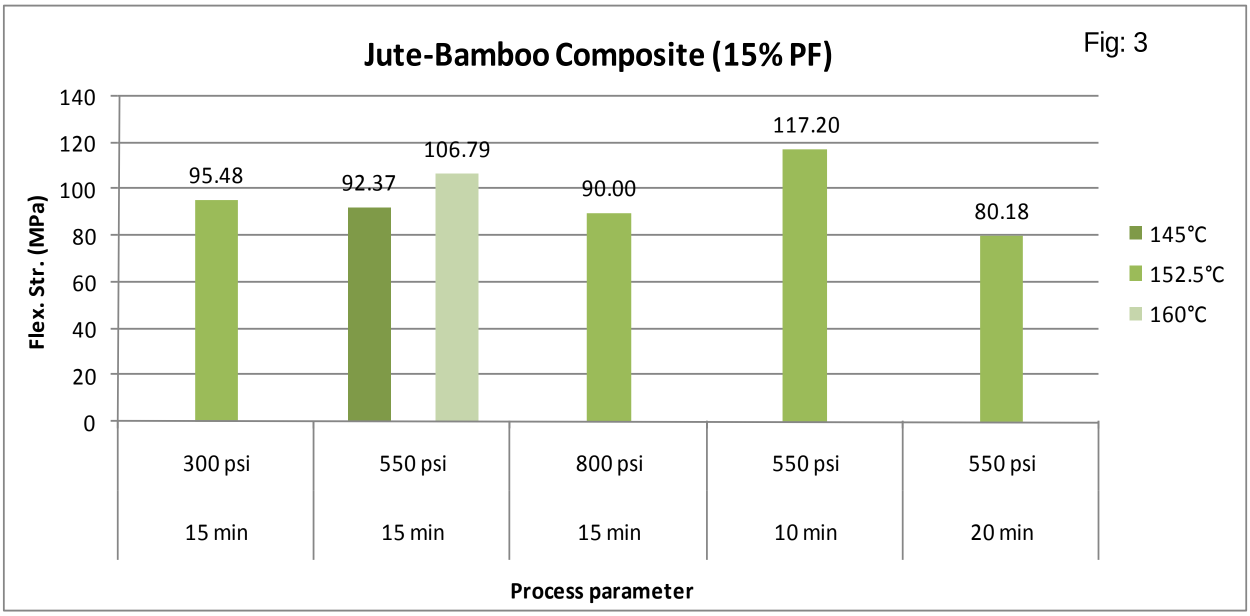
The results show that the both the flexural and tensile strength are reduced in case of jute-bamboo hybrid composite using single layer of bamboo mat in contrast to our lab-scale experiments and pilot trial made at Composite Technology Park, Bangalore. As explained earlier, this may be due to herring bone weaved bamboo mat and the old age bamboo. In this connection, it may be pointed out that the bamboo would be ideal for on one and half year old for better strength composite. For modulus, of course, the trend of reduction of value of jute-bamboo hybrid composite is observed as compared to that of jute composite.

Table- 1 Experimental Parameters as per Box-Behnkin Method

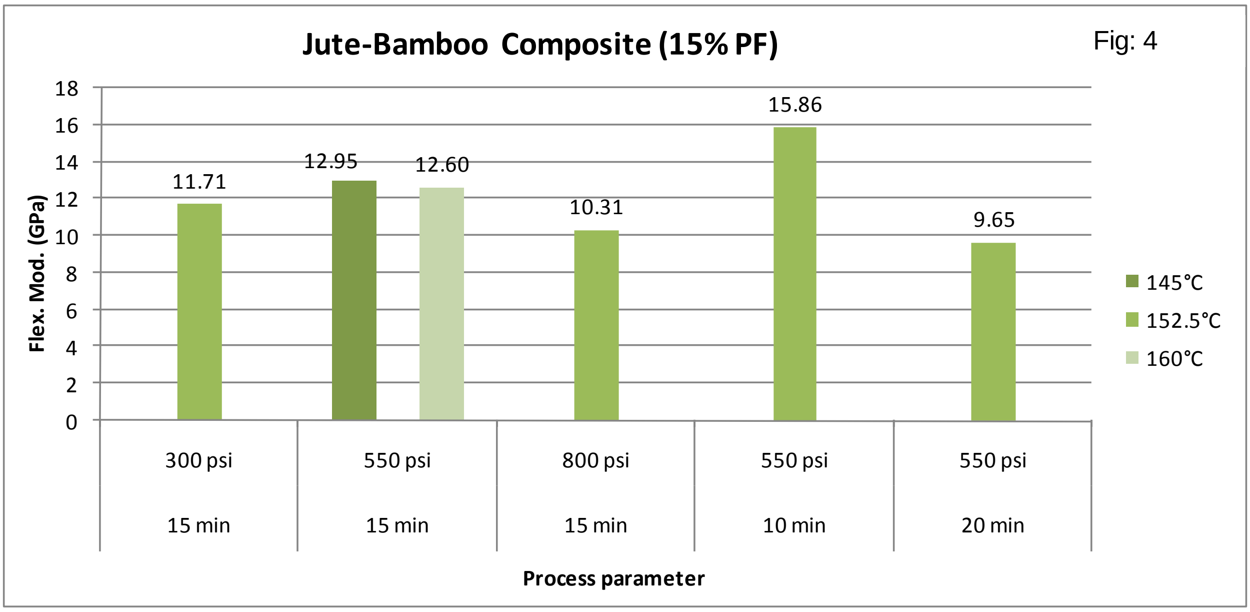
PROCESS No.	FIBRE, %	TEMPERATURE, ^oC	TIME, min	PRESSURE, psi
1	65	145	15	550
2	85	145	15	550
3	65	160	15	550
4	85	160	15	550
5	75	152.5	10	300
6	75	152.5	20	300
7	75	152.5	10	800
8	75	152.5	20	800
9	75	152.5	15	550
10	65	152.5	10	550
11	85	152.5	10	550
12	65	152.5	20	550
13	85	152.5	20	550
14	75	145	15	300
15	75	160	15	300
16	75	145	15	800
17	75	160	15	800
18	65	152.5	15	300
19	85	152.5	15	300
20	65	152.5	15	800
21	85	152.5	15	800


Jute Composite (15% PF)
Fig: 1
Flex. Str. (MPa)
120
100
80
60
40
20
0
86.58
71.31
107.04
81.89
85.23
100.87
300 psi 15 min
550 psi 15 min
800 psi 15 min
550 psi 10 min
550 psi 20 min
Process parameter
145°C
152.5°C
160°C


Jute Composite (15% PF)
Fig: 2
Flex. Mod. (GPa)
18
16
14
12
10
8
6
4
2
0
15.47
12.40
15.14
11.21
13.01
13.5
300 psi 15 min
550 psi 15 min
800 psi 15 min
550 psi 10 min
550 psi 20 min
Process parameter
145°C
152.5°C
160°C



Jute-Bamboo Composite (15% PF)
Fig: 3
Flex. Str. (MPa)
140
120
100
80
60
40
20
0
95.48
92.37
106.79
90.00
117.20
80.18
300 psi 15 min
550 psi 15 min
800 psi 15 min
550 psi 10 min
550 psi 20 min
Process parameter
145°C
152.5°C
160°C



Jute-Bamboo Composite (15% PF)
Fig: 4
Flex. Mod. (GPa)
18
16
14
12
10
8
6
4
2
0
11.71
12.95
12.60
10.31
15.86
9.65
300 psi 15 min
550 psi 15 min
800 psi 15 min
550 psi 10 min
550 psi 20 min
Process parameter
145°C
152.5°C
160°C

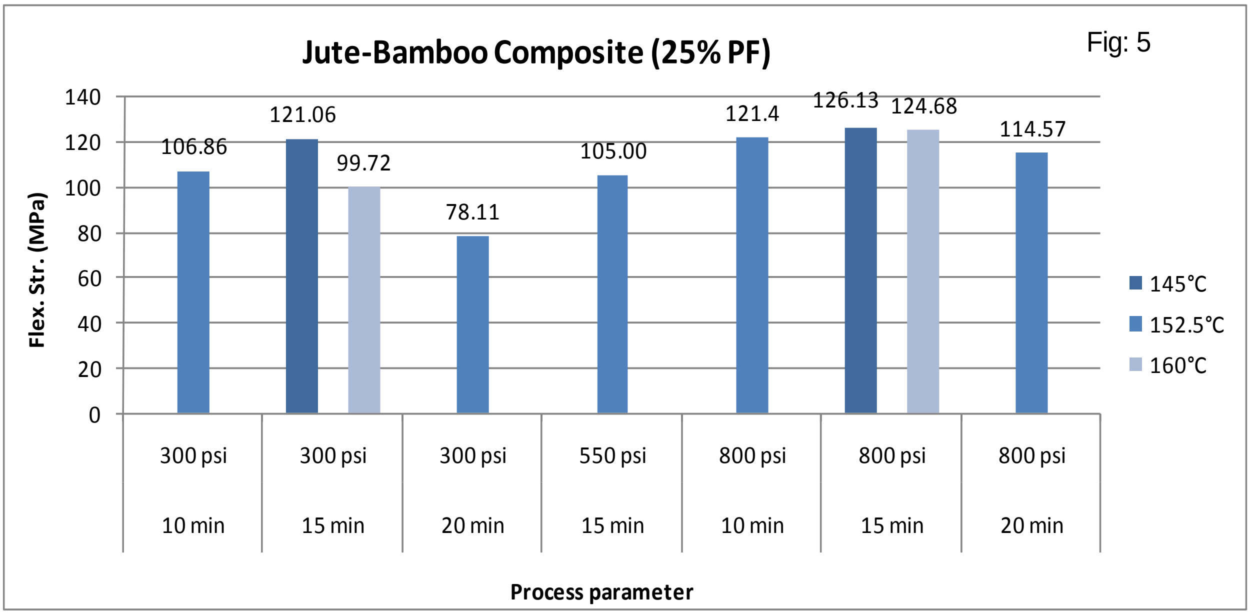


Fig: 5
Jute-Bamboo Composite (25% PF)
Flex. Str. (MPa)
140
120
100
80
60
40
20
0
106.86
121.06
99.72
78.11
105.00
121.4
126.13
124.68
114.57
300 psi 10 min
300 psi 15 min
300 psi 20 min
550 psi 15 min
800 psi 10 min
800 psi 15 min
800 psi 20 min
Process parameter
145°C
152.5°C
160°C

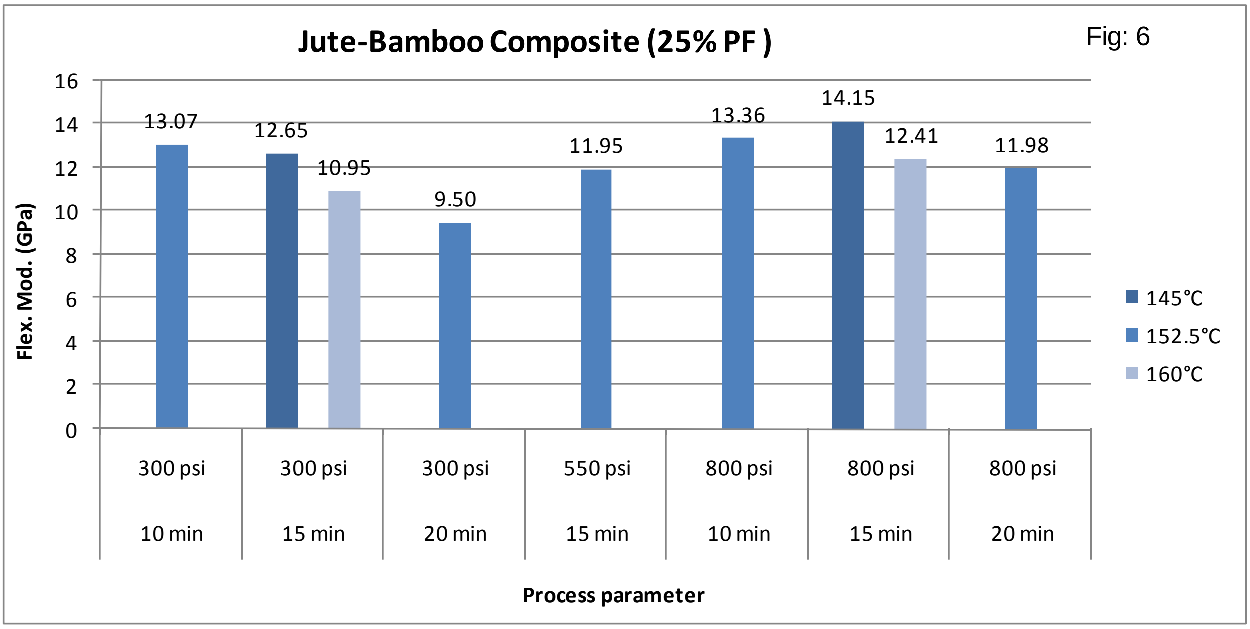


Fig: 6
Jute-Bamboo Composite (25% PF)
Flex. Mod. (GPa)
16
14
12
10
8
6
4
2
0
13.07
12.65
10.95
9.50
11.95
13.36
14.15
12.41
11.98
300 psi 10 min
300 psi 15 min
300 psi 20 min
550 psi 15 min
800 psi 10 min
800 psi 15 min
800 psi 20 min
Process parameter
145°C
152.5°C
160°C

