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INFLUENCE OF RICE STRAW AND WOOD FIBER COMBINATION ON PHYSICAL AND MECHANICAL PROPERTIES OF RICE STRAW PULVERIZED COMPOSITE BOARD

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ABSTRACT

The production of particleboards from various kinds of ligno cellulosic materials are successful on commercial scale in various parts of the country. However, much success is not seen in use of crop residues for particleboards. Rice straw and wheat straw are one such materials that are abundantly available in India that can be used to produce particleboard. The present work investigated the effect of Rice straw particles and wood fibers combination on physical and mechanical properties of the composite board. The pulverized rice straw composite boards were produced with three different composition of rice straw material (100 %, 70 %, 50 %) and wood Fibers (0 %, 30 %, 50 %). Melamine Urea Formaldehyde (MUF), Phenol Cardanol Formaldehyde (PCF), Blocked Isocyanate resin combined with PCF (BPCF), Blocked Isocyanate combined with Urea Melamine Formaldehyde (BUMF) and Blocked Isocyanate combined with PF (BPF) resins were synthesized. The resin system (10%,12%,14%) with requisite additive was admixed with rice straw and wood fibers. According to the resin system employed, the hot press temperature, specific pressure and curing time were worked out for compression of the boards. The boards were produced with 780 - 850 kg/m^3 nominal density and prior to testing, the test specimens were exposed to an atmosphere maintained at a relative humidity of 65 ± 5 percent and at a temperature of 27 ± 2 °C until their masses are nearly constant. The boards made were subjected for evaluation of physical and mechanical properties according to IS 3087. It was found that the Rice Straw particles with Wood Fibers of 50-50 combination bonded with PCF and also with MUF adhesive of 12 % resin solids confirms to the requirement of physical and mechanical properties as per IS 3087 particleboards of wood and other lignocellulosic materials (medium density) for general purposes Specification. Comparison with resin for hybrid boards of rice straw particles with wood fiber, BPCF has shown excellent properties than BPF and BUMF. The study indicated that increasing the percentage replacement of wood fibers with rice straw particles by more than 50 % decreased the internal bond strength. It can be concluded that rice straw pulverized particleboard can be successfully made with the combination of 30 % - 50 % wood fibers using PCF resin or BPCF resin.

Keywords: Composite, particleboard, rice straw, resin, wood fibers, *Eucalyptus.*

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INTRODUCTION

India is a rural civilization, known for diverse farming practices based on the agro-climatic zones. Rice and wheat cropping patterns are extensively practiced farming systems in the northern parts of India. Rice straw production in India is estimated to be around 126,6 MT, equal to the average harvest index of 0,45 (Singh 2016). However, due to a lack of economically feasible rice-straw utilization choices, farmers in India, particularly in the north-western regions of Punjab, Haryana, and western Uttar Pradesh have been forced to burn the straw in their fields.

Faced with worldwide shortages of forest resources, environmental pollution and waste of biological resources resulting from field burning of rice straw and other agriculture residues, there has recently been a revival of interest in using rice straw and other agriculture residues to produce building materials including composite panels (Zheng *et al*. 2007, Ye *et al*. 2007).

The scarcity of the quality timber materials for panel products in India has led to a rising demand and competition for wood residues by the paper industry and the rapidly growing composites industry. This makes the use of alternative fiber such as agricultural/crop residues more attractive and feasible. In addition, the move to find substitutes for solid wood has been stimulated by factors, such as diminishing resource quality, rising timber prices and growing world demand for wood products. Interest in using Rice straw mixed with low quality bamboo or other bio-based residues to produce composite panels have increased recently (Hiziroglu *et al.* 2008).

Although the price of agricultural straw is very low compared to other lignocellulosic materials, the composites fabricated using rice straw pocess good mechanical properties (Ghazilan *et al*. 2016, Shang *et. al* 2012, Lecompte and Le-Duigou 2017) The composites fabricated using cement based materials and rice straw fibers with flame retardant treatment showed significant improvements on thermal stability and flame retardancy (Jiang *et al*. 2021). The fiber composition and the color of the wheat straw change during the long storage of wheat straw. Mixtures of rice husks with wheat straws were used to produce pellets. It was determined that the biomasses blends resulted in improved quality and combustion characteristics of the pellets (Mao *et al.* 2021, Rios-Badran *et al.* 2020).

