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Sustainable Development of Particle Board from Lignocellulosic Agri Waste (*Corchorus capsularis*-Jute)

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ABSTRACT

Background: Large quantities of forest, agricultural and industrial lignocelluloses residues are available in the countries which are not finding any economic use till date except as industrial or domestic fuel. Some of these waste materials could be utilized for the preparation of particle board which could substitute the solid wood for various purposes and thus help in the conservation of depleting forest resources.

Methods: Jute stick is the one such waste material available in India about 50-55 lakh tones per Year. Keeping this in view, the suitability of jute-stick for making particle board will be evaluated in this study. The sticks were analyzed for the physical and mechanical properties of Jute sticks. Based on the material properties, it necessitated the physical modification of the jute stick particles to activate the surface for better adhesion.

Result: Jute sticks were crushed followed by pulverizing to get the particles of required size formation have been optimized for making particle board of density 700-850 kg/m^3. The implementation of this technology will encourage the efficient use of agriculture byproduct as a sustainable resource for commercial production as well as to aid in building sustainable cities and communities, in order to meet sustainable development goals which will in turn profoundly transform our world at large.

Key words: Jute stick, Particle board, Solid wood, Sustainable cities and communities, Sustainable development goals, Urea formaldehyde resin.

INTRODUCTION

The particle board in India was started in 1950 and as on date there are approximately 23 units functioning. Particle boards have been conventionally manufactured using wood chips. Since wood raw material is becoming scarce, there is a need to source raw material from other natural renewable fiber. In India, huge quantity of agricultural residue is generated every year which has very little use. Agro materials like bamboo, bagasse, rice husk, cotton stalk, jute stalk can be suitably used for the manufacture of particle board. Use of agro-waste in PB manufacture has dual benefits (Harshavardhan and Muruganandham, 2017; Muruganandam *et al*., 2016; Sainath *et al*., 2015).

FAO's Global Forest Resources Assessment estimated that the global forest area was 4.033 billion hectares where net de-forestation at the global level occurred at the rate of 0.14% per year between 2005-2010 according to FAO (2012). One of the above reasons isn't optimized utilization of wood so that there were in excess of waste wood. According to Pemkab (2012) there are 64.546 m^3/year of wood waste obtained by wood industries in Jepara Regency. In recent years, wood waste and agro fiber waste are apparently lignocellulosic materials that are potential to be converted into eco-products. They contain cellulose, hemicelluloses, lignin, ash, water and so forth. The eco-product will be renewable, recyclable and biodegradable products caused it comprises natural fibers (Pan *et al*., 2012). Yet, wood waste and agro-fiber waste have used to produce renewable fuel, bricket, animal feed, fertilizer and soon. In addition, agricultural residues from sunflower stalks are used the least for animal feed or as a source of fuel (Khristova *et al*., 1996). As part of lignocelluloses from wood forest products, used paper taken from magazine, tissue, newspaper and sludge have been narrowly developed by industries to produce wood composite. The above case is a demand for substituting solid wood as timber resources in natural forests decline. They are used to typical applications as flooring, wall and ceiling panels, office dividers, bulletin boards, furniture, cabinets, counter tops and desk tops (Wang *et al*., 2008).

In nature, wood and agro-fiber are naturally occurring composites consisting of cellulose fibers (reinforcement) in lignin (matrix). Composites having superior properties such

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as high modulus, and creep, impact and heat resistance have replaced steel, concrete and wood in transportation, building/construction, engineering, marine, aerospace and chemical industries (Kumar *et al*., 2011, Onyeagoro 2012).

Jute is a major crop of eastern India and is cultivated mainly in the state of West Bengal, Bihar, Assam, Orissa and Utter Pradesh. Many researchers have been carried out the work related to jute-based products and studied their different properties (Bhaduri *et al*., 1992; Das *et al*., 1987; Kabir *et al*., 2013; Nayak and Roy, 2011; Rahman *et al*., 2016).

Goswami prepared the jute fibre glass sheet for plywood and particle board. They concluded that the prepared panels exhibit good mechanical properties at little cost (Goswami *et al*., 2008). They developed the high-performance jute stick binderless particle board with particle ratio of 50:50 (fine: coarse) at 220°C temp and 6 min pressing time (Nitu *et al*., 2020). The low-density cement bonded composites panels were synthesized from expended polystyrene beads and jute stick particles and studied the physical and mechanical properties. They found that mechanical properties increased with waste jute fibres (Rana *et al*., 2019).

