Eco-Composite Flush Door Shutter Using Bamboo-Jute Fiber

Pijus Kanti Khatua, Suraj Chakraborty, Sibaprasad Maity, Gora Das, Arunabha Ghosh

Abstract— This paper present the development of composite flush door shutter for ecological purpose (eco-composite) using natural fibre like bamboo, jute and their basic mechanical properties. Here, 100 percent indigenous technologies were applied to make flush door shutter of solid core type. Different thermosetting resin adhesives were used as matrix at different stage. The experimental results [as per IS: 2202 (Part I)] of the physico-mechanical properties like surface finishing, tensile strength, internal bond strength, density, screw withdrawal and glue shear strength etc. of the flush door had a sufficient specific strength (influenced by the dilution of resin matrix) which is equivalent to that of the conventional wooden flush door. This technique for the production of flush door using fast growing natural fibre is cost effective and could be an ideal solution with ever depleting forest reserves.

Keywords— Fiber; Resin; Composite; Flush door..

I. INTRODUCTION

Due to increasing gap between demand and supply, wood based industries have been passing through a critical state. This is the result of unplanned cutting of forests in the past, which has led to increased environment concern prompting policy initiatives aimed at conservation of biodiversity and other environmental services of forest [1]. To come out of this critical state, various alternatives have been explored. Fiber reinforced plastic composites have been widely accepted as materials for structural and non-structural applications in recent years.

The main reason for interest in fiber reinforced plastic for structural applications is due to the high specific modulus strength of the reinforcing fibers.

Glass fibers are most commonly used as reinforcement followed by carbon and boron fibers. These fibers are highly expensive and their use is justified in high value aerospace applications. Therefore, it is worthwhile to explore the possibility of utilizing a cheaper, fast growing and renewable materials as reinforcement. Jute, bagasse, bamboo, straw and sisal appear to hold the most promise for continued development as stated by Maloney[2].

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Bamboo has also been traditionally used to construct various facilities and tools[3]. The scope for using jute and bamboo fibers in place of traditional glass fibers partly or fully stems from lower specific gravity and higher specific modulus of jute (1.29 and 40 GPa respectively) and bamboo (1.29) and 40 GPa)[4] compared with those glass fiber (2.5 and 30 GPa respectively). Besides its much lower cost, reusable nature and lower energy requirement for production and processing of jute and bamboo compared to that of artificial fibers make them an alternative fibers for use as reinforcement in resin composites. However, the potential of jute, bamboo in high value moulded product[5] composite has remained largely unrealized in view of poor wettability with organic matrix and adhesion characteristics of jute bamboo towards resin resulting in composite of poor strength and lesser environment resistance.

The performance of any lignocellulosic fiber composite is restricted by the properties of the fiber itself. If the negative properties of the natural fiber, like flammability, moisture regain, microbial attack and photochemical degradation, etc. can be improved, jute and bamboo based composites could have greatly improved performance. Many techniques[6] have been used over the years to stabilize dimensionally the structure of the lignocellulosic materials against different environmental attack as lignocellulosics are attacked by moisture. Bagasse is the fibrous by-product from sugar cane processing and has been used to produce hardboard (HB) and insulation board as recommended by Sefain[7]. De-pitying, surface modification and thermal/chemical treatments have provided comparable mechanical and physical properties to medium density fiber board (MDF) made from aspen fiber described by Mobarok[8]. The adhesive has an important influencing on mechanical and physical properties of agro-based composites. UF (urea-formaldehyde) and PF (phenol-formaldehyde) modified with 20 to 30 percent of pMDI (4, 4'-diphenylmethanediisocyanate) has provided substantially increased mechanical and physical properties of agro-based composites compared to a single UF or PF application of agro-based composites[9]. Bamboo (*Bambusoideae* sp.) was introduced in the agro based composite field in the early 19th century. Several papers have already been published on the study of bamboo fiber reinforced composite using thermosetting plastic(epoxy and polyester)[10-13]. Due to its rapid growth, high bending stiffness, and dimensional stability, bamboo has potential as a raw material for composite panel production. Many studies have evaluated the properties of bamboo based composites such as oriented strand board by Lee[14], medium density fibre board by Yusoff[15], bamboo fibre reinforced cement boards by Sulastiningsih[16] and bamboo fibre/ thermoplastic composites by Jindal[17]. It is generally