Fig: 7

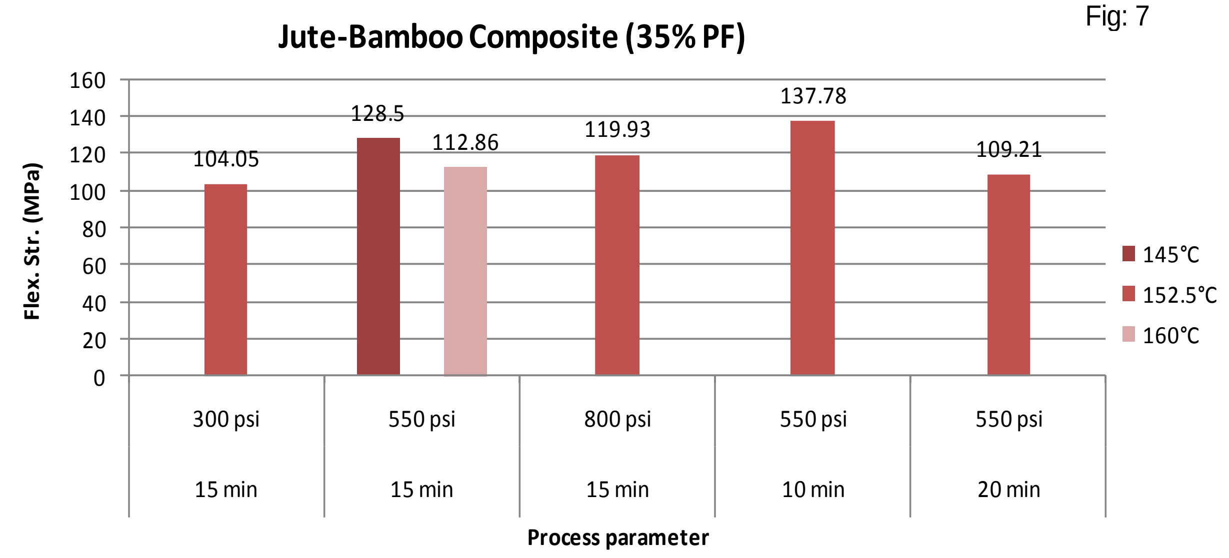
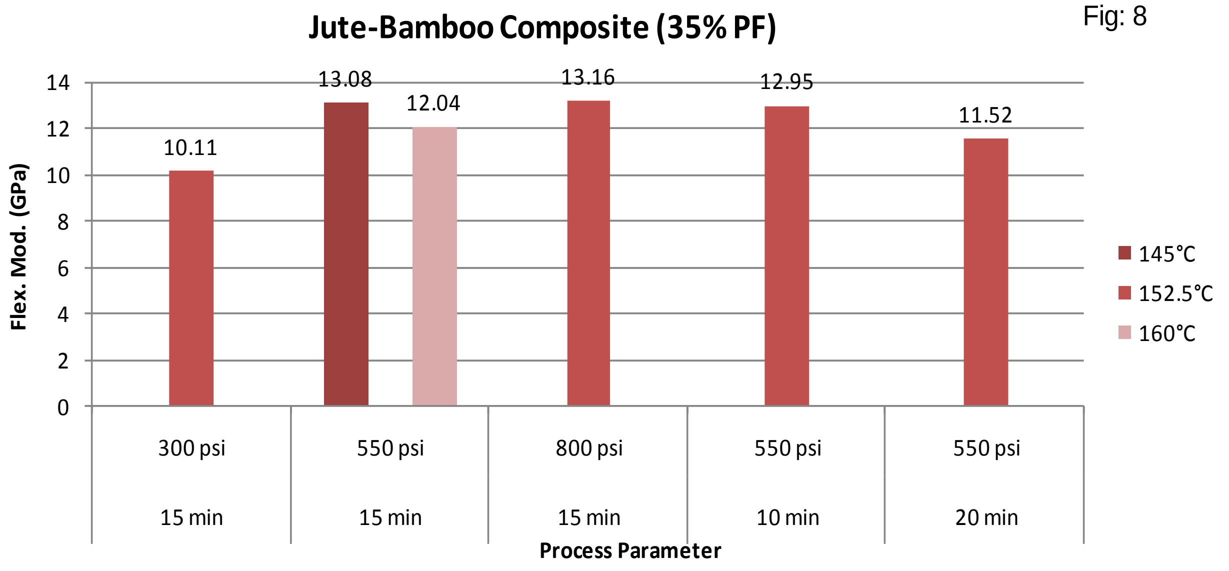
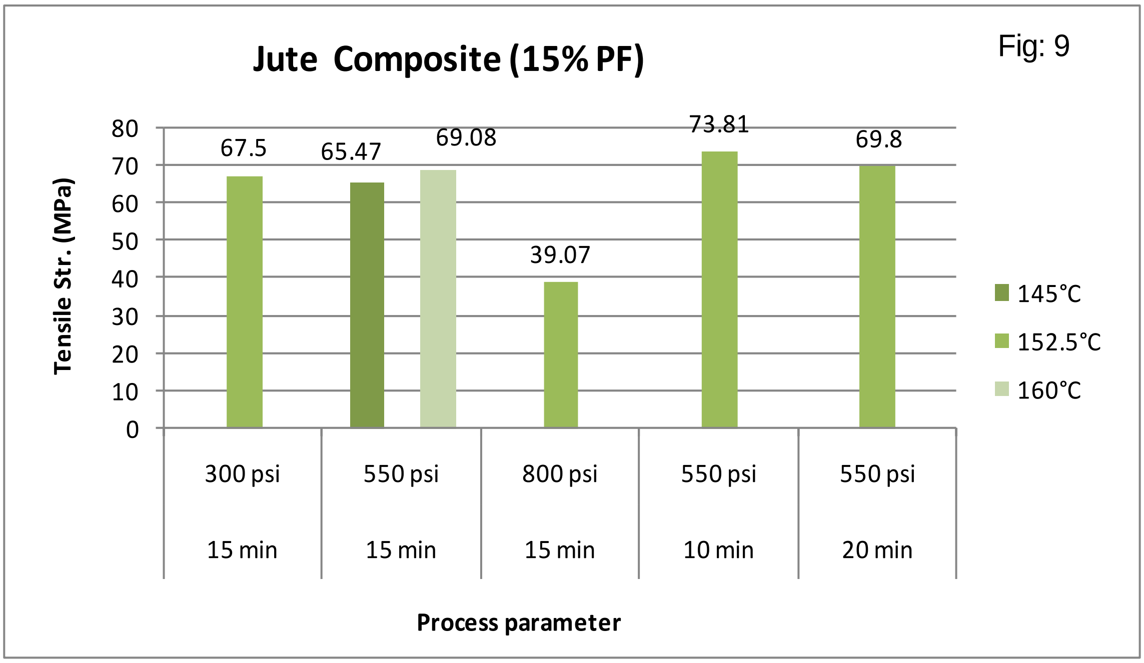
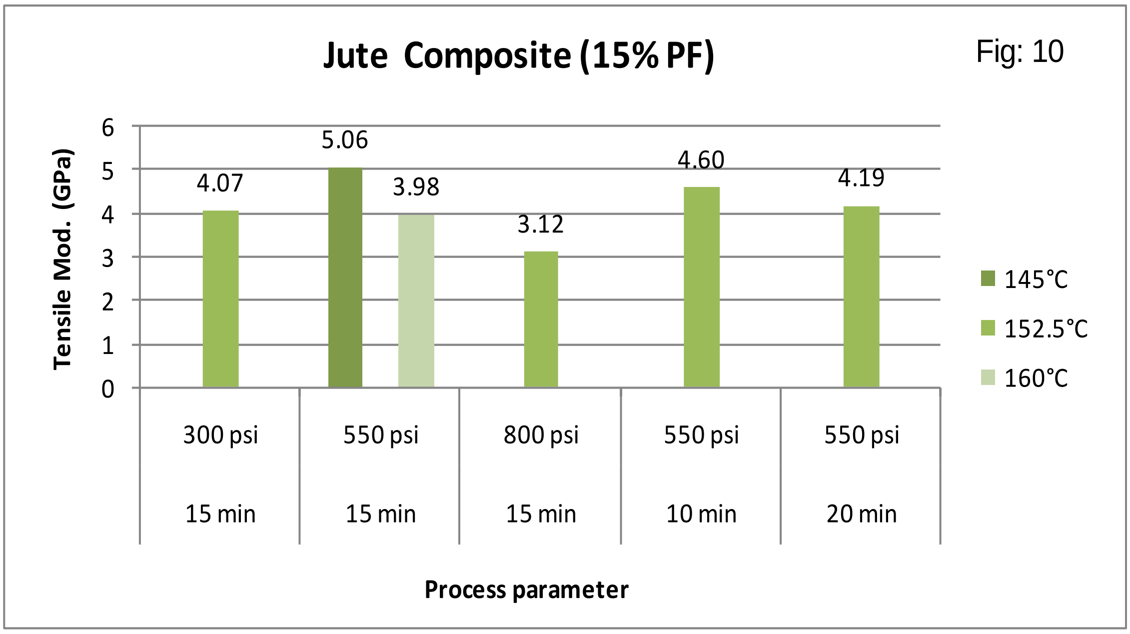

Jute-Bamboo Composite (35% PF)
Flex. Str. (MPa)
160
140
120
100
80
60
40
20
0
104.05
128.5
112.86
119.93
137.78
109.21
300 psi
15 min
550 psi
15 min
800 psi
15 min
550 psi
10 min
550 psi
20 min
Process parameter
145°C
152.5°C
160°C

Fig: 8


Jute-Bamboo Composite (35% PF)
Flex. Mod. (GPa)
14
12
10
8
6
4
2
0
10.11
13.08
12.04
13.16
12.95
11.52
300 psi
15 min
550 psi
15 min
800 psi
15 min
550 psi
10 min
550 psi
20 min
Process Parameter
145°C
152.5°C
160°C


Jute Composite (15% PF)
Fig: 9
Tensile Str. (MPa)
80
70
60
50
40
30
20
10
0
67.5
65.47
69.08
39.07
73.81
69.8
300 psi 15 min
550 psi 15 min
800 psi 15 min
550 psi 10 min
550 psi 20 min
Process parameter
145°C
152.5°C
160°C


Jute Composite (15% PF)
Fig: 10
Tensile Mod. (GPa)
6
5
4
3
2
1
0
4.07
5.06
3.98
3.12
4.60
4.19
300 psi 15 min
550 psi 15 min
800 psi 15 min
550 psi 10 min
550 psi 20 min
Process parameter
145°C
152.5°C
160°C

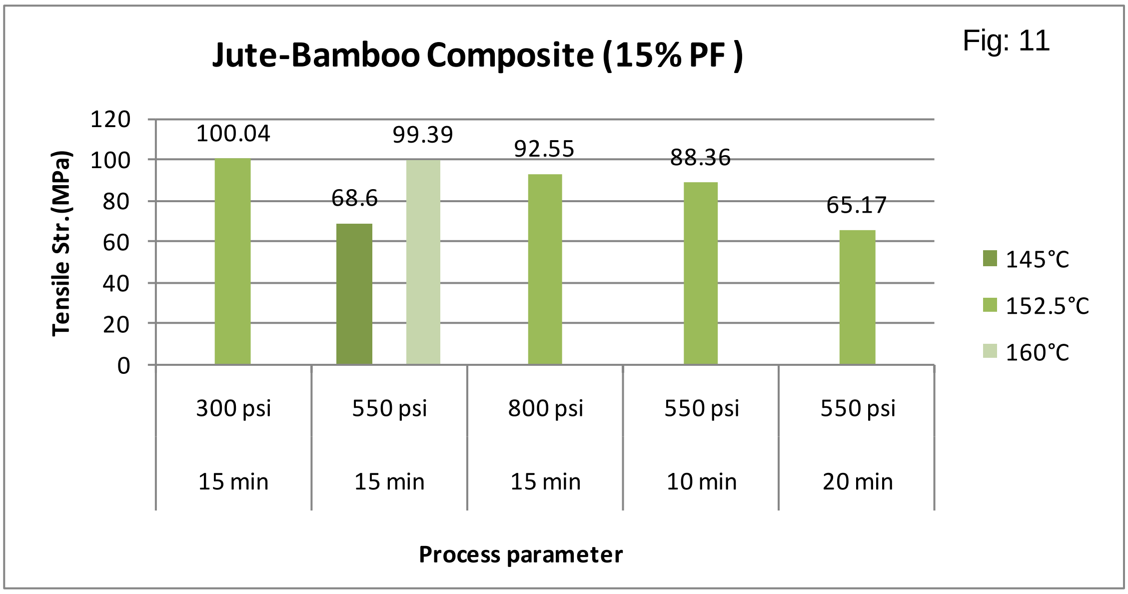


Fig: 11
Jute-Bamboo Composite (15% PF)
Tensile Str.(MPa)
120
100
80
60
40
20
0
100.04
68.6
99.39
92.55
88.36
65.17
300 psi
15 min
550 psi
15 min
800 psi
15 min
550 psi
10 min
550 psi
20 min
Process parameter
145°C
152.5°C
160°C

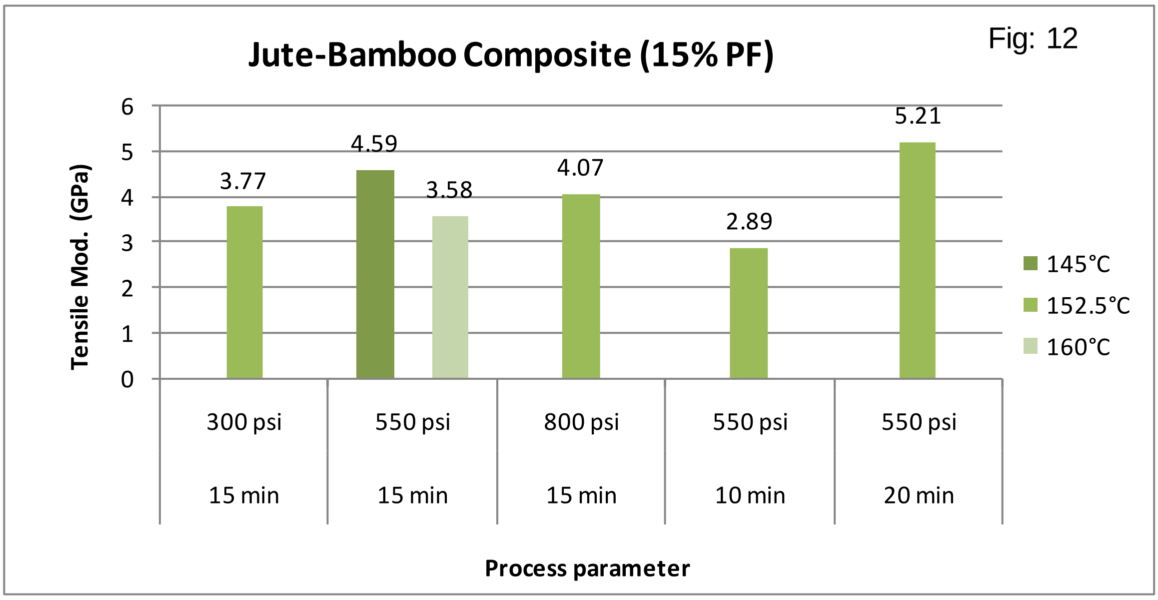


Fig: 12
Jute-Bamboo Composite (15% PF)
Tensile Mod. (GPa)
6
5
4
3
2
1
0
3.77
4.59
3.58
4.07
2.89
5.21
300 psi
15 min
550 psi
15 min
800 psi
15 min
550 psi
10 min
550 psi
20 min
Process parameter
145°C
152.5°C
160°C

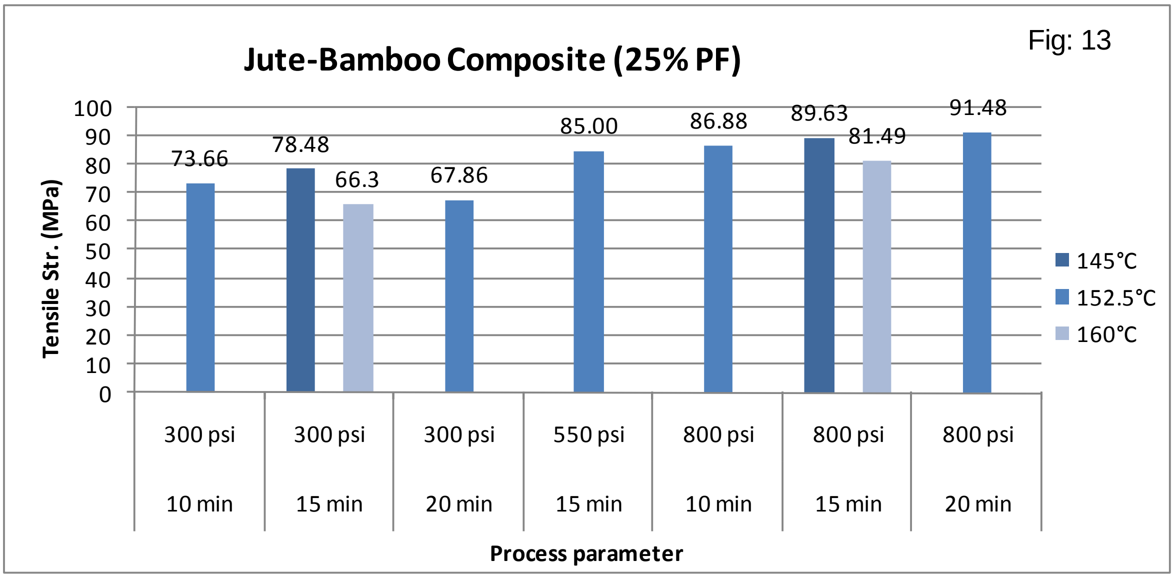


Fig: 13
Jute-Bamboo Composite (25% PF)
Tensile Str. (MPa)
100
90
80
70
60
50
40
30
20
10
0
73.66
78.48
66.3
67.86
85.00
86.88
89.63
81.49
91.48
300 psi 10 min
300 psi 15 min
300 psi 20 min
550 psi 15 min
800 psi 10 min
800 psi 15 min
800 psi 20 min
Process parameter
145°C
152.5°C
160°C