The ultimate aim of this study is to develop low cost Medium density particle board from jute stick which would substitute the expensive wood products. Therefore, the purpose of this study was to provide initial information about the technical performance of particleboard manufactured from Jute Sticks. Mechanical and physical properties were investigated and compared to those of stated in the standards.

MATERIALS AND METHODS

The jute sticks of various length and sizes were sent by the sponsor. The sticks received from the sponsor were analyzed for the physical properties of jute sticks. The moisture content and density of the jute sticks were using oven dry method for moisture content and water displacement process for density measurements. The ash content in the jute sticks were measured by taking known weight of the jute stick material in a platinum crucible of 20 ml capacity Ignited the crucible containing the sample for some time using burner till all fumes escapes and then keep it in a muffle furnace at a temperature of 650-700°C for complete charring to ash. After completed cooling the weight is taken. Based on the initial weight taken and the weight obtained after complete charring, the ash content was calculated. The studies revealed the properties as given in Table 1.

Preparation of jute sticks raw material

The jute sticks used in the study were cut into sizes of required dimensions and sent to hammer mill for sizing. Pulverizer available in the institute was utilized to pulverize the hammered particles to get the required size of the particles.

Based on the initial study, it necessitated the physical modification of the jute stick particles to activate the surface for better adhesion. Jute sticks were crushed followed by pulverizing to get the particles of required size for the manufacturing of single layered particle board.

Further the particles were dried to get the moisture content of 3-4% for the manufacture of jute stick particle board. It has been observed that when particles were being reduced to size of 1mm for the face layer the particles were just forming powder. As the bulk density of the jute was very low, Particle yield for core was very less compared to the particle yield of face.

Feeding rate

Chips can be stored in silos for feeding into hammer mill. Where storage system is not provided in some small capacity plant, the feeding into chipper should be synchronized with the capacity of the hammer mill, so that the storage box above the hammer mill is not blocked due to excess material.

Hammer process and optimization of particle size

Since bulk density is low and difficult to get uniform density in Particle. In this stage manually hammered the chopped Jute stick straw of size of 1″-2″ length to deform the raw material before feeding to the chipper section.

Optimization of particle size is also required for finding out resin requirement for adequate bonding. As a general rule, more surface area is being generated for thin, slender particles for face from unit weight of wood than that for core.

As a general rule, longer and thinner particles produce a board with high bending strength and higher dimensional stability. Shorter and thicker particles produce a board with lower bending strength, low dimensional stability and higher internal bond strength. The same principle was used while making three layered particle board.

The Jute stick particles sizes were optimized to standard sizes for face < 1 mm and for core particles $>1 \leq 3$ mm. The sizing of the particles required hammering/ crushing rather than the usual chipping of particles and then sent to the pulverizer for converting into required size for face and core separately.

Moisture content of jute sick particle

Jute sticks as a raw material is a low-density porous material and dried out rapidly and did not require further drying to chip. Hence this material is below then 20% moisture content and produces higher quantity of powder while processing in mill.

When bigger dimension Jute Sticks raw material are used as raw material, these may be cut to smaller dimension with the help of chopper before feeding into chipper. The

Table 1: Properties of jute sticks.

Properties	Value
Moisture content	4.5%
Ash content	0.4%
Lignin content	31.26%
Density	600 kg/m^3

parameter in the industrial oven for drying was standardized to bring down the moisture to 3-4%. The moisture content of the particles was analyzed on online moisture meter as higher moisture creates problem while bonding.

Binder: Urea formaldehyde resin

Conventional Urea formaldehyde resin was used for preparation of particle board with Jute stick particle board. For the preparation of resin higher molar ratio of urea/ formaldehyde used at initial stage [mole ratio 1:1.72 or weight ratio of urea: formalin = 1:2.25]. 225 parts of formalin is first charged into the reactor. The reactants are allowed to react at pH 8.0 (the pH of formaldehyde was adjusted to 8 by using caustic solution before adding urea and melamine). 90 parts of urea weighed was added to the reactor containing formalin. 10% melamine was also incorporated after the addition of urea. The pH of the final reactant mixture was maintained around 7.5-8.00. The reactant mixture is heated and condensed at 90±2°C for about 90 minutes. Then the pH is reduced to 4.5-5 by using glacial acetic acid and the condensed at 90±2°C until the precipitate is formed (Precipitation is checked by dropping a drop of resin into the beaker containing water). pH is then raised to 7.5 - 8. The resin is cooled and remaining second urea of 10% was added and the resin is cooled to room temperature. The flow properties are checked.