It has been reported that straw was not utilized for board production earlier with the use of conventional formaldehyde-based resin as it leads to poor bonding due to the presence of a layer of wax/silica around its Fiber cells. The bonding properties were improved by application of high shear forces in a refiner and an extruder by applying high shear forces, the wax and silica layer is destroyed and allows bonding with formaldehyde-based resins. Although, the swelling figures were improved, the 24 hour swelling properties for particleboards could not confirm to the requirements of European standards (Mantanis *et al*. 2000).

The Poly Methylene Di Isocyante (PMDI) resin or a combination of Urea Formaldehyde (UF) and PMDI resin system in the production of straw based particle board results in good quality surface layers (Mo *et al.* 2005).

Composite boards of specific gravities of 0,4 and 0,6 made using rice straw and wood particles were found to be suitable as a sound absorbing insulation material in wooden constructions (Yang *et al.* 2003). Factors such as particle size, raw material and the resin type employed for bonding has significant impact on physical and mechanical properties of particleboards (Li *et al.* 2010). The thickness swelling, water absorption, and linear expansion of particleboard decrease with increasing particle size. Compared with pMDI resin-bonded panels, the rice straw particleboard bonded using urea-formaldehyde resin exhibits much poorer performance. The waxy coating of rice straw hinders the bonding of particleboard made using conventional UF resins without physical or chemical modifications of rice straw (Papadopoulous 2007).

In the production of straw based particle board reinforcement material, the fractions employed and the technique adopted to fabricate the composites have huge impact on the mechanical properties of the panels (Sudhakar and Srinivas 2014) .

It has been reported that the utilization of 23,97 million tonnes of rice straw per year in bio composites making can economize on 1,61 million hm^2 of the forest, and decrease the emission of CO_2 by 63,76 million tonnes. Bo *et al.* (2022) have studied the performance and environmental implication assessments of green bio-composite from rice straw and bamboo.

Anvar *et al.* (2020) have studied the interaction of adhesive with the substrate surface in a new composite material based on modified gypsum and treated rice straw and concluded that the moisture sorption rate of untreated straw specimens is 22 % higher compared with the treated straw specimens and makes up 3,5 % at a relative air humidity of 60 %.

Vijaykumar *et al.* (2020) have utilized groundnut shell and rice straw reinforcement with polypropylene to make hybrid polypropylene composite for civil structural application . This material is found to be cost effective and eco-friendly material as an alternative to the existing gypsum boards

The factors of alkali treatment and untreated rice straw on the bending strength of the rice straw reinforced geopolymer composites were investigated. (Huang *et al*. 2021). The results indicated significant improvement in the bending strength of the geopolymer for both the untreated and alkali treated rice straw. However, the alkali treated rice straw exhibited a higher enhancement effect. The thickness swelling rate and water absorption of these two composite materials increased with the increase in the fiber content.

A new process for the manufacture of straw-reinforcing thermoplastic composites study revealed that the structure improved the LLDPE matrix' s reinforcement. The Dynamic mechanical analysis, differential scanning calorimetry, and thermogravimetric analysis have indicated that the composites manufactured by the wrap and twist method reduced viscous deformation and increased rigidity (Xu *et al*. 2022) .

The investigation on the the mechanical properties of rice straw fiber reinforced polypropylene composites at different weight fractions (0 %, 5 %, 10 %, 15 %, 20 % and 25 %) of rice straw fibre has indicated that there was no significant change in the bending and impact properties with 5 and 10 % of polyrpropylene combination. However, the tensile strength decreased with increase in the composition of polypropylene addition (Raju *et al*. 2022).

The impact of rice straw particles (RSp) percentage incorporation with a constant fraction of Furcraea foetida (FF) shows that a drastic reduction in the density of the samples with the addition of 15 wt.% of RSp The water absorption of the samples increased with increase in the rice straw particle concentration. The RSp reinforcement in the chopped form created intermediate stress concentrating zones which resulted in the decreased mechanical properties of hybrid composites (Madivala *et al.* 2023)

Recently the use of two or more natural fibers to fabricate hybrid composites are popularly practiced for improving the functionalities of the composites. Various studies have revealed that the low strength fibers can be blended with fibers of other gradient with higher mechanical properties to fabricate a composite with improvement in the mechanical properties. Studies on hybrid hazelnut/walnut shell-filled acrylonitrile butadiene styrene composite showed better tensile (σt: 34 MPa) and flexural (σf: 59 MPa) strength compared to composites made with individual fibers (Kuram 2022).