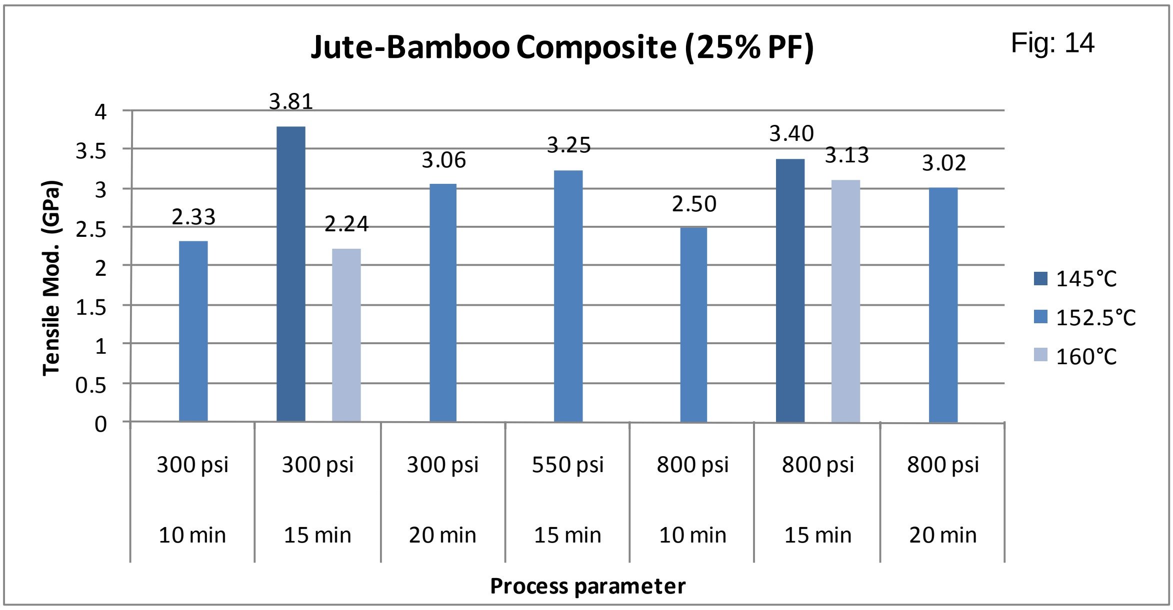
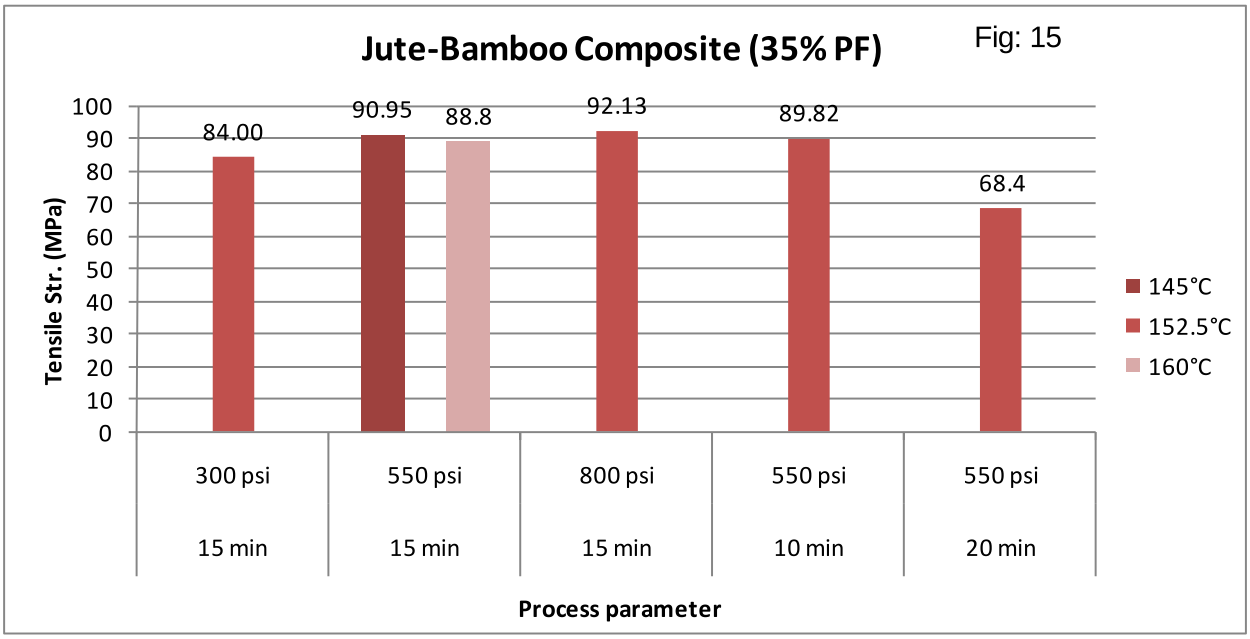
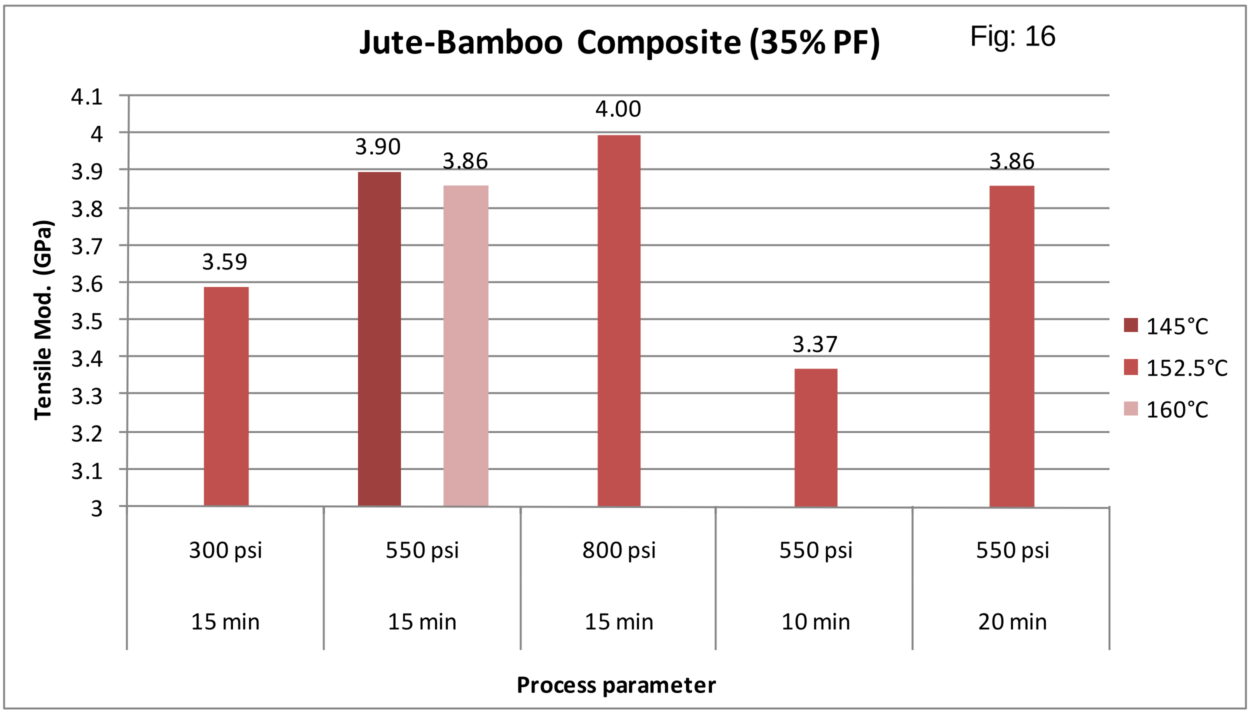
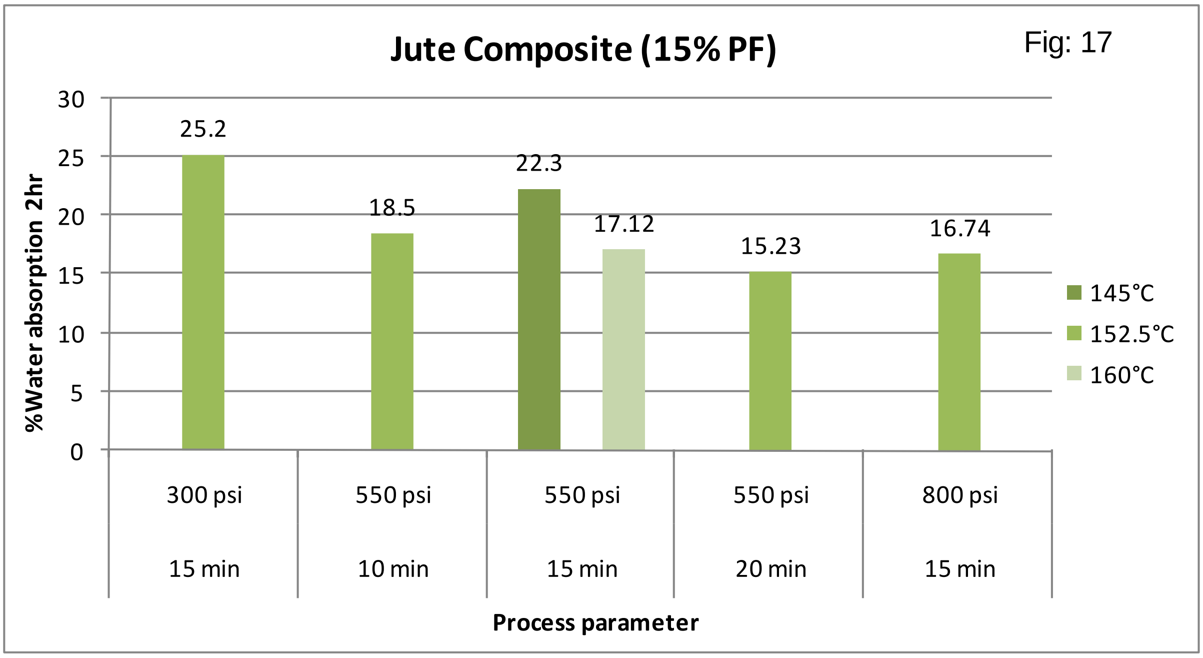


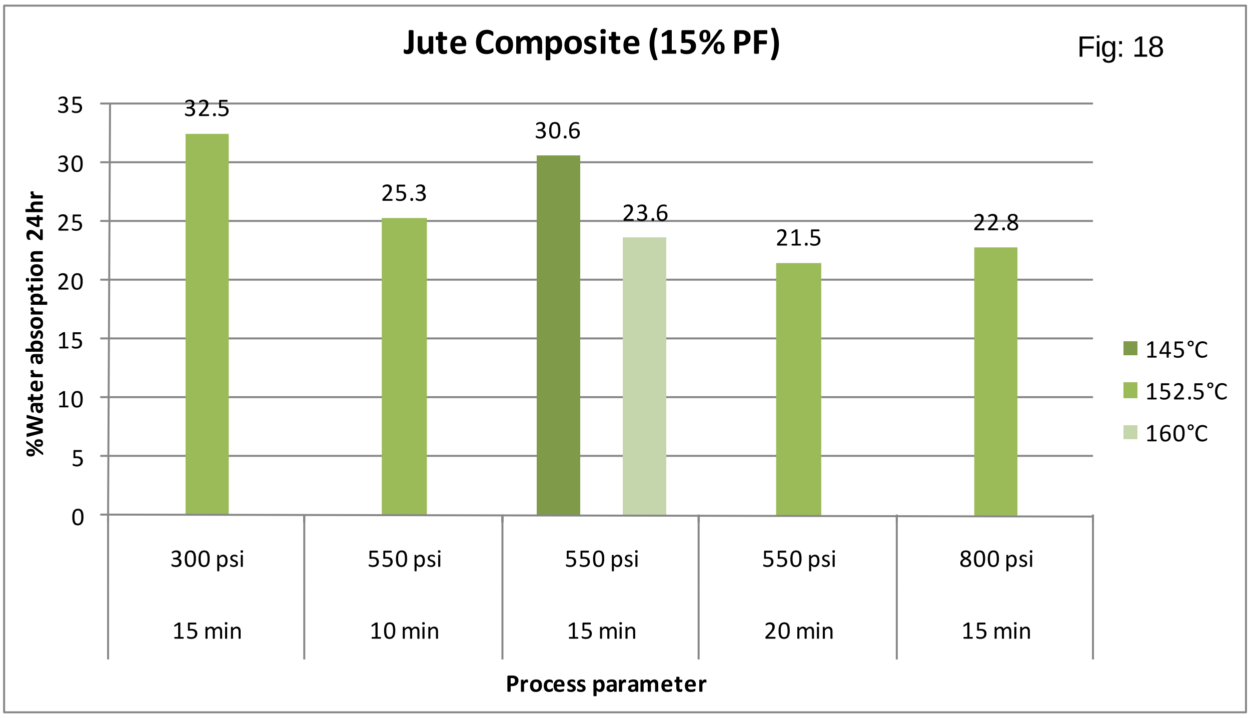
Fig: 14
Jute-Bamboo Composite (25% PF)
Tensile Mod. (GPa)
4
3.5
3
2.5
2
1.5
1
0.5
0
2.33
3.81
2.24
3.06
3.25
2.50
3.40
3.13
3.02
300 psi 10 min
300 psi 15 min
300 psi 20 min
550 psi 15 min
800 psi 10 min
800 psi 15 min
800 psi 20 min
Process parameter
145°C
152.5°C
160°C