For the present work, both melamine and urea have been used as scavenger to mop free formaldehyde from UF resin. In fact, the first charge is consisted of 90 Kgs. Urea and 10 Kgs. Melamine. 10 Kgs. of urea was used as second urea added after the reaction was arrested. The flow properties of resin are given in Table 2.

Storage of resin

Since resin is the binder for the particles in particle board, it is necessary to use resin of uniform quality to obtain uniform bond quality. It is therefore necessary that the resin in each batch is uniform with respect to viscosity, water tolerance, solid content, pH.

Since all synthetic polymers, which makes the backbone resin, increases its viscosity rapidly as temperature increases, the resin should be made such that it has identical viscosity and be stored at low temperature so that increase in viscosity is negligible.

The flow properties of the glue are being dictated by the viscosity of the resin, it is necessary that resin of uniform viscosity be used. Otherwise, if resin of different consistency is being used, the quantity of resin passing through the nozzle will vary under same condition of pressure and temperature. Storage of resin below 25°C is ideal.

Blending

It is well known that total surface area of the fine particles used as face layer is much larger than that of coarse particles used for core in making three layered particle board. Consequently, finer particles will consume more resin than core particles.

For the present study, a continuous blender has been used. Hence, two separate blenders for face and core have been used. Although fine particles are being used for face and coarse particles are being used for core. Therefore, proper sieves are used to segregate the non-uniform size of particle for face and core layer for uniform distribution of particle. This will not only improve the surface finish but also physical and mechanical properties PB.

Resin uses for face and core particles

100 parts oven dry face particles	12 parts solid resin.
100 parts oven dry core particles	14 parts solid resin.

The adhesive formulation is given in Table 3.

A shaft and shovel type blender are being used for blending resin and additive mix with furnish. The objective of blending is to achieve an even and uniform distribution of resin over the particles. Hence, a central nozzle spray gun is used to mix the glue on to the particles. Accordingly, travel time of particles in blender is adjusted [in minutes] to obtain for uniform mixing.

Mat forming

Table 2: Flow properties of resin

Particulars	Results
Flow time of resin in B4 flow cup	21 -24 seconds
Water tolerance	1:3
Solid content	50%
Gelation time	62 seconds
Shelf life	One month

Table 3: Adhesive formulation.

Particulars	Face particles	Core particles
Liquid MUF resin	100 kg	100 kg
Wax 1% emulsion	1 kg	1 kg
Liquor ammonia	400 ml	700 ml
Hardener (Ammonium chloride)	400 gm	700 gm
Water (mixing of hardener)	200 gm	280 gms
Particle flow rate	1.5 kgs/10 sec	2.5 kgs/10 sec
Glue flow rate	400 gms/10 seconds	470 gms/10 seconds

For the present work, a two-roller mat former has been used. Certainly, it very important part of methodology to assess the uniformity in physical and mechanical properties of final board.

Pre-pressing

A Single daylight Pre-press of platen size 1.4 m × 0.72 m was used for pre-pressing the mat assembly. Pre-pressing was done for time duration of 1 min at a specific pressure of 6 kg/cm^2. The thickness of mat after Pre-pressing was in the range of 40-50 mm for final board thickness of 12 mm.

Hot-pressing

The UF resin was blended with the particles and the adhesive formation have been optimized for making multi layered particle board of density 700-850 kg/m^3. The hot press parameter for manufacturing 3 layered/multilayered particle boards were worked out *i.e.*, hot press temperature of 165±5°C, specific pressure of 25 kg/cm^2 for 6 minutes in compression cycle and 12 kg/cm^2 for 6 months for curing cycle for a board of 12 mm thickness. The boards were free of any visual defects. The panels were then stabilized for 24-48 hours to attain equilibrium moisture (Fig 1).

After stabilizations the panels were trimmed and cut to sizes for evaluating the physical and mechanical properties as per IS: 3087: Specification for Medium Density Particle Board multi-layered grade 2 (Indian standard 3087, 2005). The properties of the board conform to the requirements of IS: 3087. The same formulations were repeated for checking the consistency in the results and observed that the results obtained were consistent and meets the requirement of grade 2 multilayered medium density particle board as per IS:3087.