The possibility of producing panel boards from groundnut shell (GS) and rice husk (RH) using modified adhesive system were studied (Banjo *et al.* 2022). The blending percentages of groundnut shell and rice husk has been varied in the range of 30 %, 50 % and 70 %. In addition, only GS and RH panels have been made using 100 % of the materials. The test results reveal that the GS and RH does yield good adhesion resulting in poor mechanical properties. Agirgan *et al.* (2022) It has been determined that the combination of rice straw and polylactic acid (PLA) composite yielded good thermal insulation (0,01618 W/m K) and sound absorption coefficient (0,99) and suggested its utility for civil applications.

The properties of the composites produced using polypropylene (PP) and Wheat Straw(WS) waste as filler by varying the particle size and percentage of wheat straw was investigated. (Singh *et al.* 2023) It has been reported that the composite made only with polypropylene yield best density, water absorption, tensile and impact strength properties but poor for WS-containing composites.

The main objective of this study was to explore the suitability of manufacturing Rice straw composite board using rice straw particles of size 1mm to 5mm with and without replacement of wood fibers. The effect of different composition during the bonding with PCF, MUF and combination of isocyanate blocked resins with PCF, UMF and PF as a binding material on the physical and mechanical properties of the boards were determined.

MATERIALS AND METHODS

Material

the rice straw and *Eucalyptus* wood fibers used in this study were sourced from M/s. Madhya bharat papers limited, Birghani village, Champa, Janjgir-champa, Chhattisgarh.and M/s. Green ply industries limited, Rudrapur, Udham singh nagar district, Uttarakhand.

Melamine Urea Formaldehyde resin (MUF), Phenol Cardanol Formaldehyde resin (PCF), PF and blocked isocyanate resin were synthesized at the laboratory of Indian Plywood Industries Research and Training Institute (IPIRTI), Bangalore. The isocyanate resins were obtained from M/s. Covestro India Ltd., Mumbai and the other chemicals were sourced from M/s. AIC Enterprises, Bangalore, India.

Material processing and characterization

The research experiments were designed by keeping in view the basic chemical characteristics of the rice straw. Rice straw being a highly siliceous material, the resin developed, and the particle processing parameters have been optimized to have good bond integrity with each particle even in presence of small traces of silica in the material.

The rice straw collected from the industry were chopped to required size and then processed through hammer mill and pulveriser to obtain the size of 1 - 3 mm in length. of the particles. The moisture content in the Rice straws was maintained at 3 % - 4 %. The fine dust particles of approximately 0,2 % - 0,3 % (dry basis) obtained were discarded. Very fine particles consume more resin to achieve the bond integrity between two surfaces.

The chemical composition of the pulverized rice straw particles and wood Fibers were analyzed in the laboratory (Table 1).

Table 1: Chemical composition of rice straw and wood.

Sl. No.	Particulars	Rice straw	Wood
1	Cellulose (%)	40,8	40 - 55
2	Hemicellulose (%)	25,9	30 - 35
3	Lignin (%)	17,9	25 - 30
4	Silica (%)	12,00	0,5 - 1

The length, width and kurl index of the wood fibers were determined using a ProGres capture camera with image analysis software as given in Table 2 and Figure 1.

Table 2: Characteristics of wood fiber.

Sl No.	Particulars	Value obtained
1	Fiber Length	0,9 - 1,085 mm
2	Fiber width	28 - 31,84 µm
3	Curl Index	11 -15,8
4	pH	6,85
5	Total Dust	13,2 - 15 %