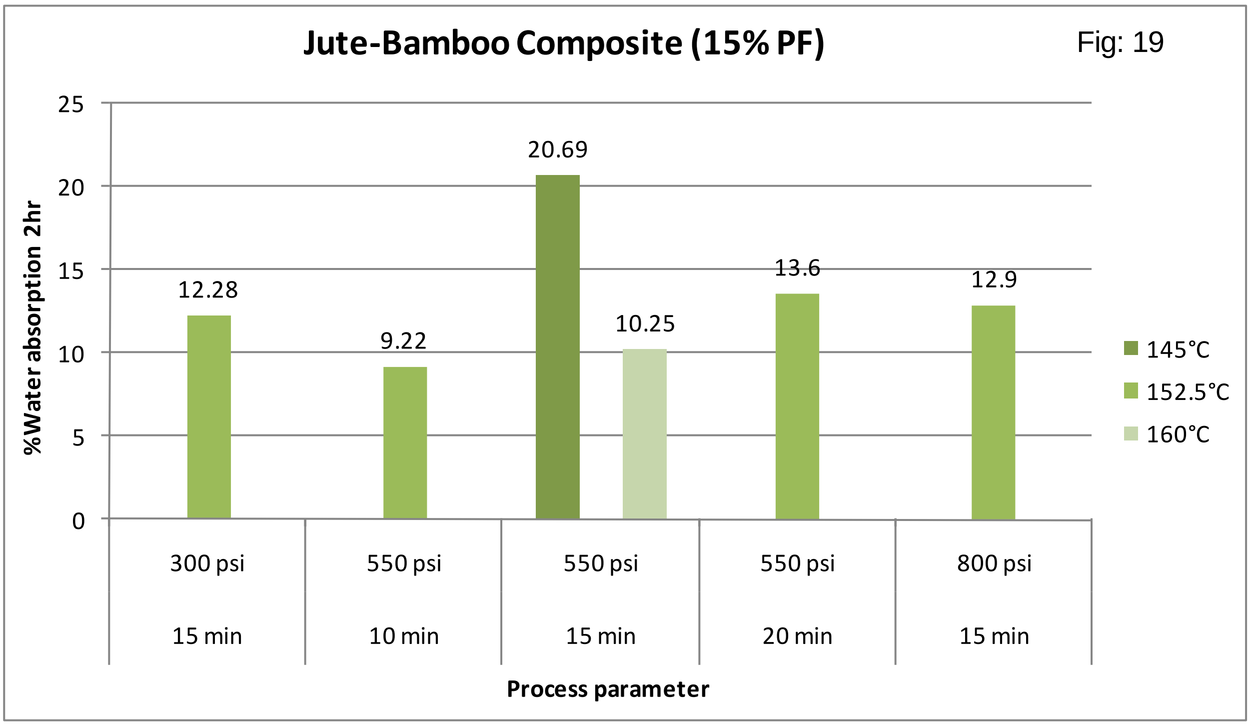
,

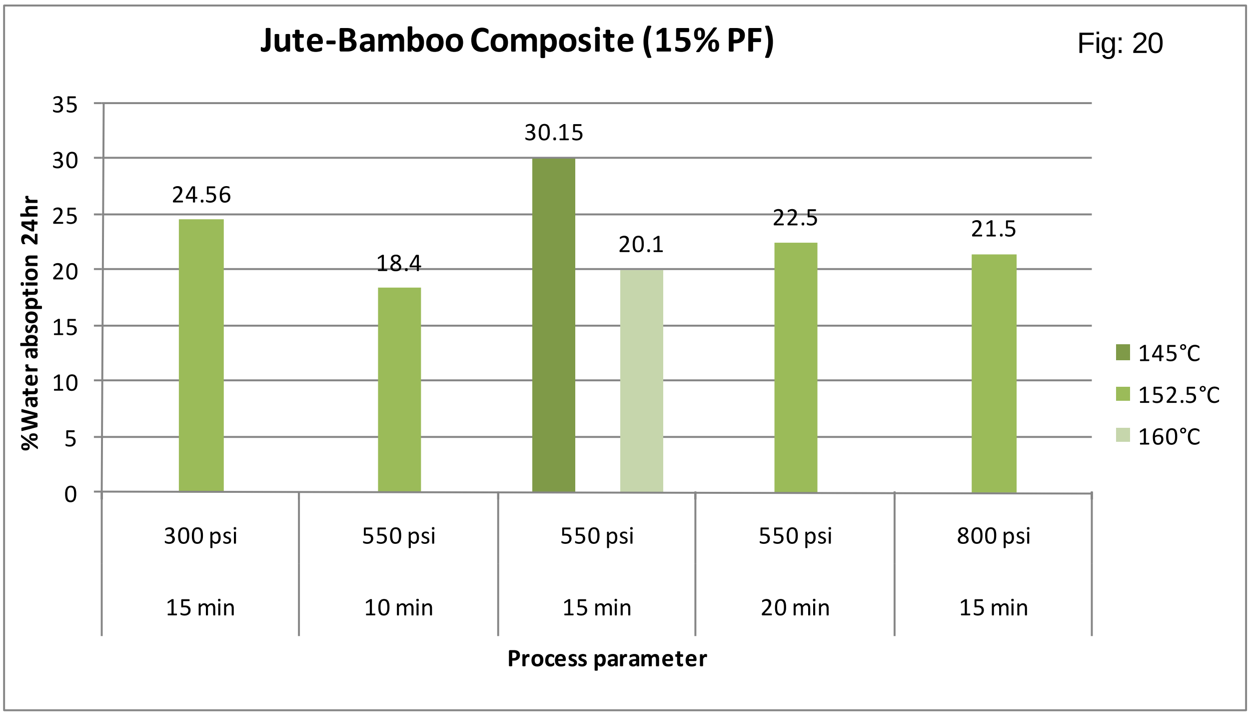

Jute-Bamboo Composite (35% PF)
Fig: 15
Tensile Str. (MPa)
100
90
80
70
60
50
40
30
20
10
0
84.00
90.95
88.8
92.13
89.82
68.4
145°C
152.5°C
160°C
300 psi 15 min
550 psi 15 min
800 psi 15 min
550 psi 10 min
550 psi 20 min
Process parameter

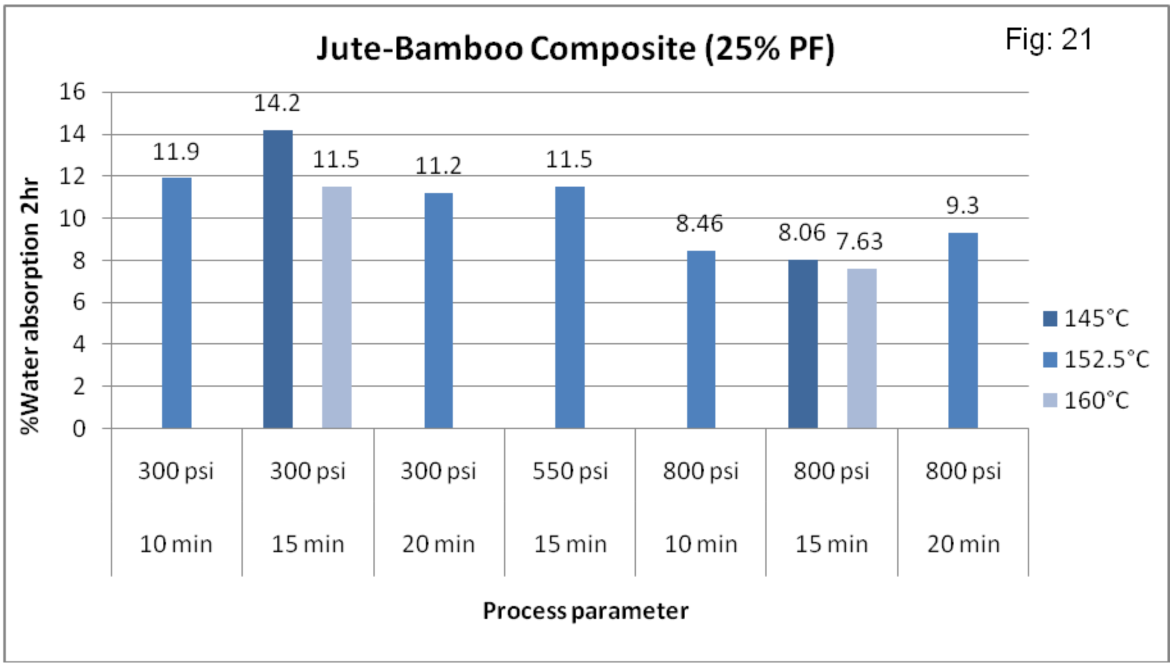

Jute-Bamboo Composite (35% PF)
Fig: 16
Tensile Mod. (GPa)
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
3.59
3.90
3.86
4.00
3.37
3.86
145°C
152.5°C
160°C
300 psi 15 min
550 psi 15 min
800 psi 15 min
550 psi 10 min
550 psi 20 min
Process parameter

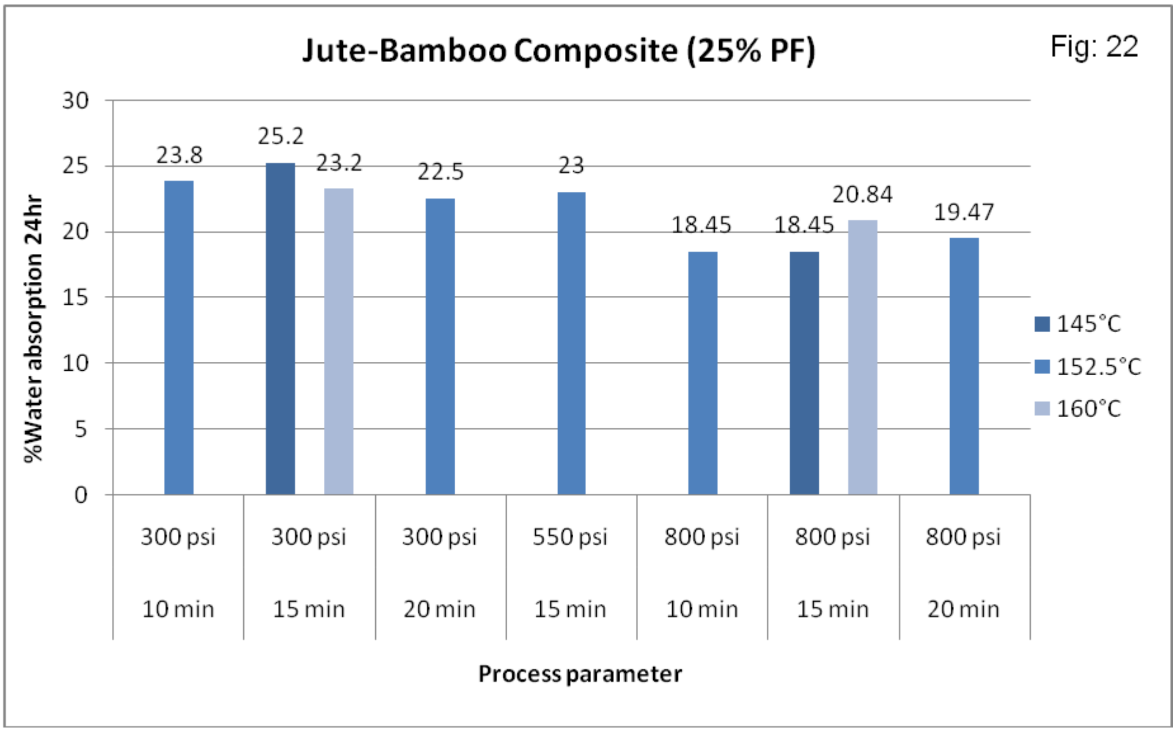

Jute Composite (15% PF)
Fig: 17
%Water absorption 2hr
30
25
20
15
10
5
0
25.2
18.5
22.3
17.12
15.23
16.74
145°C
152.5°C
160°C
300 psi
15 min
550 psi
10 min
550 psi
15 min
550 psi
20 min
800 psi
15 min
Process parameter

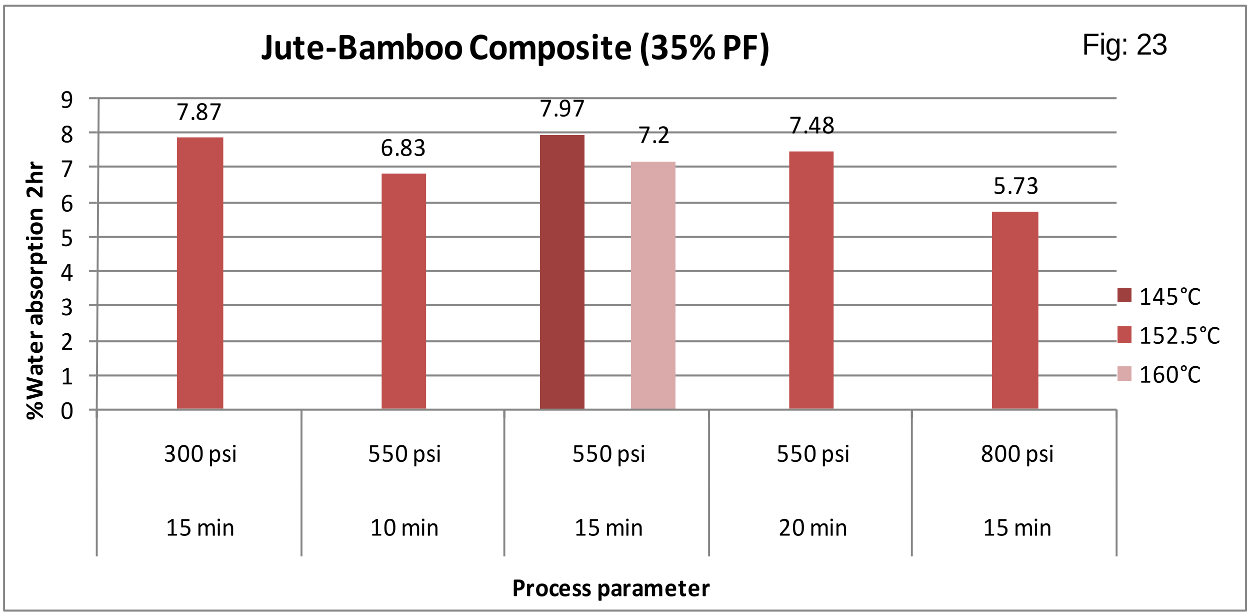

Jute Composite (15% PF)
Fig: 18
%Water absorption 24hr
35
30
25
20
15
10
5
0
32.5
25.3
30.6
23.6
21.5
22.8
145°C
152.5°C
160°C
300 psi
15 min
550 psi
10 min
550 psi
15 min
550 psi
20 min
800 psi
15 min
Process parameter

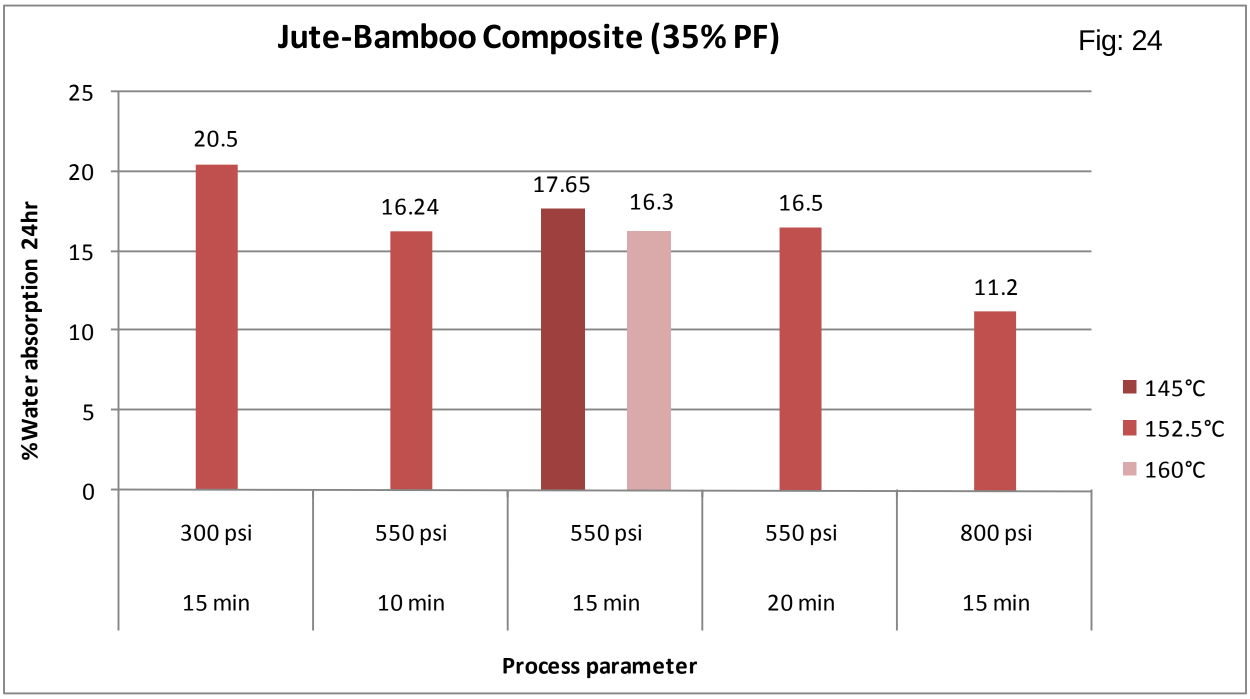

Jute-Bamboo Composite (15% PF)
Fig: 19
%Water absorption 2hr
25
20
15
10
5
0
12.28
9.22
20.69
10.25
13.6
12.9
300 psi
15 min
550 psi
10 min
550 psi
15 min
550 psi
20 min
800 psi
15 min
Process parameter
145°C
152.5°C
160°C