RESULTS AND DISCUSSION

Based on the lab and pilot scale study, it necessitated the physical modification of the jute stick particles to activate the surface for better adhesion. Jute sticks are crushed followed by pulverizing to get the particles of required size for the manufacturing of multi layered particle board. Jute particle board is manufactured using 10% urea formaldehyde resin content. The panels are pressed at a temperature of 165°C with pressure of 25 kgs/cm^2 for compression cycle for a period of 7 minutes and later the curing cycle of 12 kgs/cm^2 for a period of 5 minutes. The curing time was based on the final thickness of the boards. In this case the materials achieved requisite compression without loss of raw material quantum used. This method is necessary so as to make the fiber of jute particles loosen

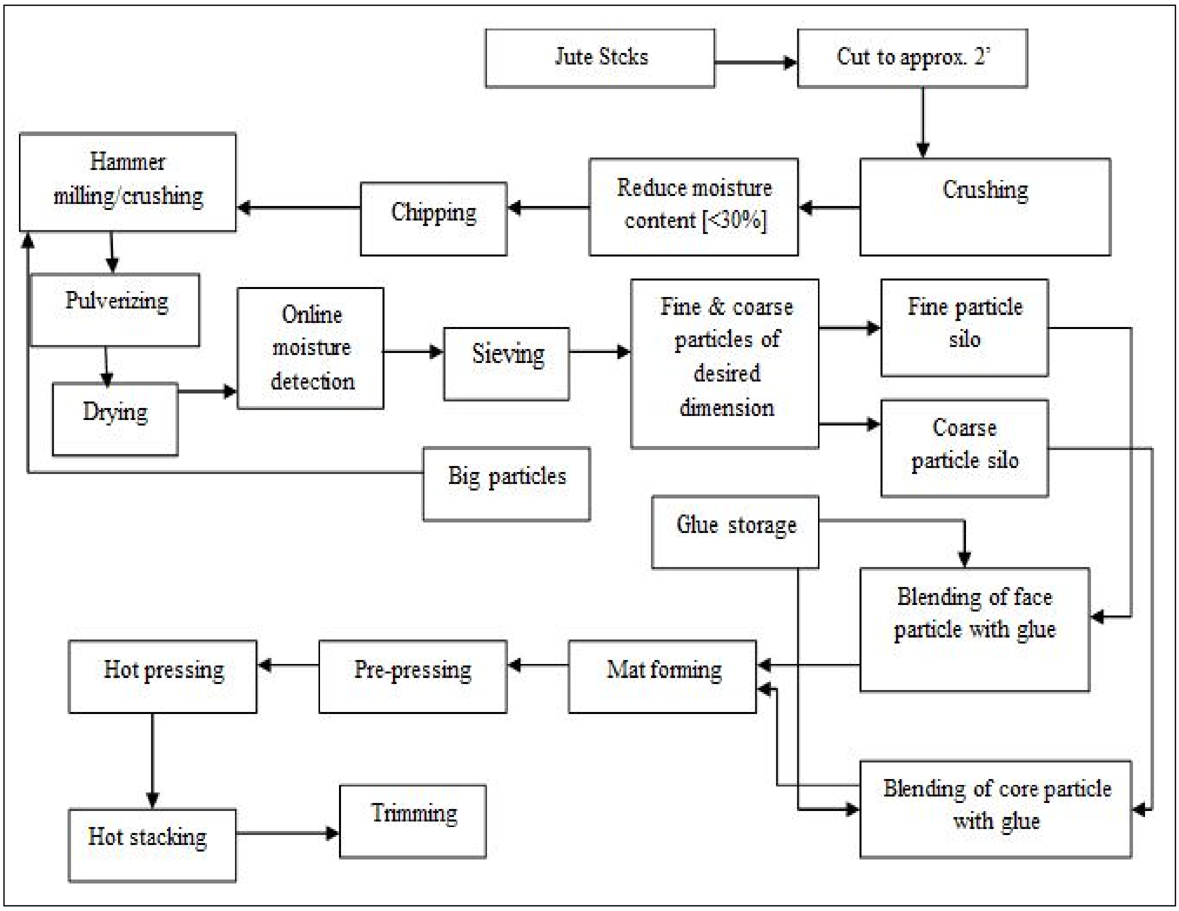

Fig 1: Flow Chart for manufacture of particle board from jute sticks.