accepted that longer fibres obtain an increased network system by themselves and result in increased bending properties of composites[8]. Indian Jute Industries Research Association (IJIRA) first has taken up the work on use of impregnated jute for making of composite boards and moulded products[18]. Indian Plywood Industries Research and Training Institute (IPIRTI) has also done a lot of work on impregnated jute for making of composite along with wood veneer as done by Naha[19]. A patent on the work "Warp and weather resistance solid core wood door and method of making" has been patented on one United State patent [20]. In the wake of disastrous damages caused by earth quake in Gujarat, the Advanced Composite Mission of TIFAC/department of Science and Technology (GOI) has planned to construct 500 low cost shelters made of jute coir composite boards and rice husk particle boards with bamboo mat veneer supported on steel channels and angles[21]. The jute coir composite boards as an alternative to wood products has been developed under the project launched by the advance composite mission in partnership with M/s. Natura Fiber Tech. Pvt. Ltd. Two composite boards, namely, core veneer boards (Jute face veneer alternate core and rubber wood veneer inside) as plywood substitute and natural fiber reinforced boards (Jute face veneer and coir) as MDF substitute, have been developed under the project[21].

The development of natural fiber composite in India is based on a two pronged strategy of preventing detection of resources as well as ensuring good economic return. Polymeric coating of natural fiber with PF and RF (Resorcinol formaldehyde) by different approaches is highly effective in enhancing the reinforcing character showing as high as 20% to 40% improvement in flexural strength and 40% to 60% improvement in flexural modulus.

These modifications improve the wet ability of fiber resin and lead to enhancing bonding.

Phenolic resin is one of the first synthetic resins exploited commercially for the preparation of jute composite products mainly because of its high heat resistance, low smoke emission, excellent fire retardant properties and compatibility with jute fibers.

Moreover, wood batten has been replaced by the use of bamboo and jute stick particle reinforced composite board with low condensed PF resin resol type and its use has been found quite comparable with wooden batten. The use of bamboo and jute stick particle reinforced board as batten in fills and use of impregnated jute fiber felt both to function as glue core and face is a very new concept.

The objective of this study is to utilize jute felt/febric and bamboo for replacing wood stiles, rails and battens in fill to have solid dense hard door and for bonding with wood in flush door manufacture to have all properties of wooden flush door shutter giving a scope of using it as an alternative source of wood.

II. MATERIALS

2.1. Non-woven jute fiber felt

For the work non-woven jute fiber felt of weight 1900-1950 gm/m^2 of 10 mm thickness were used in compact form without any hessian support. The woven jute fabric of weight 400 – 600 GSM and 1.5 mm thickness were also used for this project. Jute felt and febric both are available in the market(collected from Gloster Ltd., 21, Strand Road Kolkata) in roll form and this roll was cut to size as per the dimension required for the study. The strength properties are given in Table 1 and 1A.

Table 1 : Strength properties of jute febric

Sl. No.	Type of jute febric	Thickness	Wt./m^2 (kg./m^2)	Tensile strength (MPa)	Elongation at break (%)
1.	Nonwoven	1.85	0.266	0.064	17.84
2.	Woven	0.88	0.228	0.598	7.69

Test done by Instron Tensile Tester, Model No. 5567

Table 1A: Mechanical properties of bamboo and jute

Type of fiber	Physical properties		Mechanical properties						
	Density (g/m^3)	Diameter (μm)	Tensile strength (MPa)		Young's Modulus (GPa)		Specific Strngth (MPa/gm^{-3}) Ave.	Specific Modulus (GPa/gm^{-3}) Ave.	Falure strain(%)
			Ave.	M.I.[a]	Ave.	M.I.[a]			
Jute	1290[c]	29 – 52	380	152	25.2	7.1	293.2	18.1	1.38
Bundle of bamboo	809[b]	85 - 122	438	221	35.9	13.4	556.2	41.9	1.30

Phenolic resin based jute fiber composite products have been used for quite sometime as certain substitutes for wood. Today, where cost and performance have a high impact on economics, phenolic resin has been accepted in many high performance applications for composite[22].

M.I.(Minimum Individual).

[a] The observations number was about 50

[b] Density of bamboo bundle is referred to Ref.[5].

[c] Density of jute is calculated from the specific gravity referred to Ref.[29].

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[Tensile tests were conducted using a small-capacity testing machine (ASG-H/Ez Test- 00: shimadzu) at 1 mm/ min of crosshead speed].

2.2. Bamboo mat sliver

Bamboo mat(as core) of 1 mm. thickness and bamboo sliver from four side planer machine(as face) of 1 mm. thickness were collected from MMJ Exports Pvt. Ltd. Namsai, Lohit District, Arunachal Pradesh.