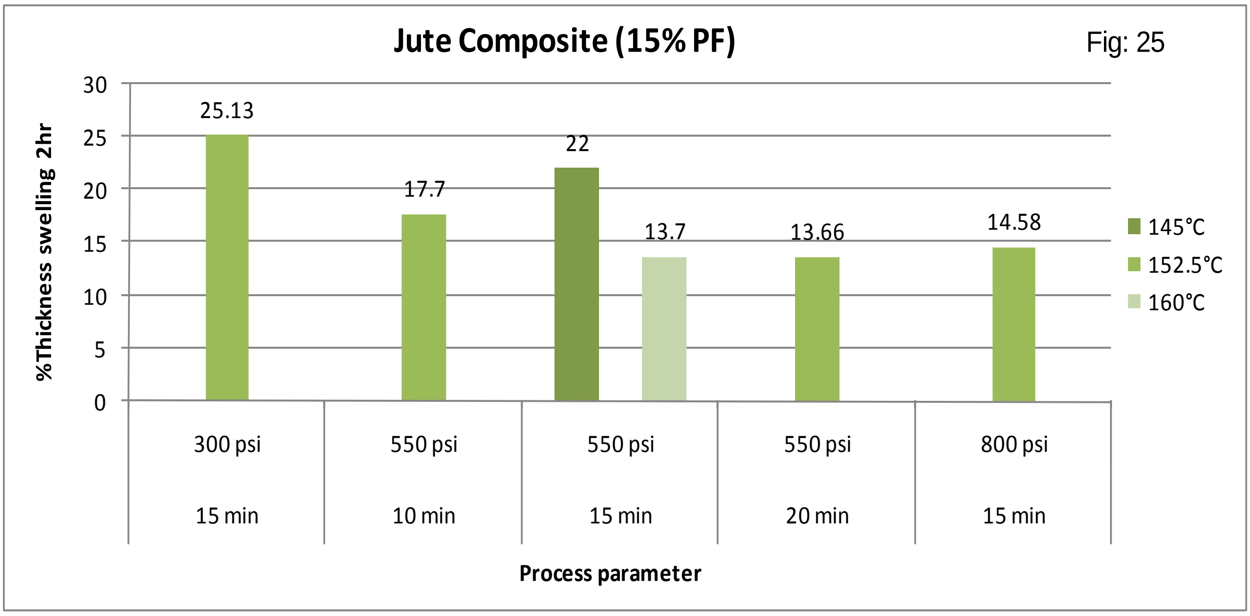

Jute-Bamboo Composite (15% PF)
Fig: 20
%Water absoption 24hr
35
30
25
20
15
10
5
0
24.56
18.4
30.15
20.1
22.5
21.5
300 psi
15 min
550 psi
10 min
550 psi
15 min
550 psi
20 min
800 psi
15 min
Process parameter
145°C
152.5°C
160°C

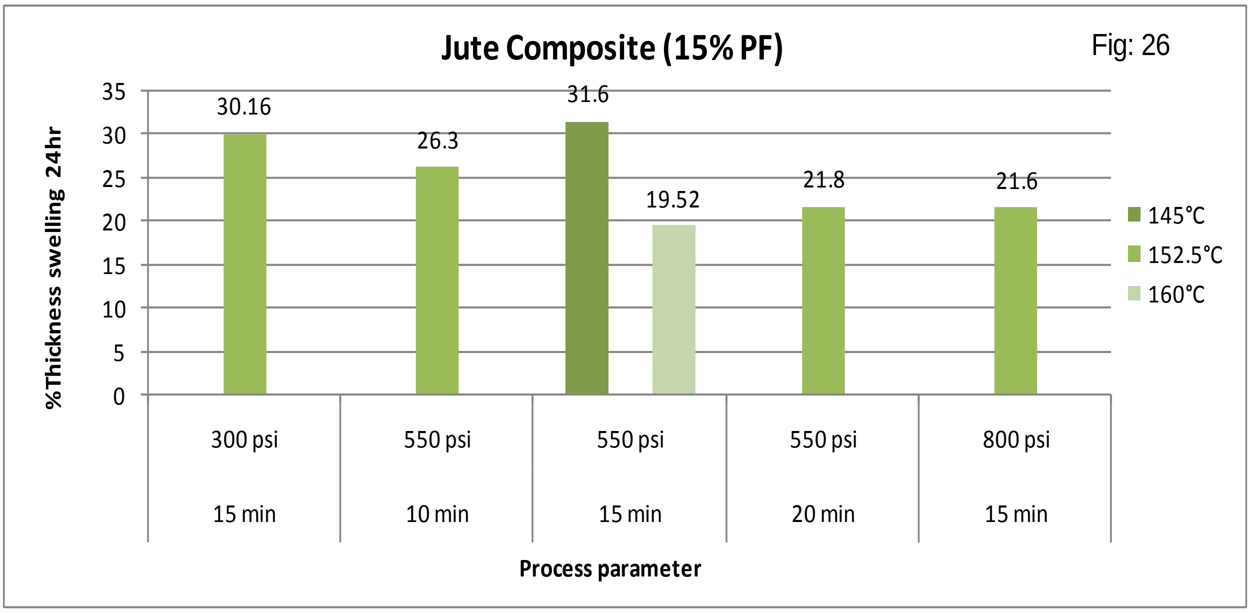

Jute-Bamboo Composite (25% PF)
Fig: 21
%Water absorption 2hr
16
14
12
10
8
6
4
2
0
11.9
14.2
11.5
11.2
11.5
8.46
8.06
7.63
9.3
145°C
152.5°C
160°C
300 psi 10 min
300 psi 15 min
300 psi 20 min
550 psi 15 min
800 psi 10 min
800 psi 15 min
800 psi 20 min
Process parameter

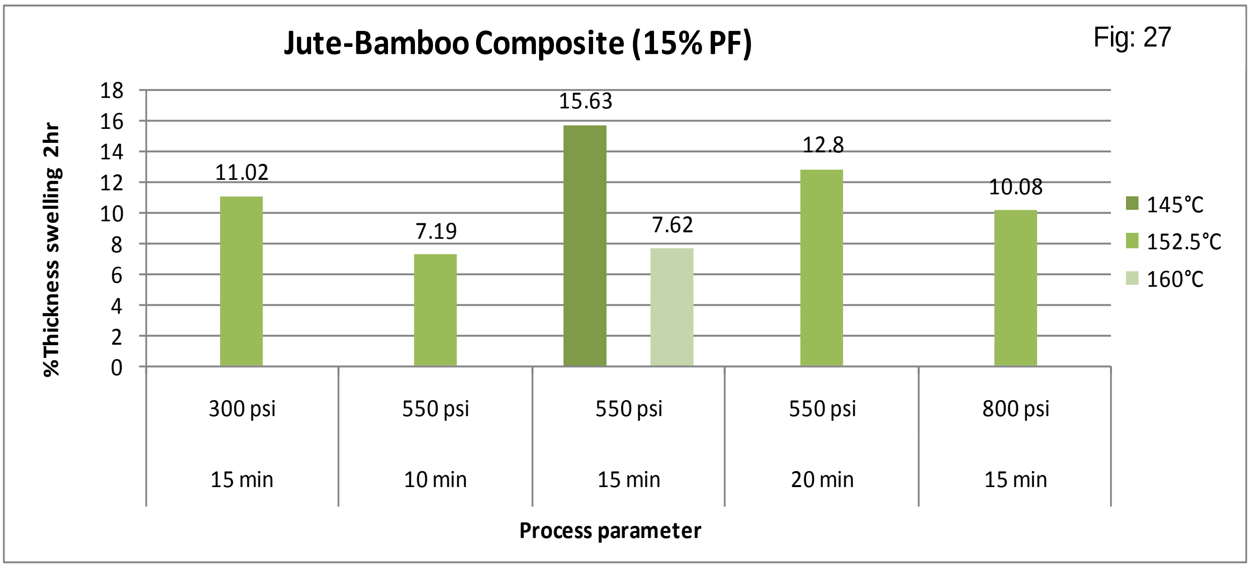

Jute-Bamboo Composite (25% PF)
Fig: 22
%Water absorption 24hr
30
25
20
15
10
5
0
23.8
25.2
23.2
22.5
23
18.45
18.45
20.84
19.47
145°C
152.5°C
160°C
300 psi 10 min
300 psi 15 min
300 psi 20 min
550 psi 15 min
800 psi 10 min
800 psi 15 min
800 psi 20 min
Process parameter

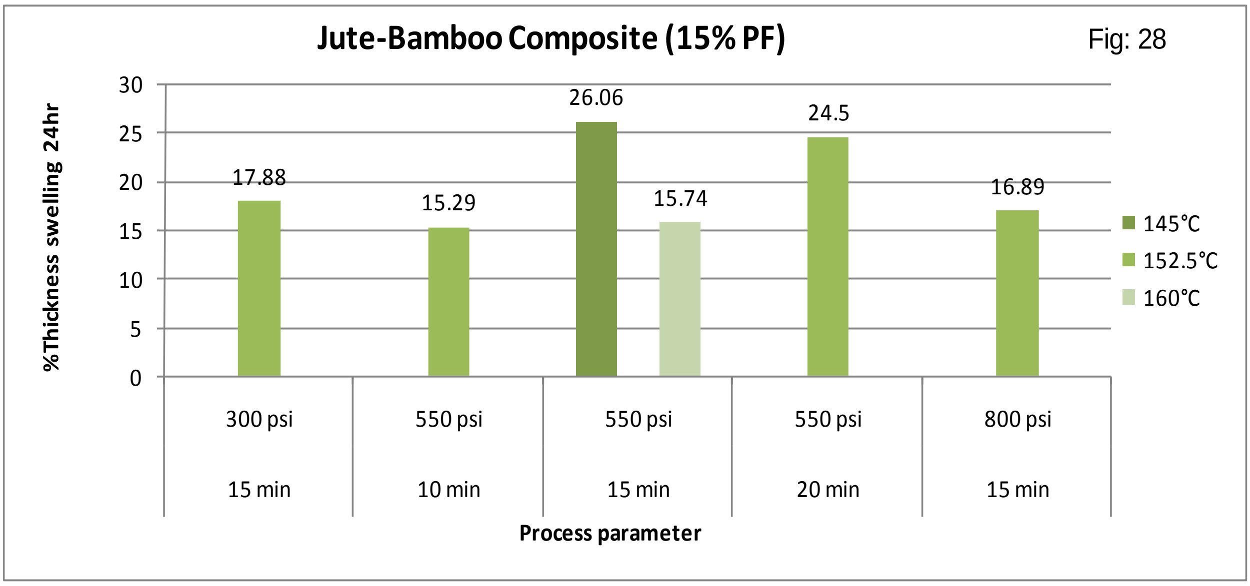

Jute-Bamboo Composite (35% PF)
Fig: 23
%Water absorption 2hr
9
8
7
6
5
4
3
2
1
0
7.87
6.83
7.97
7.2
7.48
5.73
300 psi
15 min
550 psi
10 min
550 psi
15 min
550 psi
20 min
800 psi
15 min
Process parameter
145°C
152.5°C
160°C

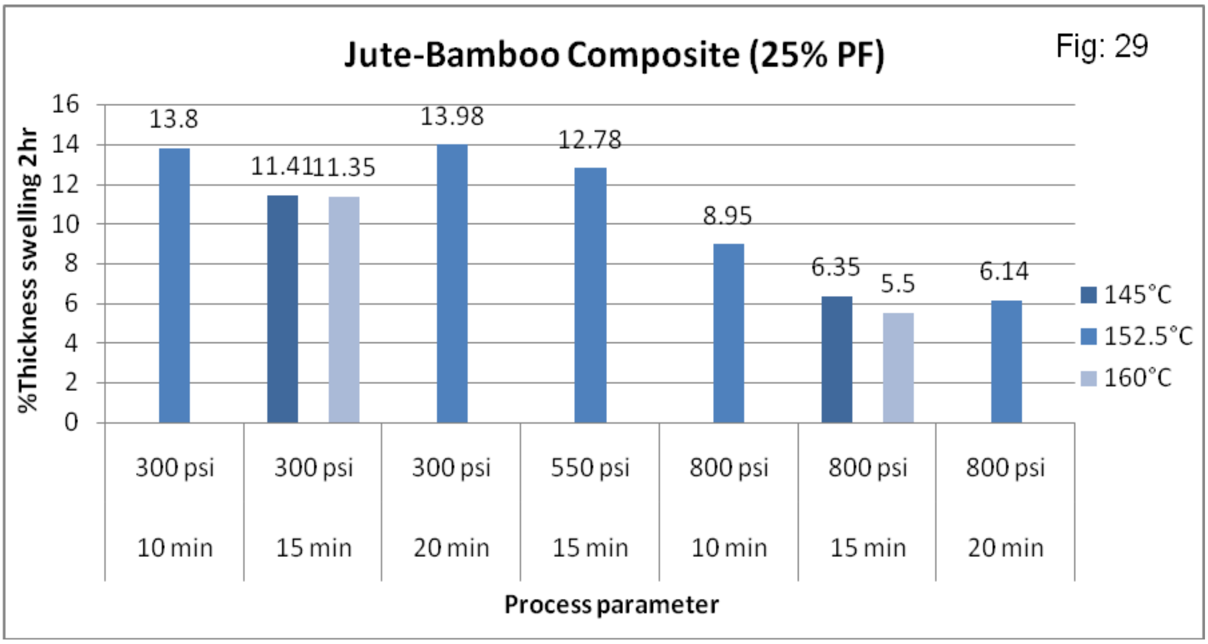

Jute-Bamboo Composite (35% PF)
Fig: 24
%Water absorption 24hr
25
20
15
10
5
0
20.5
16.24
17.65
16.3
16.5
11.2
300 psi
15 min
550 psi
10 min
550 psi
15 min
550 psi
20 min
800 psi
15 min
Process parameter
145°C
152.5°C
160°C

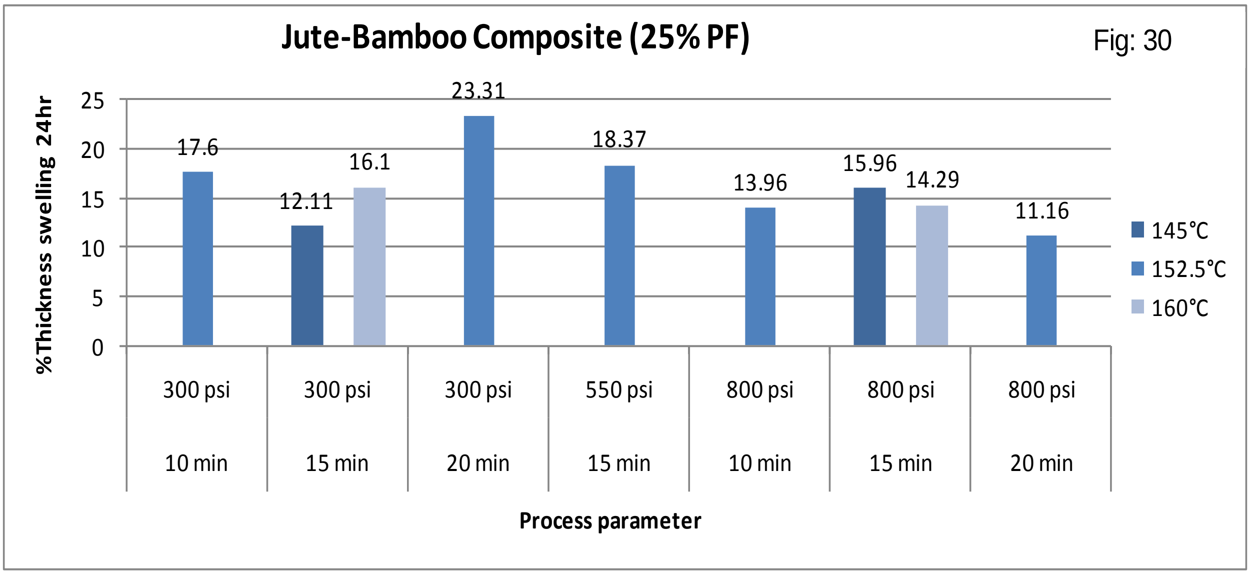

Jute Composite (15% PF)
Fig: 25
%Thickness swelling 2hr
30
25
20
15
10
5
0
25.13
17.7
22
13.7
13.66
14.58
145°C
152.5°C
160°C
300 psi
15 min
550 psi
10 min
550 psi
15 min
550 psi
20 min
800 psi
15 min
Process parameter