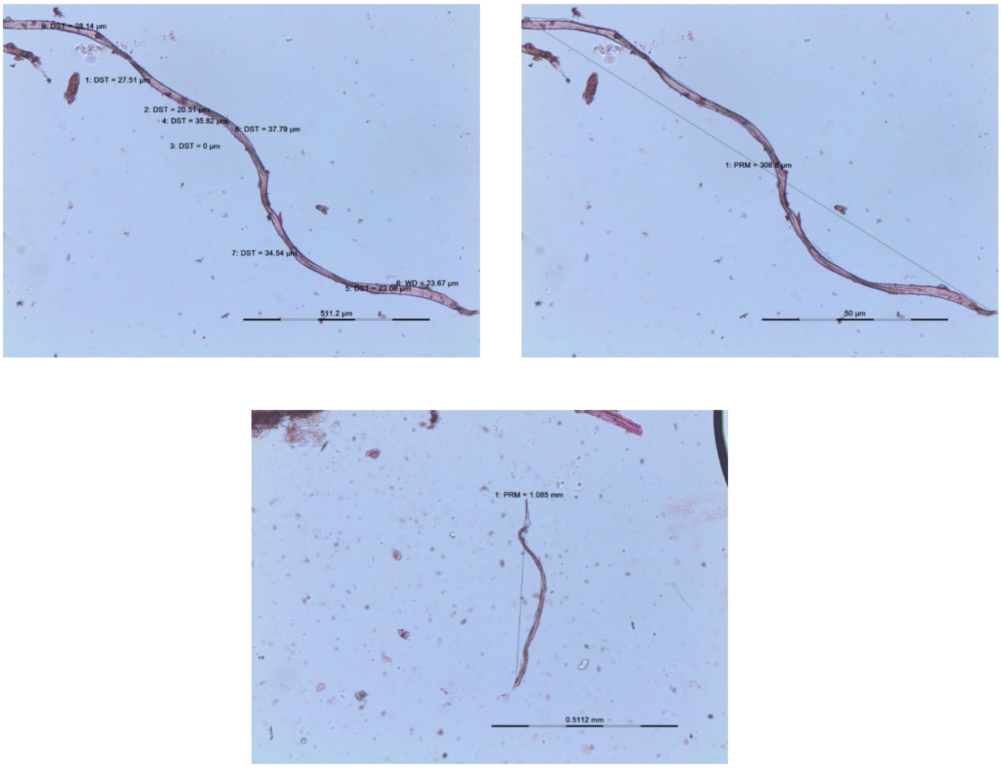

Figure 1: Fiber characterization: length, width and curl index measured under 10x magnification (progress capture camera with image analysis software)

Board production

The test boards were produced as multilayered with Rice straw particles (100 %,70 %, 50 %) and wood fibre (0 %, 30 %, 50 %) compositions. The particles and the fibers were oven dried until the moisture content reached to 3 - 4%. The various combination of wood Fibers of proportionate percentage on the weight of rice straw particles were blended with respective glue mix. The glue formulation comprised of resin admixed with other ingredients like wax emulsion or hardener for amino resin. The details of the boards and the resin formulation are as given in Table 3 and Table 4 respectively.

Table 3: Details of rice straw and rice straw- wood pulverized Multi layered board.

Sl. No.	Rice straw (%)	Wood (%)	Percentage of Resin solids		Resin blended
			Face (%)	Core (%)	
A	100	-	12	10	Phenol cardanol formaldehyde resin
B	100	-	12	10	Melamine Urea Formaldehyde resin
C	70	30	10	14	Melamine Urea Formaldehyde resin
D	70	30	10	14	Phenol cardanol formaldehyde resin
E	70	30	12	12	Melamine Urea Formaldehyde resin
F	70	30	12	12	Phenol cardanol formaldehyde resin
G	70	30	14	14	Melamine urea formaldehyde resin
H	70	30	14	14	Phenol cardanol formaldehyde resin
I	50	50	12	12	Phenol cardanol formaldehyde resin
J	50	50	12	12	Melamine urea formaldehyde resin

The percentage of resin solids indicated is based on the weight of oven dry rice straw /wood Fibers.
The wood fibers used in this work is of eucalyptus species having density of 550 kg/m^3

Table 4: Details of rice straw pulverized particles + wood fiber hybrid board.

Sl. No.	Rice straw (%)	Wood (%)	Percentage of Resin solids	Resin blended
K	70	30	12	Blocked isocyanate resin in combination of phenol cardanol formaldehyde resin (BPCF)
L	70	30	12	Blocked isocyanate resin in combination of urea melamine formaldehyde resin (BUMF)
M	70	30	12	Blocked isocyanate resin in combination of phenol formaldehyde resin (BPF)

The percentage of resin solids indicated is based on the weight of oven dry rice straw /wood Fiber.