2.3. Low condense PF resin (Resol type)

Laboratory scale PF resin for the work was prepared where phenol to formaldehyde ratio was 1:1.8. Prepared resin was diluted as impregnated medium(PF resin of solid content 50%) with water at ratio1:1(control), 1:1, 1:1.5 and 1:2 were used for the impregnation of the jute felt.

2.4. Low condense MF resin

Laboratory scale MF resin for the work was prepared where melamine:formaldehyde:water ratio 1:2:1. Water was mixed initially as water tolerance of MF resin is very low compare to PF resin. Characteristics of the PF & MF resin are given in Table 2.

Table 2: Characteristics of PF & MF resin adhesives.

Resin type	Flow time through B_4(IS:3499) cup in sec.	Water tolerance of the resin (liquid resin: water)	pH	Solid content (%)
PF	16	1:12	9.5	50
MF	17	1:2	8.4	34

2.5. Impregnation of jute felt

Jute fiber felt as shown in Fig.1 required for flush door shutter of specific dimension was taken giving an allowance 1 inch both in the length and width for shrinkage and soaked in medium prepared from the low condensed PF resin for specific time. Resin soaked felt was squeezed in squeezed rollers to take out the excess resin medium and then weighed again. Then it was dried in the open atmosphere or to shorten drying time, dried in reconditioning chamber at 75 – 80^0 C. 80^0 C to bring down the moisture content of the felt by 4 – 7 percent.

Fig.1. Non woven jute felt.

III. EXPERIMENTAL AND FEBRICATION

3.1. Making of bamboo- jute stick particle-reinforced board

Dried jute sticks were disintegrated into small particles and mixed with dried bamboo dust at equal wt. ratio. Suitable hardener 2% was mixed with MF resin adhesive for low temperature curing.

After proper mixing 12% and 15% liquid MF resin on drying weight of particle were mixed thoroughly. Single layer particle board was made in hot press using curing temperature 110^0C, pressure 12 kg/cm^2, and time 25 minutes for 25 mm. thick boards. The strength properties of fiber board greatly influence on fiber sizes. Fiber sizes correlate to total surface area, which affects resin efficiency. In particles, a smaller percentage of fine fractions lowered the strength properties of composites[23]. The strength loss was due to the relatively larger surface area (up to 88% increased surface area) of the fine materials. Test results (IS: 3084-1995) of the bamboo-jute particle board [24,25] are given in Table 3.

Table 3: Internal bond strength of bamboo-jute sticks particle-reinforced composite board

Sample No.	Type of Resin used	% of glue w.r.t. solid particle	Density of the board (kg/m^3)	Breaking Load in (kg)			Avg. breaking load (kg)	IB strength (MPa)
				1	2	3		
1	PF	12	0.593	290	268	319	292.3	1.146
2	PF	12	0.597	301	344	315	320.0	1.255
3	PF	15	0.600	350	373	364	362.3	1.421
4.	PF	15	0.650	372	371	365	369.3	1.448

Tests were done by Tensometer. Make: Kudal instrument, Bangalore, India.

3.2. Manufacture of composite board for Stile and rail

Step 1. Dried impregnated bamboo mat(11 pieces) and woven jute(12 pieces) glue core were assembled alternatively and finally bamboo sliver face for making 25 mm thick board.

Step 2. Stile and rail for frame of different dimension were collected by trimming the board and joined together by metal corrugated flushner.

3.3. Manufacturing of flush door shutter

Over and below the particle board infill composite frame, dried impregnated jute fiber felt was placed and then hot pressed at specific pressure of 14 kg/cm^2 setting the curing temperature at 140°C, putting the assembly in between two steel plates. Time of pressing was 9-10 minutes for making 30 mm thick flush door shutter. Test results (IB strength as per IS: 3084-1995) of the jute felt skinned flush door shutters [26,27] are quite comparable with traditional wooden flush door shutter as shown in Table 4 and Fig. 2 .