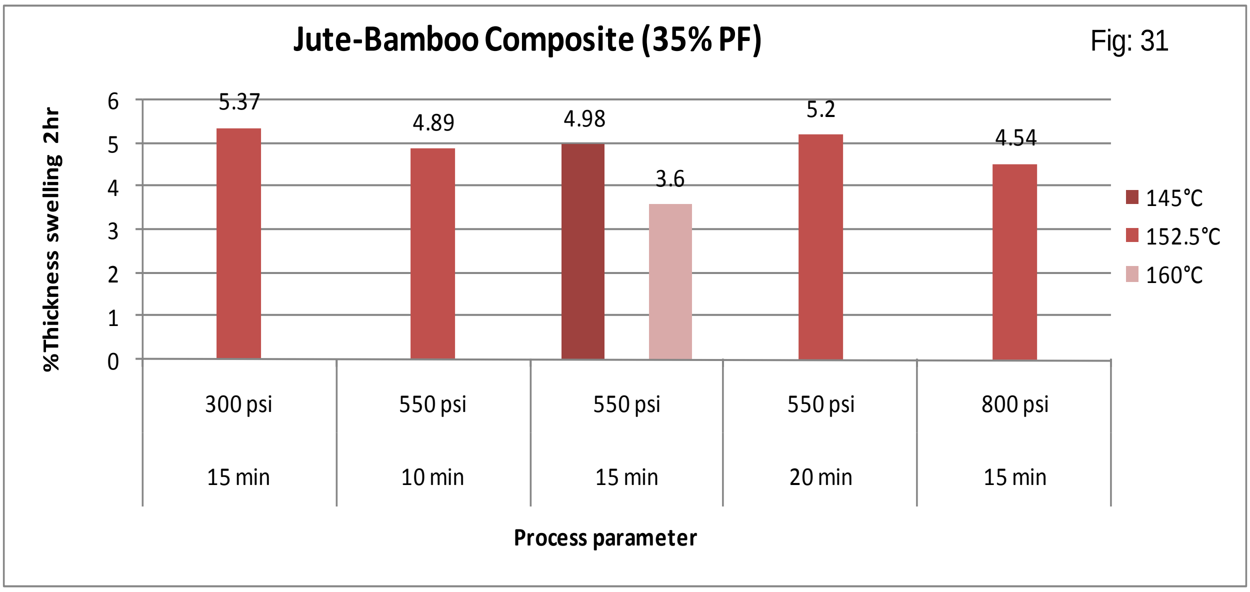

Jute Composite (15% PF)
Fig: 26
%Thickness swelling 24hr
35
30
25
20
15
10
5
0
30.16
26.3
31.6
19.52
21.8
21.6
145°C
152.5°C
160°C
300 psi
15 min
550 psi
10 min
550 psi
15 min
550 psi
20 min
800 psi
15 min
Process parameter

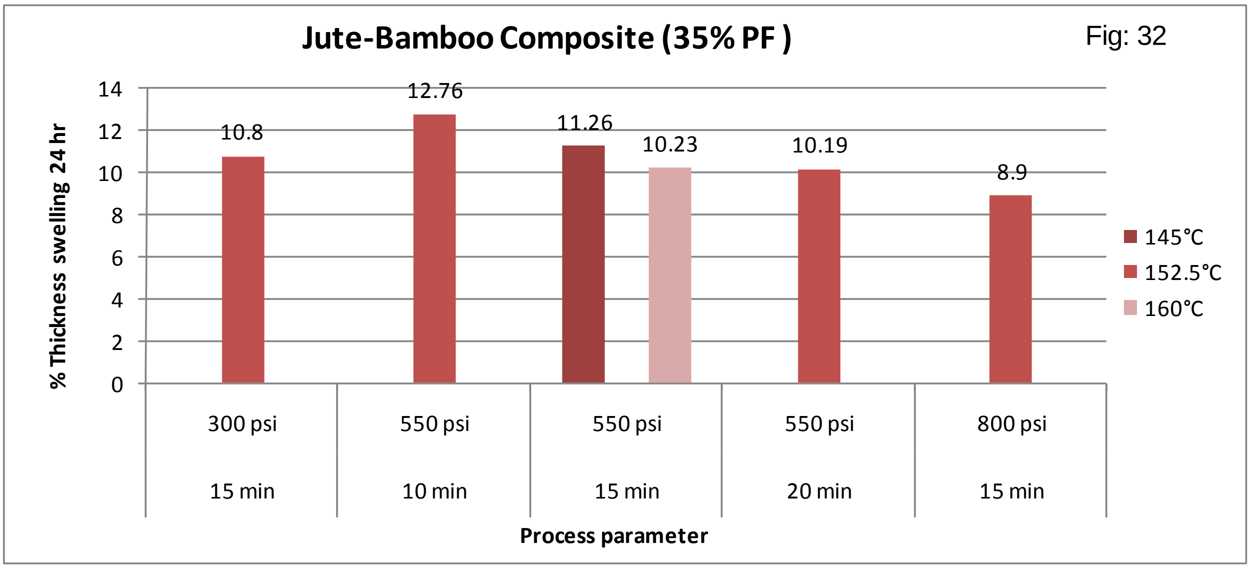

Jute-Bamboo Composite (15% PF)
Fig: 27
%Thickness swelling 2hr
18
16
14
12
10
8
6
4
2
0
11.02
7.19
15.63
7.62
12.8
10.08
145°C
152.5°C
160°C
300 psi
15 min
550 psi
10 min
550 psi
15 min
550 psi
20 min
800 psi
15 min
Process parameter


Jute-Bamboo Composite (15% PF)
Fig: 28
%Thickness swelling 24hr
30
25
20
15
10
5
0
17.88
15.29
26.06
15.74
24.5
16.89
145°C
152.5°C
160°C
300 psi
15 min
550 psi
10 min
550 psi
15 min
550 psi
20 min
800 psi
15 min
Process parameter

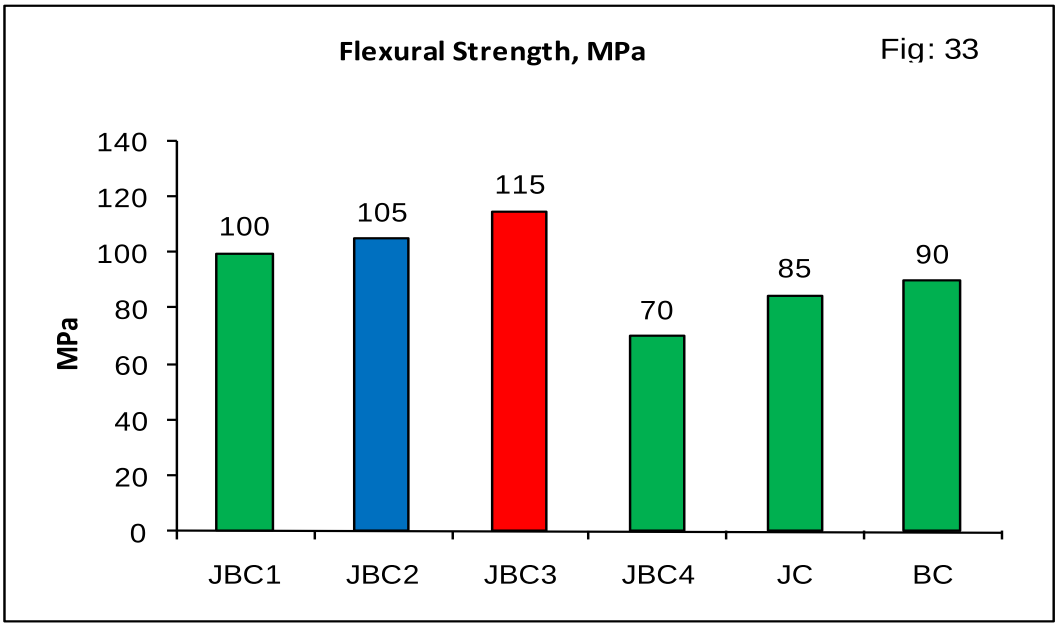

Jute-Bamboo Composite (25% PF)
Fig: 29
%Thickness swelling 2hr
16
14
12
10
8
6
4
2
0
13.8
11.41
11.35
13.98
12.78
8.95
6.35
5.5
6.14
145°C
152.5°C
160°C
300 psi 10 min
300 psi 15 min
300 psi 20 min
550 psi 15 min
800 psi 10 min
800 psi 15 min
800 psi 20 min
Process parameter

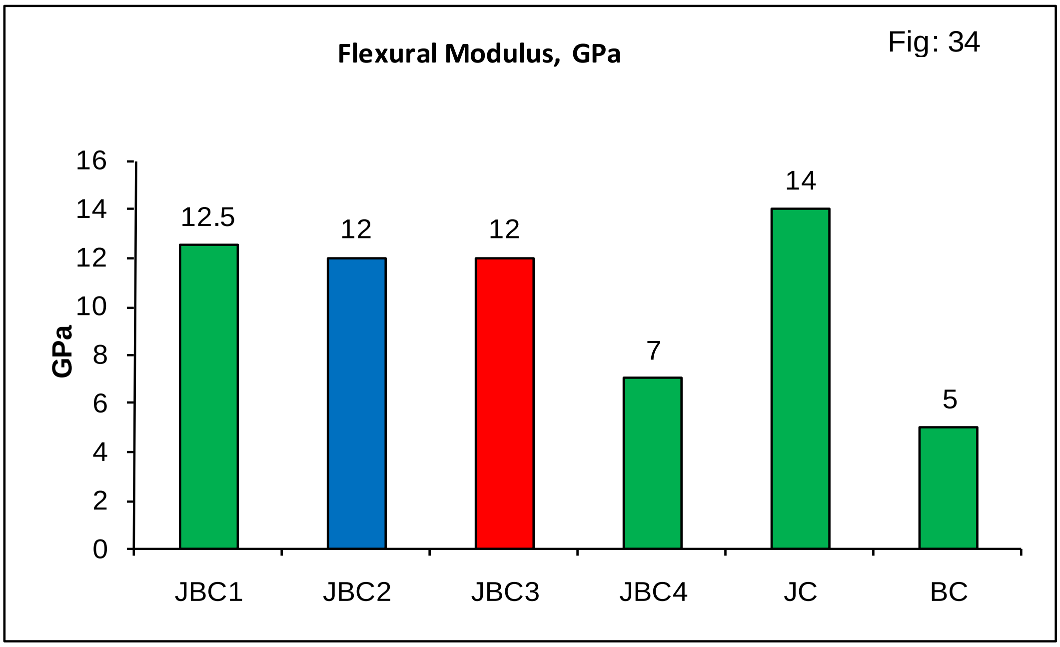

Jute-Bamboo Composite (25% PF)
Fig: 30
%Thickness swelling 24hr
25
20
15
10
5
0
17.6
12.11
16.1
23.31
18.37
13.96
15.96
14.29
11.16
145°C
152.5°C
160°C
300 psi 10 min
300 psi 15 min
300 psi 20 min
550 psi 15 min
800 psi 10 min
800 psi 15 min
800 psi 20 min
Process parameter


Jute-Bamboo Composite (35% PF)
Fig: 31
%Thickness swelling 2hr
6
5
4
3
2
1
0
5.37
4.89
4.98
3.6
5.2
4.54
145°C
152.5°C
160°C
300 psi
15 min
550 psi
10 min
550 psi
15 min
550 psi
20 min
800 psi
15 min
Process parameter


Jute-Bamboo Composite (35% PF)
Fig: 32
% Thickness swelling 24 hr
14
12
10
8
6
4
2
0
10.8
12.76
11.26
10.23
10.19
8.9
145°C
152.5°C
160°C
300 psi
15 min
550 psi
10 min
550 psi
15 min
550 psi
20 min
800 psi
15 min
Process parameter

Properties at Optimum Process Parameters





JBC1= Jute - Bamboo Hybrid Composite with one layer of Bamboo mat(15% matrix resin) ; JBC2= Jute- Bamboo Hybrid Composite with one layer of Bamboo mat (25% matrix resin) ; JBC3=Jute – Bamboo hybrid Composite with one layer of Bamboo mat (35% matrix resin) ; JBC4 = Jute – Bamboo Hybrid Composite with two layers of Bamboo mat (15% matrix resin) ; JC = Jute composite (15% matrix resin) ; BC = Bamboo mat composite (15% matrix resin)