The glue blended particles/fibers were placed into a mat forming box with base dimensions of 330 mm x 330 mm. The mat composition comprised of the bottom face layer (20 %) followed by core layer (60 %) in the middle and then finally top face layer (20 %). The bonding process to requisite thickness and size was then carried by compression in a hot press in dimension of 350 mm x 350 mm x 12mm under condition of temperature of the platens at 150 °C - 160 °C for particleboard (Table 3 combination) and 170 ° C for hybrid board (Table 4 combination), pressure of 25 kg/cm² (24 bar) for compression cycle and 12 kg/cm² (11,8 bar) - 16 kg/cm² (15,6 bar), the total curing time of 12 minutes for urea and melamine glue bonded panels and 15 minutes for phenolic and isocyanate bonded boards.

The detailed flow chart of the process is given in Figure 2.

Figure 2: Flow chart for the manufacture of rice straw particle board.

Determination of the board properties

The boards downloaded from the hot press were stacked under ambient conditions for about 24 - 48 hours to attain equilibrium moisture content and then trimmed. The trimmed boards were further dimensioned to required sizes and subjected for testing according to IS 3087:2005 (2005) Particle boards of wood and other lignocellulosics materials (medium density) specification. Five identical specimens of each composition were tested. Prior to testing, the test specimens were exposed to an atmosphere maintained at a relative humidity of 65 ± 5 percent and at a temperature of 27 ± 2 °C until their masses are nearly constant. The water absorption (WA) properties, Thickness swelling (TS) due to general absorption, modulus of rupture (MOR), modulus of elasticity (MOE) and tensile strength perpendicular to surf ace/Internal Bond (IB) strength were determined as per the test procedures of IS 3087:2005 (2005).

RESULTS AND DISCUSSIONS

The influence of rice straw and wood fiber combination on the physical and mechanical properties of rice straw pulverized composite board was determined as given in Table 5.

Table 5: Physical and Mechanical properties of boards.

Board Nos	Density (kg/m^3)	WA (%)		Thickness swelling, 2hrs (%)	MOR (MPa)	MOE (MPa)	IB (MPa)
		2 hours	24 hours				
Value as per IS 3087	500-900	40 max	80 max	12	11	2000	0,3
C	800	42 Sd ±0,32 Cv 1,28	72 Sd ±0,26 Cv 0,48	54 Sd ±0,16 Cv 0,37	15,39 Sd ±0,06 Cv 0,40	2971 Sd±7,42 Cv 0,25	0,1 Sd±0,01 Cv 1,88
D	812	45 Sd ±0,38 Cv 1,35	96 Sd ±0,32 Cv 1,28	43 Sd ±0,16 Cv 0,29	20,31 Sd ±0,34 Cv 1,68	3174 Sd ±10,82 Cv 0,34	0,15 Sd±0,04 Cv 7,07
E	818	29 Sd ±0,46 Cv 1,36	57 Sd ±0,24 Cv 0,42	30 Sd ±0,72 Cv 2,38	16,19 Sd ±0,17 Cv 1,08	2580 Sd±4,84 Cv 0,42	0,15 Sd±0,01 Cv 3,54
F	800	28 Sd ±0,24 Cv 0,84	47,8 Sd ±0,14 Cv 0,30	23 Sd ±0,19 Cv 0,81	14,74 Sd ±0,05 Cv 0,37	2234 Sd±2,45 Cv 0,11	0,2 Sd±0,01 Cv 5,45
G	822	22 Sd ±0,32 Cv 1,28	48 Sd ±0,32 Cv 1,28	23,86 Sd ±0,43 Cv 1,79	16,43 Sd ±0,06 Cv 0,40	2580 Sd±1,67 Cv 0,06	0,2 Sd±0,01 Cv 5,07
H	817	12,76 Sd ±0,36 Cv 1,83	26,4 Sd ±0,09 Cv 0,33	11,82 Sd ±0,13 Cv 1,10	19,63 Sd ±0,32 Cv 1,28	2130 Sd±0,50 Cv 0,23	0,3 Sd±0,32 Cv 1,28
I	872	19,66 Sd ±0,32 Cv 1,82	27,25 Sd ±0,13 Cv 0,35	8,66 Sd ±0,13 Cv 1,50	25,12 Sd ±0,08 Cv 0,31	3491 Sd±2,55 Cv 0,07	0,5 Sd±0,01 Cv 2,00
J	815	17,4 Sd ±0,02 Cv 0,19	38,06 Sd ±0,32 Cv 0,34	11,35 Sd ±0,08 Cv 0,67	21 Sd ±0,43 Cv 2,06	2580 Sd±1,67 Cv 0,06	0,3 Sd ±0,01 Cv 3,75
K	812	12,16 Sd ±0,22 Cv 1,17	38,5 Sd ±0,13 Cv 0,34	5,99 Sd ±0,11 Cv 1,83	19,39 Sd ±0,01 Cv 0,05	3071 Sd±0,84 Cv 0,03	0,48 Sd±0,01 Cv 1,13
L	738	18,85 Sd ±0,12 Cv 1,19	54,9 Sd ±0,15 Cv 0,25	16,17 Sd ±0,01 Cv 0,08	15,30 Sd ±0,05 Cv 0,36	2974 Sd±0,84 Cv 0,03	0,23 Sd±0,02 Cv 3,79
M	840	16,99 Sd ±0,13 Cv 0,77	58,29 Sd ±0,32 Cv 1,28	6,84 Sd ±0,01 Cv 0,15	16,19 Sd±0,01 Cv 0,09	2980 Sd±0,55 Cv 0,02	0,48 Sd±0,01 Cv 1,13