Table 4: Internal bond strength of flush door

Dilution of Resin	Sample No.	Internal Strength of Flush Door					
		Wood in fill			Particle Board in fill		
		Load (kg)	IB Strength (MPa)	Average Internal Bond Strength (MPa)	Load (kg)	IB Strength (MPa)	Av. IB Strength (MPa)
1:0	1	500	1.961	1.933	485	1.901	1.889
	2	486	1.906		479	1.878	
1:1	1	482	1.890	1.871	445	1.744	1.725
	2	472	1.851		435	1.705	
1:1.5	1	428	1.678	1.694	391	1.533	1.527
	2	436	1.709		388	1.521	
1:2	1	275	1.078	1.086	262	1.027	0.988
	2	279	1.094		242	0.949	

Tests were done by Tensometer. Make: Kudal instrument, Bangalore, India

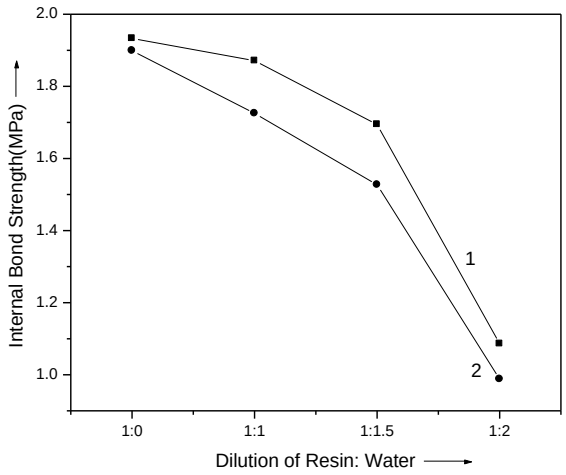

Fig. 2. Internal bond strength of -1) wooden flush door shutter, 2) bamboo-jute composite flush door shutter.

IV. RESULT & DISCUSSION

4.1. Different dilutions of resin medium

Resin medium used for impregnation had been prepared of higher water tolerance and of flow time of 14-16 seconds through B_4 cup (IS: 3944). The reason for using such low condensed resin is to have suitable drainage of resin through the non-woven jute fiber felt medium used for higher retention. Different dilutions of resin medium have been done with a view to ensure economy in the system. If resin medium is used alone, without dilution, then cost of product will be more or less similar to traditional wooden flush door shutter due to high retention of undiluted resin medium in the felt. In this work, dilution level has been restricted to 1: 2 because beyond this level results of the flush door shutter have been found erroneous and at the level, results of flush door shutter are not fully satisfactory.

4.2. Bonding of impregnated jute felt with frame and particle board in fills

From this project work it can be inferred that PF resin impregnated non-woven jute felt can suitably replace the face and glue core veneers from wooden flush door shutter of solid core type. Impregnated jute felt has also been found to bond well with stiles and rails used for making frame and with particle board in fills as per requirement. These findings prove that jute fiber felt has polarity like wooden veneer to bond with stiles and rails as well as batten in fills and also get converted to hard dense body when pressed in hot press and may act as veneer. Moreover, the aqueous resin system utilized for impregnation was found compatible to jute felt as jute has some polar functional groups.

4.3 Thickness compression of resin impregnate jute felt during curing

Jute fiber felt taken after resin impregnation and drying was studied for its compression of at different specific pressures and at fixed temperature of about 140°C. It was found about 75% of the thickness compressed of the jute felt used for the work when hot pressed at specific pressure of 14 Kg/cm^2. Results are given in Table 5 and shown in Fig. 3.

Table 5: Thickness of PF based jute composite samples in m. at different pressure

Pressure (MPa)	Thickness of jute composite samples (m x 10^3)			
	1:0 (control)	1:1 dilution	1:1.5 dilution	1:2 dilution
1.176	2.32	2.18	2.12	2.16
1.373	2.28	2.12	2.11	2.09
1.569	2.26	2.05	2.06	2.04

1.765	2.13	1.94	1.97	1.85

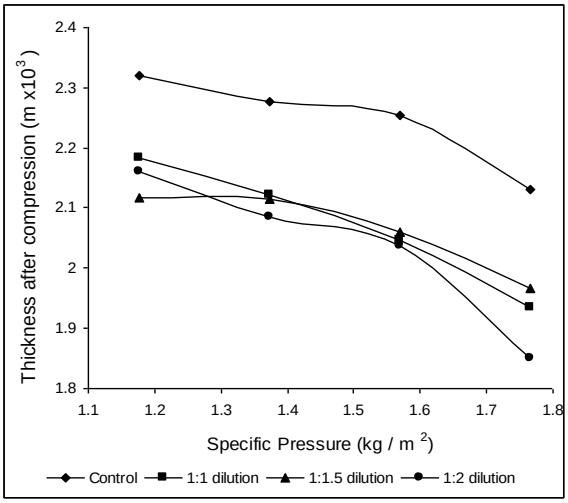

Fig. 3. Variation of thickness of jute composite at different pressure for a specific dilution of resin impregnation.