Properties at Optimum Process Parameters

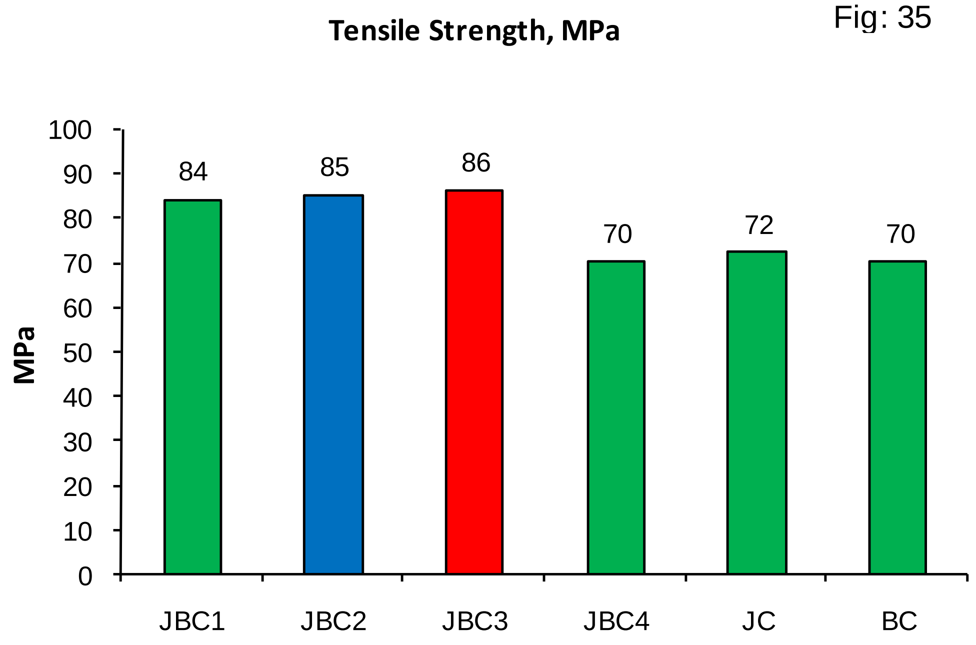


Fig: 35

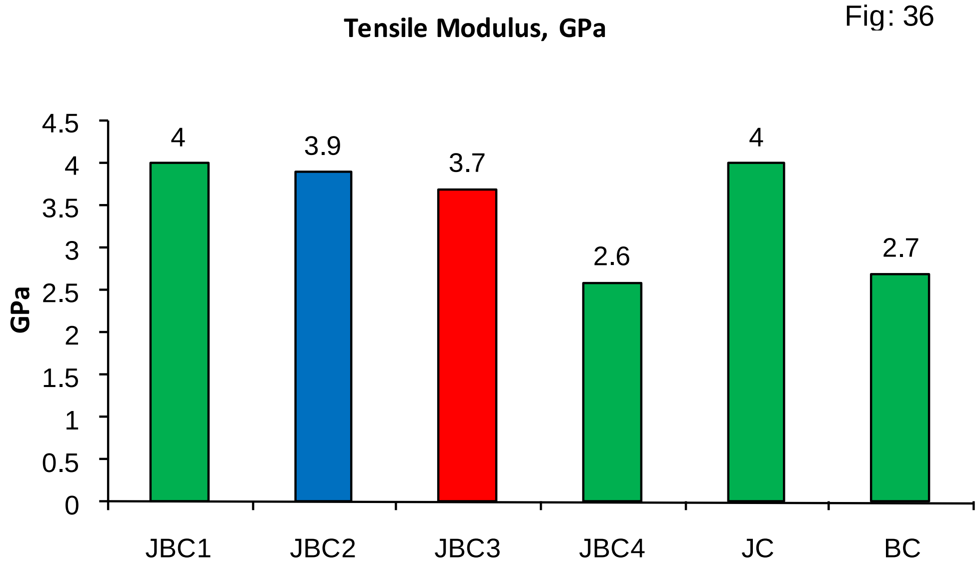
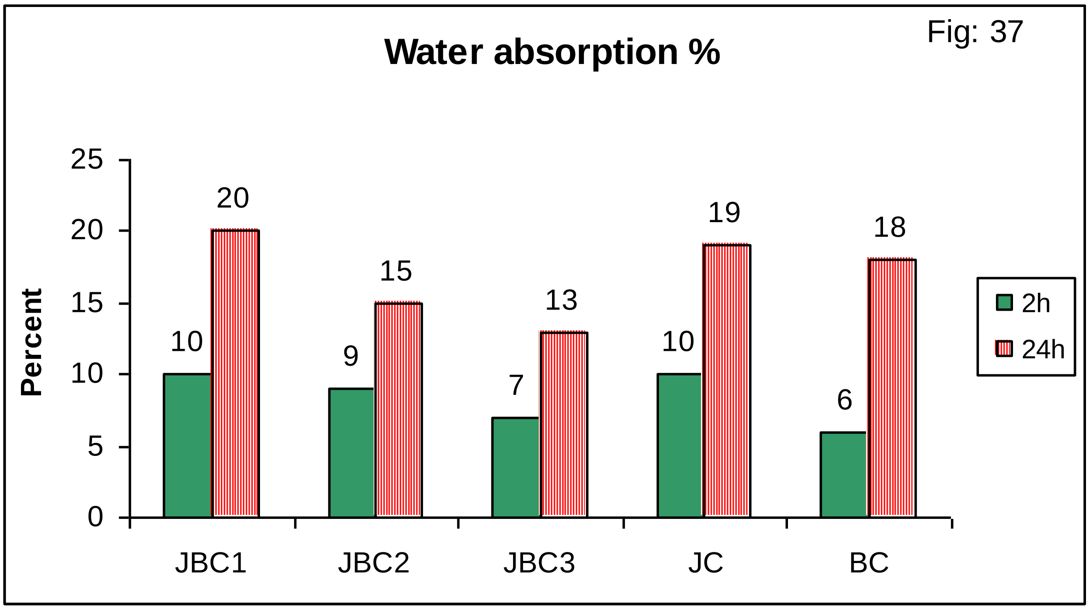


Fig: 36

Properties at Optimum Process Parameters



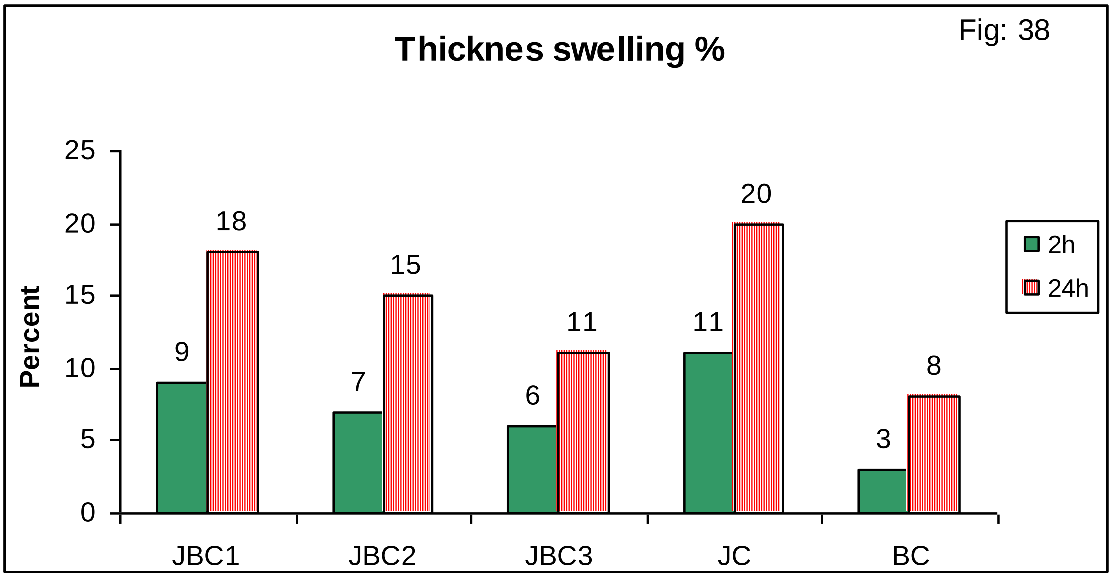


Table 2: % Reduction of noise level at different frequencies (Source Noise 107 dB)

Sample Description		Exposed side	% Reduction of Noise	
			Frequency 3150 Hz	**Frequency 200 Hz**
15% Resin content	Jute composite	jute	27	14
	Jute Bamboo composite	Jute	25.7	5.6
		Bamboo	29	6
25% Resin content	Jute composite	jute	29	16.8
	Jute Bamboo composite	Jute	26	5.6
		Bamboo	31.8	11.68
35% Resin content	Jute composite	jute	32.7	17.76
	Jute Bamboo composite	Jute	28	6.54
		Bamboo	32.7	14.95

Table 3: Abrasion Rate Taber Abraser 503 (weight loss per 500 cycles of abrasion under 2 lb load)

Sample	After 500 revolution Reduction of weight, gm
JBC35 (Bamboo Side coated)	0.1150
JC35 (coated)	0.3660
Laminated Wood Flooring	0.0962

Table 4: Resistance to spread of flame (RDSO/2007/CG-2(Rev.10))

Specimen	Test Surface	Class
Jute bamboo composite (single side bamboo)	Bamboo	B
Jute bamboo composite (single side bamboo)	Jute	C
Jute bamboo composite (both side bamboo)	Bamboo	B

Table 5: Mechanical Properties of Composite Boards Fabricated at CTP, Bangalore

Sample	Flexural Strength MPa	Flexural Modulus GPa	Tensile Strength MPa	Tensile Modulus GPa
Jute Composite (JC)	65.33	5.89	54.59	3.17
Jute Bamboo Composite (JBC1)	71.31	6.04	68.11	1.92
Jute Bamboo Composite (JBC4)	61.50	4.81	58.90	1.63

Table 6: Mechanical Properties of Composite Boards Fabricated at IPIRTI,Bangalore

Sample	Flexural Strength MPa	Flexural Modulus GPa	Tensile Strength MPa	Tensile Modulus GPa
Jute Composite (JC)	81.24	7.5	57.33	3.27
Jute Bamboo Composite (JBC1)	40.79	4.01	49.11	3.17
Jute Bamboo Composite (JBC4)	28.60	3.14	36.24	2.24

Table- 7a Properties of Jute-Bamboo Composite with Respect to Other Specifications

Properties	Jute-Bamboo composite	MDF General purpose IS: 12406	High Density wood Particle Boards (BWR) IS: 3478	Ply Wood Shuttering IS: 4990 amen-3	Decorative Laminates IS: 2046	Fibre Hard Boards IS: 1658
Density, g/cc	1 – 1.3	0.6 - 0.9	0.9 – 1.2			> 0.8
Tensile Strength (MPa)	50 - 100		30 – 35		60 - 70	
Tensile Modulus (GPa)	2 – 5					
Flexural Strength (MPa)	75 - 135	25 - 28	34 – 45	45 - 50	80 - 100	30 - 50
Flexural Modulus (GPa)	9 – 15	2.3 – 2.8	3.6 – 4.5	6.7 – 7.5	9 - 10	
% Water absorption, 24 h	12 - 30	12 - 45	10 - 25			20 - 40
% Water absorption, 2 h boiling	5 - 18				3 - 25	

Table- 7b Properties of Jute-Bamboo Composite with Respect to Other Specifications

Properties	**Jute-Bamboo composite**	**Compressed Wood Laminate (Compregs)** **IS: 3513 Gr: GH**	**Compressed Wood Laminate (Compregs)** **IS: 3513 Gr:GM**
Density, g/cc	1 – 1.3	1.25 – 1.35	0.95 – 1.25
Tensile Strength (MPa)	50 - 100	90 - 155	59 - 108
Tensile Modulus (GPa)	2 – 5		
Flexural Strength (MPa)	75 - 135	100 - 145	59 - 88
Flexural Modulus (GPa)	9 – 15		
Impact Strength kJ/m^2 (unnotched, ISO 180)	24.6	29.4	19.6
% Water absorption, 24 h	12 - 30		
% Water absorption, 2 h boiling	5 - 18		

Chapter 4

Cost analysis of Jute - Bamboo hybrid composite board

1. **Price of 7' x 3' Door, Thickness of Panel Frame 1.5", Panel Thickness 1"**

DOOR TYPE	PRICE (Rs)
WOOD CP TEAK	7,500
KAPOOR WOOD	4,600
BLOCK BOARD (35 mm)	3,300
***JUTE – BAMBOO COMPOSITES**	4,800

* Cost of Jute-Bamboo Board: Rs 2700 per cu. ft. & Door Thickness: 1"

2. **Comparative Cost**

Imported Plywood (MR quality), 4mm	Rs 36.25 per sq. ft. (Ex-warehouse)
Commercial Plywood (Hard wood), 4mm	Rs 23.50 per sq. ft. (Ex-warehouse)
Jute-Bamboo Composite Board, 3mm	Rs 27.35 per sq. ft.

3. **Estimated Project Cost**

Item	Cost (Rs in Lakh)
Land & Building	250
Equipment	690
Total	**940**

4. **Requirement of Human Resources on Two Shift Basis**

Direct	84
Management and Office	11
Security	10
Total	**105**

Production per Annum: 521406 no. of Boards (8' x 4' x 3 mm)

Direct Human Resource:					
Nature of job	**Wages / month, Rs**	**Number of Heads / shift**	**Number of Heads / two shift**	**Total wages / month, Rs**	**Total wages / annum, Rs**
Unskilled	6500.00	28	56	364000.00	4368000.00
Skilled	8500.00	10	20	170000.00	2040000.00
Supervisor	12000.00	4	8	96000.00	1152000.00
Total =		42	84	630000.00	**7560000.00**

Human Resources for Management & Administration:				
Nature of job	**Salary / month, Rs**	**Number of Heads**	**Total salary / month, Rs**	**Total salary / annum, Rs**
Works manager	60000.00	1	60000.00	720000.00
Technical Manager	50000.00	1	50000.00	600000.00
Technical Officer	35000.00	2	70000.00	840000.00
Administrator	25000.00	1	25000.00	300000.00
Marketing officer	30000.00	2	60000.00	720000.00
Office assitant	8000.00	2	16000.00	192000.00
Unskilled	6500.00	2	13000.00	156000.00
Total =		11	**294000.00**	**3528000.00**

Nature of job	**Salary / month, Rs**	**Number of Heads / 12 hr.**	**Number of Heads / day**	**Total salary/ month, Rs**	**Total wages / annum, Rs**
Security staff	6500.00	5	10	65000.00	780000.00
Total =		5	10	65000.00	**780000.00**

Total Wages & Salary: Rs 118.68 Lakh

Requirement of Power: 270 kW

5. Expenditure Components (Including Depreciation & Repairing):

	Quantity Per untrimmed Board, kg	**Cost per unit**	**Cost Per Board**	**Cost Per Month (43450 nos, board)**	**Cost Per Month with wastage / rejection (6%)**	**Cost Per Annum**
		Rs	Rs	Rs (in Lakh)	Rs (in Lakh)	Rs (in Lakh)
Raw Materials						
Jute Fibre	7.73	30.00	231.9	100.761	106.81	1281.72
Bamboo Mat	1.93	45.00	86.85	37.74	40.00	480.00
Phenol	1.086	145.00	157.47	68.42	72.53	870.36
Formalin 37%	1.967	25.00	49.175	21.37	22.65	271.8
Sodium Hydoxide	0.186	35.00	6.51	2.83	3.00	36.00
Water	1.62	1.00	1.62	0.70	0.742	8.904
Additive			42.68	18.54	19.65	235.80
Sub Total (I)			**576.205**	**250.361**	**265.382**	**3184.584**
Power (Inst. capacity 270 kW)	230 kW (85% of installed capacity) for 16 hr x 300 days	7.00				77.112
Fuel Cost for heating of hydraulic press & dryer	12 hr/ day for 300 days. 66 kg/hr. 792 kg/ day	40.00				95.04
Sub Total (II)						**172.152**
Wages						75.60
Administrative Over head						43.08
Sub Total (III)						**118.68**
Depreciation						94.00
Repairing & Maintenance						37.50
Sub Total (IV)						**131.50**
Total (I+II+II+IV)						**3606.916**

6. PROJECTED BREAK EVEN ANALYSIS

Board size 8 ft x 4 ft x 3 mm thick	Annual Production of boards, (Number)	Sale Price per board, Rs	Earning per Annum, Rs in Lakh	Less discount	Annual earning after discount, Rs in Lakh
	521406	875	4562.3025	8%	4197.32

Components	Rs in Lakh	Cost respective to percent utilization of production capacity Rs in Lakh						
		30%	**60%**	**65%**	**70%**	**75%**	**85%**	**90%**
A. Income / Sales	**4197.32**	1259.20	2518.39	2728.26	2938.13	3147.99	3567.73	3777.59
B. Variable Cost								
Cost Of Sales	3606.92	1082.07	2164.15	2344.50	2524.84	2705.19	3065.88	3246.22
Less:								
Administrative Overheads	43.08	12.92	25.85	28.002	30.16	32.31	36.62	38.77
Repairs & Maintenance	37.5	11.25	22.5	24.375	26.25	28.13	31.87	33.75
Depreciation	94	28.2	56.4	61.1	65.8	70.5	79.9	84.6
Wages	75.6	22.68	45.36	49.14	52.92	56.7	64.26	68.04
Sub Total		**1007.02**	**2014.04**	**2181.88**	**2349.71**	**2517.15**	**2853.23**	**3021.06**
C. Contribution (A - B)		**252.18**	**504.35**	**546.38**	**588.42**	**630.44**	**714.50**	**756.53**
D. FIXED COST								
Wages	75.6	37.8	75.6	75.6	75.6	75.6	75.6	75.6
Administrative Overheads	43.08	43.08	43.08	43.08	43.08	43.08	43.08	43.08
Repairs & Maintenance	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5
Depreciation	94	94	94	94	94	94	94	94
Sub Total		**212.38**	**250.18**	**250.18**	**250.18**	**250.18**	**250.18**	**250.18**
Profit (C - D) [before Tax & repayment of loan & interest]		**39.80**	**254.17**	**296.20**	**338.24**	**380.26**	**464.32**	**506.35**

General Conclusion

The project – Jute-bamboo hybrid composite board has been successfully developed with different thickness and varying density for various end uses. The composite board is of better mechanical strength than jute composite previously developed at IJIRA. Most suitable composite consists of single layer of bamboo mat on one side (20 per cent) and jute non-woven mat (65 per cent) on the other side as reinforcing agent and the rest (15 percent) as binder matrix of phenol formaldehyde (water soluble grade) resin. This composition is found to be technically and economically viable for common end use as wood substitute and is matching existing standards. The strength of the composite may be further enhanced with increase of binder content up to 35% as required for other end uses like, compressed wood board, flooring etc. It is interesting to observe that with increase of bamboo content the strength is reduced. It is also observed that under conventional and optimum condition that the strength of jute- bamboo hybrid composite of above combination is better than that of 100% bamboo composite and 100 % jute composite.. In conclusion, it may be stated that the product – jute – bamboo hybrid composite developed is cost effective and performance driven as well.