Sd - standard deviation; Cv- Coefficient of variation, %.

Board density is one of the important factors that affect mechanical properties of ParticleBoard. As seen in Table 5, the average density values determined varied from 800 - 872 kg/m³. The results showed that the range of measured densities were with variance of 9 % as the particles were manually blended and mat formed. The density difference would not have influenced the mechanical properties. According to TS EN 312 (2012) standard and study by İstek and Sıradağ (2013) when the average board density deviation is ± 10 %, the other board properties will change significantly. It was determined that the boards made using 100 % rice straw particle coded A & B could not yield the requisite bond integrity inferring poor quality. Hence these panels were not further evaluated for physical and mechanical properties. This is mainly due to the presence of larger amount of silica in the 100 % rice straw combination. The results of the hybrid panels Coded C to M are described in this paper.

Figure 3 and Figure 4 shows the effect of resin blending percentage and type of resin on water absorption and thickness swelling properties of boards. As seen in Figure 3, the water absorption properties indicates the lowest of 12,16 % for K composition boards and highest of 45 % for D composition boards with respect to 2 hours soaking in water and for 24 hours the lowest of 26,4 % was also found for the H composition boards and highest of 96 % was found for the D composition boards . The water absorption properties decreased significantly with the increase in the resin content to the core layers. However, water absorption properties of all the boards meets the requirement of IS:3087:2005 (2005) for grade -2 Particle Board.

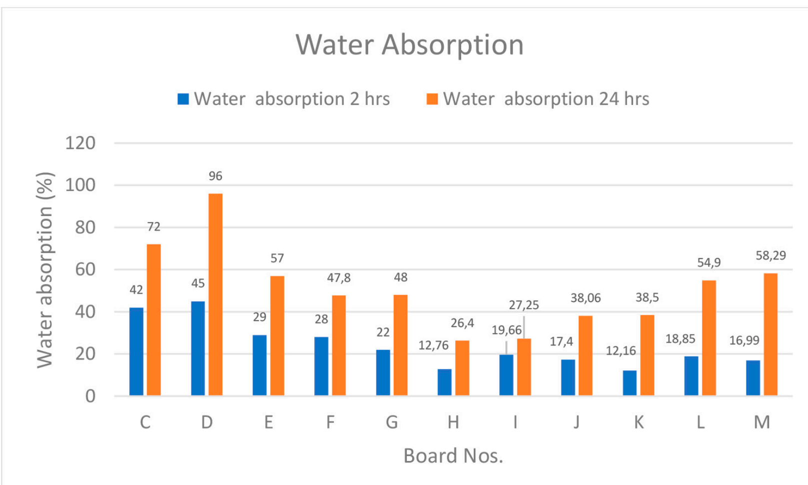

Figure 3: Water absorption properties of rice straw particles and wood fibers.

It can be seen that as the percentage of resin increases the water absorption decreased within MUF resin bonded boards. Amino resin could not effectively wet and penetrate the rice straw surface due to hydrophobic wax and inorganic silica on the outer surface of rice straw (Papadopoulous 2007). Hence even melamine in the urea formaldehyde resin failed to decrease the thickness swelling values of 14 % resin blended particleboards. Comparing the resins 14 % PCF resin bonded particleboard has shown excellent water absorption properties as compared with grade 2 particleboard.