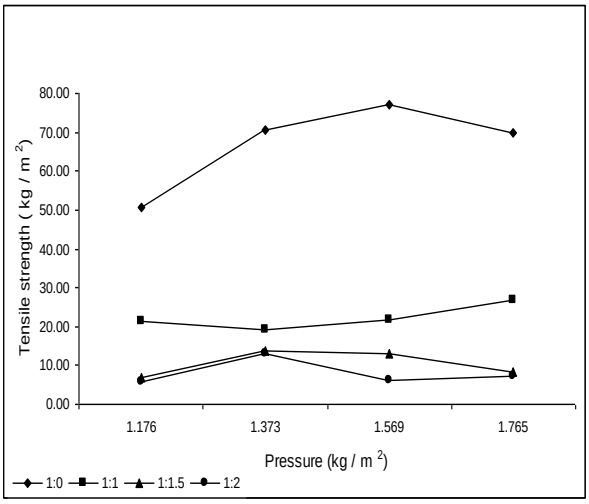

Fig. 4. Tensile strength of jute veneer composite at different pressure for a specific dilution of resin impregnation.

4.4. *Tensile strength of compressed impregnated jute felt*

Tensile strength were conducted by Tests were done by Tensometer. Make: Kudal instrument, Bangalore, India. On the basis tensile strength of jute composite, it may be graded as 1: 0 > 1: 1 > 1: 1.5 > 1: 2. Jute fiber felt was studied for finding its tensile strength[28] after impregnation and subsequent compression in hot press at different specific pressures and at fixed temperature of 140°C. The results are given in Table 6 and shown Fig. 4.

Table 6: Tensile strength of PF resin-jute felt composite veneer

Sample Specification		Sample Code	Tensile Strength (MPa)	Elongation at break (%)
Pressure (kg/cm^2)	Dilution of Resin			
1.176	1:0	A	50.72	1.85
	1:1	B	21.18	1.94
	1:1.5	C	7.05	2.00
	1:2	D	5.75	1.88
1.373	1:0	a	70.72	1.63
	1:1	b	19.08	1.74
	1:1.5	c	13.86	1.74
	1:2	d	13.20	1.76
1.569	1:0	A'	77.25	1.62
	1:1	B'	21.83	1.84
	1:1.5	C'	13.20	1.78
	1:2	D'	6.14	1.77
1.765	1:0	a'	69.80	1.83
	1:1	b'	26.93	1.85
	1:1.5	c'	8.37	1.94
	1:2	d'	7.32	1.86

Tests were done by Tensometer. Make: Kudal instrument, Bangalore,India

4.4. *Finishing of flush door*

From the above gradation and from the look it may be said that the product needs proper finish with increase of dilution to attract markets. Without any finish, colour of flush door shutter is brownish black and the colour tones differ with dilutions as shown in Fig. 5.

Fig. 5. Picture of flush door without any painting or lamination.

To break the monotony of the same colour and lack of uniformity of the colour spread on the surface, proper finishing of the surface of the flush door shutter is needed. Therefore to make the product appealing to the market the product requires either colour finish or use of plastic lamination available in the market as overlay as given in Figure. 6.

Fig. 6. Picture of flush door after lamination.

4.5. Physico-mechanical strength of Flush door

Flush door shutters were subjected to evaluation as per IS: 2202 (Part -1) 1999, and found to conform to all tests as laid down in the said specification up to dilution level 1:1.5 as given in Table 7.

Table 7: Test results of flush doors as per Indian Standard, IS: 2202 (Part – I)

Four (4) sample of flush door shutter of different resin dilution are tested, Resin used: PF; Face: Impregnated jute fiber skin; Core: bamboo and jute stick particle-reinforced composite board; Ratio of resin: 1:0, 1:1, 1:1.5, 1:2