In future, there is enough scope for commercialization. It is recommended that one should go ahead for commercialization starting from jute fibre to jute non- woven through carding, cross-lapping and needle punching unit on one hand and captive resin manufacturing unit on the other hand along with composite manufacturing unit to make it an independent unit. Initially, the capital investment may be more but in the long run it will help quick return with attractive profit margin. Secondly, the future development may be oriented to moulded composite products with jute and bamboo as reinforcement.

Annexure-I

तार : आई पी आई आर आई, कलकत्ता-34
Grams: IPIRTI, Calcutta- 34

फ्याक्स : 91-033-2498-3120
Fax : 91-033-2498-3120
दूरभाष : 2498-3120
Phone : 2498-3120
E-Mail :ipirti@vsnl.net

भारतीय प्लायवुड उद्योग अनुसंधान और प्रशिक्षण संस्थान
INDIAN PLYWOOD INDUSTRIES RESEARCH AND TRAINING INSTITUTE
फील्ड स्टेशन, कलकत्ता / FIELD STATION, KOLKATA
(भारत सरकार, पर्यावरण एवं वन मंत्रालय का स्वायत्त निकाय)
(Autonomous Body of the Ministry of Environment & Forests, Govt. of India)
2/2, बीरेन राय रोड, वेस्ट, सरसुना, कलकत्ता -700 061
2/2, Biren Roy Road West, Sarsuna, KOLKATA – 700 061

सं: No.:KFS/Phy/Testing/Jute Composites/2375/10-11/699

दि: Dated: 26.10.2010

TEST REPORT

6(Six) samples of Jute Composites (A to F) of different grades we are received from M/s. Indian Jute Industries' Research Association, 17, Taratala Road, Kolkata – 700 088

Ref. Letter No. Nil dated 09.04.2010
Project Code of IJIRA : JTM-20

Sample was tested for internal bond Strength and Screw withdrawl Strength.

Sl. No.	Sample Code No.	Thickness (mm)	Screw Withdrawl Strength (N)	Internal Bond Strength	
				Peakload (N)	IB Value (N/m^2)
1	A	8.12	507	1850	0.74
2	B	5.04	402	1750	0.70
3	C	4.02	388	1700	0.68
4	D	8.05	478	1900	0.76
5	E	8.06	488	1950	0.78
6	F	7.98	496	1900	0.76

Note: (a) Test results are relevant only to the material received for testing. Remnant of tested material if any will be retained for a period of 6 months only, from the date of issue of test report.
(b) Publication or reproduction of this test report in any form than by complete set of the whole report in the language written is not permitted without the written consent of IPIRTI.

Officer-In-Charge

प्रभारी अधिकारी
Officer-in-Charge
भारतीय प्लाईवुड उद्योग
Indian Plywood Industries
अनुसंधान और प्रशिक्षण संस्थान
Research & Training Institute
२/२, बीरेन राय रोड (पश्चिम), सरसूना
2/2, Biren Roy Road (West), Sarsuna
कोलकाता - ७०० ०६१
Kolkata - 700 061

A- Jute composite, B & E- Jute-Bamboo composite (Jute-bamboo-Jute),

C & F- Jute-Bamboo composite (Jute-bamboo)

D- Jute-bamboo composite (Bamboo-jute-bamboo)

Annexure-II

CENTRAL GLASS & CERAMIC RESEARCH INSTITUTE

196, Raja S.C. Mullick Road, Kolkata -700 032, India
(A CONSTITUENT ESTABLISHMENT OF CSIR, GOVT. OF INDIA)

CGCRI

TEST REPORT NO. GC/1535/TCC/1405/10-11 Dated: 19.11.2010 ISSUED TO : **M/s Indian Jute Industries' Research Association.** 17, Taratala Road **Kolkata – 700 088** **West Bengal**	*TELEGRAM*: GLASCERCH, JADAVPUR UNIVERSITY *TELEPHONE* : 2473-3469/3496/3476-7 *FAX* : (033)-24837339, 24730957, *E-MAIL* : bmukherjee@cgcri.res.in /skdeb@cgcri.res.in. Customer Ref. No. Nil; Dated: 11.10.2010 Sample/Testing charges received on: 19.10.2010 Sample Reg. no. GC/1535/TCC/1405/MPE/10-11 Dated.: 19th October, 2010

Description of sample received: One set of sample of Jute – Bamboo Composite Laminate – two pieces (334 & 335).

Name of Test(s) desired & done: (1) Compressive Strength, (2) Inter Laminar Shear Strength & (3) Hardness – Barcol.

Report/Result **Page: 1 of 1**

RESULTS

Machine Used

For tests (1) & (2) Instron – UTM and (3) Bar4col hardness Tester

Sl. No.	Test	Result
1	Compressive Strength MPa (Kg/cm^2)	37.17 (378.99) [Mean of 5 tests] Sd = 3.94 (40.22)
2	Inter Laminar Shear Strength MPa (Kg/cm^2)	Side(A) – 7.58 (77.30) [Mean of 5 tests] Sd = 1.33 (13.60) Side(B) – 9.18 (93.59) [Mean of 5 tests] Sd = 1.96 (19.96)
3	Harness – Barcol (Measured both the surface)	11 [Mean of 20 tests] Sd = 4.7

Issued by :

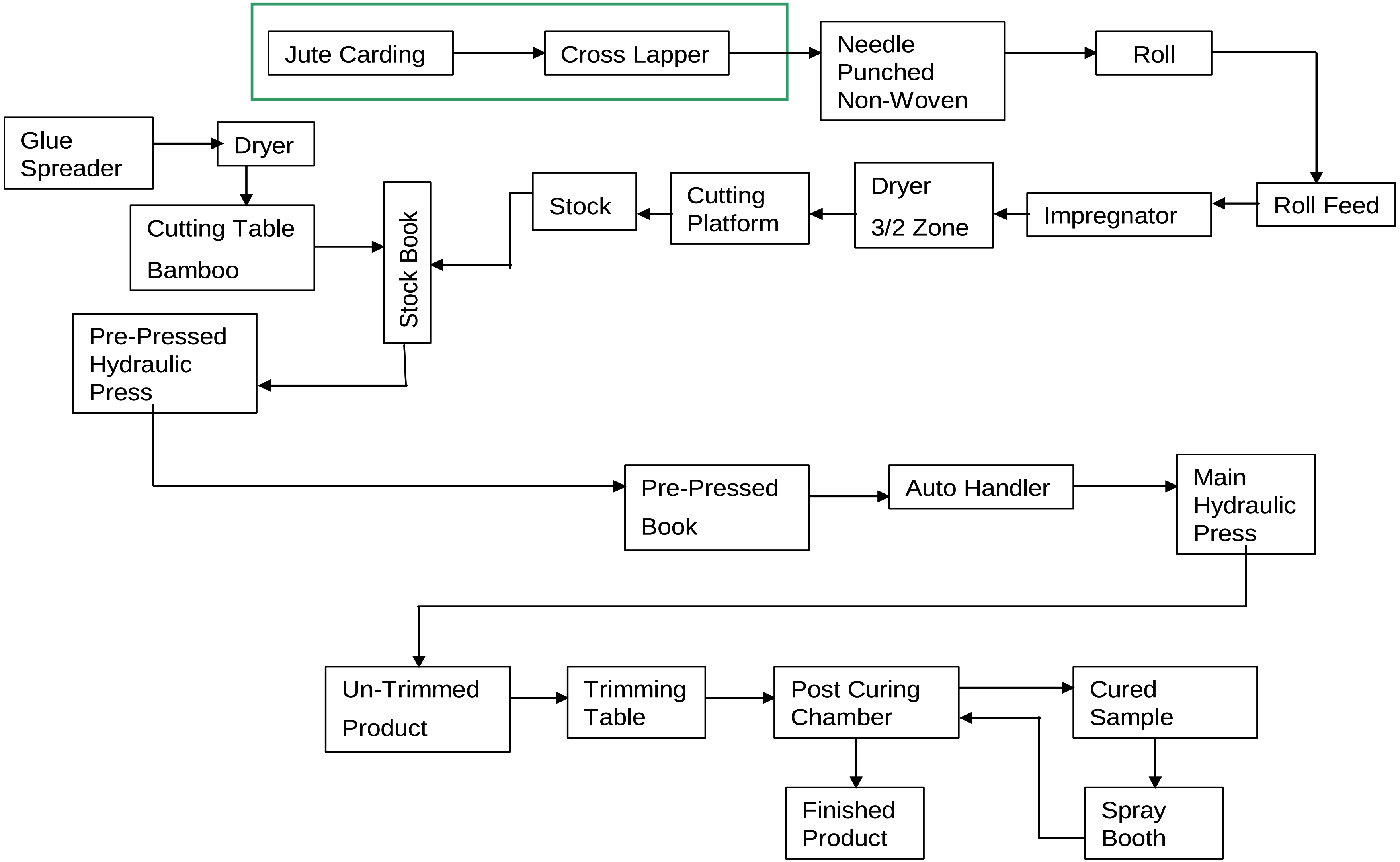
Central Glass & Ceramic Research Institute ★ Kolkata-32 ★ TCC

19/11/10

Scientist & Head
Testing & Calibration Cell

Annexure-III

Flow Diagram for Commercial Production



Annexure-IV

Costing of Jute - Bamboo hybrid composite board Size: 8 ft x 4 ft x 3 mm

Finish Product, Board, size (8'x4'x3mm)	Length cm	Width cm	Thicknesscm	Vol of Board cc	Density of board gm/cc	Wt. of Board kg	Waste allowance	Total materials required / Board kg
	244	122	0.3	8930.4	1.2	10.71648	3%	11.0379744
								11.05

a) Without captive nonwoven & resin plant

Total fibre per board, kg	Total binder with additive per board, kg	Jute fibre per board, kg	Bamboo per board, kg	Cost of Jute nonwoven per kg Rs	Cost of bamboo mat per kg Rs	Cost of Resin including additives per kg Rs
8.84	2.21	6.188	2.652	55	35	110

Cost of Jute fibre per board Rs	Cost of bamboo mat per board Rs	Cost of Resin including additives per board Rs	Total raw material cost per board Rs	25% Conversion charge Rs	Production Cost per board Rs
340.34	92.82	243.1	676.26	169.065	845.325
					846

b) Assuming the availability of captive nonwoven & resin plant

Total fibre per board kg	Total binder with additive per board kg	Jute fibre per board kg	Bamboo per board kg	Cost of Jute fibre per kg Rs	Cost of bamboo mat per kg Rs	Cost of Resin including additives per kg Rs
8.84	2.21	6.188	2.652	35	35	95

Cost of Jute fibre per board Rs	Cost of bamboo mat per board Rs	Cost of Resin including additives per board Rs	Total raw material cost per board	Conversion charge, 25%	Production Cost per board, Rs
216.58	92.82	209.95	519.35	129.8375	649.1875
					650

Remark: With captive nonwoven & resin plant the product will be feasible for commercial production.

Annexure-V

List and Cost of Essential Equipments for Commercial Production

	Description	Ex. Factory Cost ₹ (Lakh)
1	Horizontal Impregnator	44
2	Glue spreader with tank	10
3	Hydraulic Press (100"x50" hot & cold system, 8 daylight)	180
4	Hydraulic Press (pre press) - 100"x50" single daylight	50
5	Auto Handler	40
6	Sanding m/c	8
7	Trimming m/c	10
8	Resin Plant	10
9	Water softener	3
10	Drying chamber	10
11	Hydraulic scissor table	5
12	S.S. Storage Tank for chemicals	10
13	Nonwoven Plant	150
14	Transformer	14
15	SS Plate, 144 nos	100
16	Caul Plate, 32	6
17	Pollution Control Plant	7
18	Emulsion Plant with Electronic Stirrer	3
19	Thermic Fluid heat generator	30
	Total	**690**

Annexure-VI

Excel Composites Pvt. Ltd.

MANUFACTURER OF FRP / SMC, JUTE (NFTC)
REINFORCED COMPOSITES FOR INDIAN RAILWAY

OFFICE & WORKS : BODAI INDUSTRIAL COMPLEX,
2nd LANE (EAST), P.O. JUGBERIA, KOLKATA-700 110
TELEFAX : 033 2537 3234
email : excel_composites@yahoo.com

JAS-ANZ VEXIL BPS MS

APPROVED WITH SSI/ NSIC// RDSO

TO WHOM IT MAY CONCERN

This is to certify that Scientists / Technologists from Indian Jute Industries' Research Association conducted pilot scale trial for fabrication of jute bamboo composite at our factory at Bodai Industrial Complex, 2nd Lane (East), Talbanda, P.O- Jugberia, Dist- 24 Pgs(N), Kolkata- 700 110
They brought the treated bamboo mat and used our impregnator cum dryer for treatment of jute felt with pf resin as per their formulation. Jute bamboo composite boards were produced with our hydraulic press under their supervision.

It was found that the technology is feasible with appropriate machineries. We wish their success for this new development.

For EXCEL COMPOSITES (P) LTD.

Managing Director

Date: 23/11/2012

Annexure-VIIa

Laboratory Trials at IJIRA

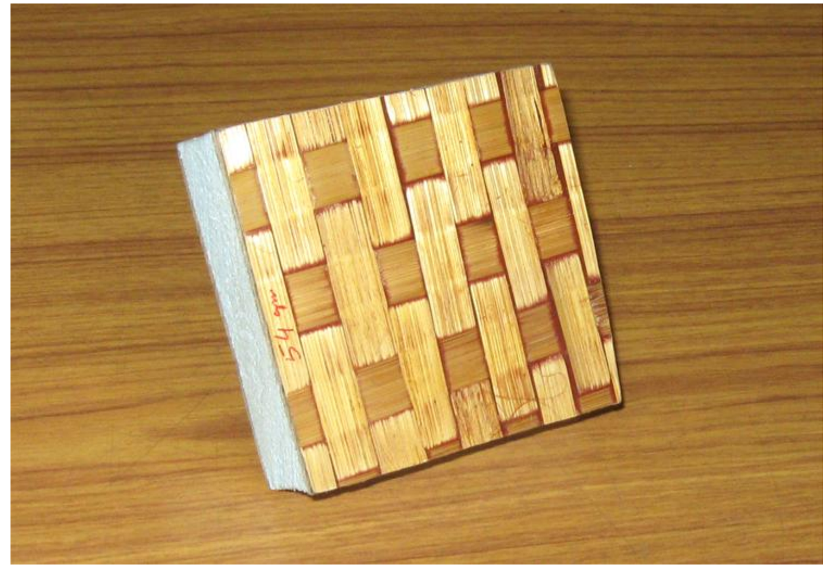
Annexure-VIIb

Pilot Scale Trials at IPIRTI, Bangalore

Annexure-VIII

Jute Bamboo Composite Board- 4ft x 3ft

Jute Bamboo Composite Sandwich Panel



Model Emergency Shelter from Sandwich Panel

Jute Bamboo Composite Board