Table 4: Physical and mechanical properties of Jute stick particle board.

Tests	Prescribed Value	Results
Density		
a) Average, Kg/m^3		
b) Variation from mean den, %	500-900±10	1104±7.32
Moisture content, %		
a) Average		
b) Variation from mean m c	5 -15±3	6.04±0.9
Water absorption, %		
a) After 2 hours soaking	Max. 40	9.5
b) After 24 hours soaking	Max. 20	14.4
Swelling due to general abs (after 2Hr. soaking), %		
a) Thickness	Max. 12	4.2
b) Width	Max 0.5	0.05
c) Length	Max 0.5	0.05
Modulus of rupture, N/mm^2		
a) Average	Min. 11	24.1
b) Min. Individual	Min 10	22.8
Modulus of elasticity, N/mm^2		
a) Average	Min. 2000	3710
b) Min. Individual	Min. 1800	3563
Tensile strength perp to surface (Internal Bond strength), N/mm^2		
a) Dry Test	Min. 0.3	0.70

and easily interacts with the resin. Boards made are being evaluated for physical and mechanical properties as per IS; 3087 (Specification for Particle board). The test results are given in Table 4.

As per the Table 4, it is found that the average density of jute stick particle is 1104 Kg/M^3 which is 22.6% higher than the required value. High density of panel is due to hammering of chopped jute sticks for uniform density of particles and also, it's required for optimizing the process parameter for the manufacturing.

Moisture content % of the final board is very important property in this study for board quality particularly to bond quality of products. Hence, utmost care has been taken for moisture content of products during process as jute sticks are porous in nature and having property to absorb the moisture from environment. Moisture content percentage obtained value is 6.04% which is in the range of required standard.

In water absorption percentage test, for 2 hours and 24 percentage soaking tests, the average obtained values are 9.5% and 14.4% which show that these values are meet the required specification and don't gain the weight during test, this is due to proper bonding of adhesive and surface modification jute sticks.

Swelling due to general absorption tests after 2 hours soaking test, the changes in thickness, width and length are 4.2%,0.05% and 0.05% respectively and obtained results are 65% lower in thickness swelling while width and length value are 90% lower than the required value and these results are in acceptable range as per standard. The reason of improvement in the properties are same and explained in water absorption test percentage test.

In observation of mechanical tests, from Table 4, specific to Modulus of Rupture in bending, Modulus of Elasticity in bending and internal bond strength are also conducted as per IS 3087: 2005. It is observed that average value of MoR is 24.1 N/mm^2 which is 119% higher than the required value while minimum individual value is 22.8 N/mm^2 and this value is also 128% higher than the required value, while Modulus of Elasticity test, average value and minimum individual values obtained are 3710 N/mm^2 and 3563 N/mm respectively and these values are 85.5% and 97.9% respectively and higher from the prescribed value. These high tests value is due to the enhancement density of jute sticks particles and it is further refined while optimizing the process parameter during manufacturing process.

Internal Bond (IB) strength test of any lignocellulosic board is mainly guided by resin quality. In this study IB test is carried out in dry stat and the average results from sample boards are 0.7N/mm^2 which 133% higher than the required value. This excellent bond quality is due to proper UF resin formulation and addition of 10% melamine and proper uniform blending of particles which attributes to Excellent internal bond strength of jute stick particle.

CONCLUSION

Investigations were carried out to find the suitability of jute sticks for the manufacture of particle boards. The hot press parameter for manufacturing 3 layered/multilayered particle boards were worked out *i.e.*, hot press temperature of

165±5°C, specific pressure of 25 kg/cm^2 for 6 minutes in compression cycle and 12 kg/cm^2 for 6 months for curing cycle for a board of 12 mm thickness. From the test results of particle board made from Jute Sticks, it is found that the Jute sticks is suitable for the manufacture of flat pressed three-layered Grade-2 (FPT-2) Particle boards and meets the requirements as prescribed in IS 3087: 2005 "Specification for Particle Boards of wood and other lignocellulosic materials (Medium Density) for general purpose" for Grade 2 Medium Density Particle board.

Conflict of interest: None.

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