Sl. No.	Tests	Requirement as per IS: 2202 (Part – I)		Results			
				Resin : water (Used for impregnation of jute felt)			
				1 : 0	1 : 1	1 : 1.5	1 : 2
1	a) Dimensions, mm	Height :Tolerance: ± 5 mm	On nominal dimensions	1905mm	1905mm	1905 mm	1905 mm
		Width : Tolerance: ± 5 mm		695 mm	695 mm	695 mm	695 mm
		Thickness: Tolerance: ±1mm		25.2 mm	25.4 mm	25.5 mm	25.8 mm
	b) Squareness	Variation in thickness between any two points – not more than 0.8mm		Nil	Nil	Nil	Nil
		Deviation not more than 1mm per 500 mm length		Nil	Nil	Nil	Nil
2	General flatness	Twist, Cupping & Warping not greater than 6 mm		3 mm	4 mm	4 mm	5 mm
3	Local planeness	Depth of deviation not greater than 0.5mm		No Deviation	No Deviation	No Deviation	No Deviation
4	End immersion test	No delamination(del^{n})		No del^{n}	No del^{n}	No del^{n}	No del^{n}
5	Glue adhesion test	No delamination		No del^{n}	No del^{n}	No del^{n}	del^{n}
6	Knife test	Minimum pass standard		Minimum pass standard	Minimum pass standard	Minimum pass standard	Minimum pass standard
7	Impact indentation test	No cracking, tearing or delamination		Conforms	Conforms	Conforms	Conforms
		Depth of indentation not greater than 0.2 mm		Nil	Nil	Nil	0.05 mm
8	Slamming	No visible damage after 50 drops		No damage	No damage	No damage	Roughness on surface
9	Flexure (deflection in mm)15 mts after loading 50 Kg	Deflection at maximum load not greater than 1/30 of length & 1/15 of width, whichever is less.		13 mm	13 mm	15 mm	18 mm
	3 mts after load removal	Residual deflection not greater than 1/10 of maximum deflection		1 mm	1 mm	1 mm	1 mm
10	Shock resistance Soft & light body impact,	No visible damage		No damage	No damage	No damage	No damage
	Soft & heavy body impact	No visible damage		No damage	No damage	No damage	No damage
11	Buckling (deflection in mm)	No deterioration(detn.)		No detn.	No detn.	No detn.	No detn.
	After 5 mts of 40 Kg loading	Initial deflection not greater than 50mm		23 mm	25 mm	29 mm	37 mm
	15 mts after load removal	Residual deformation after 15 minutes of unloading not greater than 5 mm.		1 mm	1 mm	1.5 mm	2 mm
12	Edge loading (deflection in mm)	Deflection at max. load not greater than 5 mm		0.38 mm	0.41 mm	0.45 mm	0.53 mm
	After 15 mts of 100 Kg loading	Residual deflection after removal of load not greater than 0.5 mm		0.04 mm	0.04 mm	0.48 mm	0.07 mm
	3 mts after load removal	Not more than 2mm during loading		No lateral buckling	No lateral buckling	No lateral buckling	No lateral buckling
	lateral buckling	No residual buckling after load removal		No residual buckling	No residual buckling	No residual buckling	No residual buckling
13	Screw withdrawal strength, N	Not less than 1000		E: 3760N S: 4400N	E: 3650N S: 4150N	E: 3610N S: 4100N	E: 3550N S: 3950N
		Surface condition: No visible damage to the surface either by delamination or extra chipping off		No damage to the surface	No damage to the surface	No damage to the surface	No damage to the surface

14	Varying humidity test	No visible warping, twisting or delamination.	Conforms	Conforms	Conforms	Conforms
		Maximum departure from the general planenes not more than 1 mm	Conforms	Conforms	Conforms	Conforms
		Recovery – At least 90% of the change in dimension.	Conforms	Conforms	Conforms	Conforms
15	Misuse	No permanent deformation of the fixing or any other part of the door set in hindering its normal working after the test.	No defor-mation	No defor-mation	No defor-mation	No defor-mation

Tests were done by Universal Testing Machine (Ten ton): by Kalpak, Gujarat,India

V. CONCLUSION

1) Flush door shutter replacing face and glue core by impregnated jute fiber felt conforms to the relevant specifications [BIS: 2202 – (Part-I) – 1999] and finish can also be given to this door like wooden flush door shutter with colour paint or by lamination.
2) The dilution has great effect on surface looking, thickness swelling, tensile strength and internal bond strength.
3) Jute fiber felt was studied for finding its tensile strength after impregnation and subsequent compression in hot press at different specific pressures and at fixed temperature. The results indicate that jute felt is a good natural substitute for wooden veneer.
4) Internal bond strength of flush door is given in Table – 4. Such decreasing effect of IB strength arises probably due to decrease in solid content in the impregnating medium.
5) The fire retardant property can be impart easily during resin impregnation both jute and bamboo fiber/particle.
6) The study concluded that wood substituted bamboo jute composites could be an ideal solution with ever depleting forest reserves where utilization of fast growing renewable resources will be beneficiary for plywood panel industries to meet the challenges during scarcity of wood and reduce the landed cost of imported wood materials.

VI. ACKNOWLEDGEMENT

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