Thickness swelling properties is the key parameter to assess the dimensional stability of composite boards. The K composition boards has resulted with minimum Thickness swelling of 5,99 % which was very less compared to the other compositions as seen in Figure 4. The maximum thickness swelling was found to be 54 % for C composition boards. The H, I, J, K and M composition boards was found to meet the minimum thickness swelling requirements as per IS:3087:2005 (2005) for grade 2 particle board. The reason for the decrease is probably due to the cardanol present in the PCF resin could effectively wet the outer surface of straw and enhance chemical bonding.

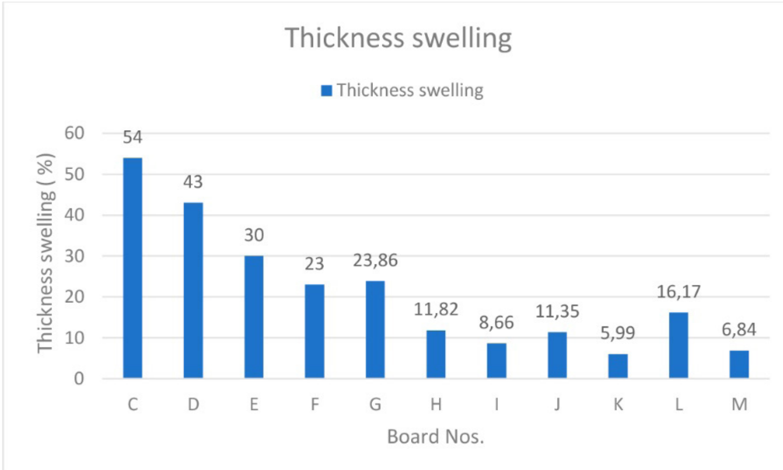

Figure 4: Thickness swelling properties of Rice straw particles and wood fibers.

As seen in Figure 5, the Internal Bond strength analyzed indicates that Internal bond strength increases from 0,1 - 0,5 MPa as the percentage of resin increases. However, the values obtained for the composition of C,D,E,F, G and L boards does not confirm to those required as per the Indian standards. The I composition boards shows highest value of 0,5 MPa. K and M composition boards indicated 0,48 MPa IB and the H and J composition boards shows 0,3 MPa. The IB of H, I, J, K and M composition boards were seen to meet the those required value for Grade 2 multilayered particle board as per IS 3087:2005 (2005).

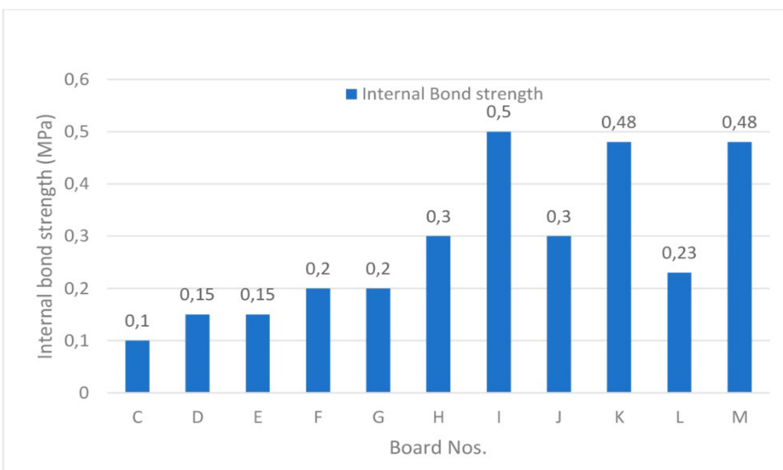

Figure 5: Internal bond strength of rice straw particles and wood fibers.

Figure 6 shows the effect of resin percentage and type of resin on MOR properties. The average MOR of the I composition boards was 25,1 MPa which was the highest of those of the other composition of Boards. The lowest MOR value of 14,7 was determined for F composition boards. As seen in Figure 7, the G composition boards shows the highest average MOE value of 3491 MPa and the lowest 2130 MPa for H composition boards.

The MOR and MOE values did not depend on the variation in the particle composition or the resin system. The MOR and MOE value increased with increase in the resin solids of core layer. According to IS 3087:2005 (2005), all the composition boards confirmed to the prescribed values of MOR and MOE for general purpose interior applications. ParticleBoard bonded with PCF resin shows excellent Mechanical properties. PCF resin wets the surface of rice straw pulverized particle and form better bonding and results in satisfactory physical and mechanical properties.

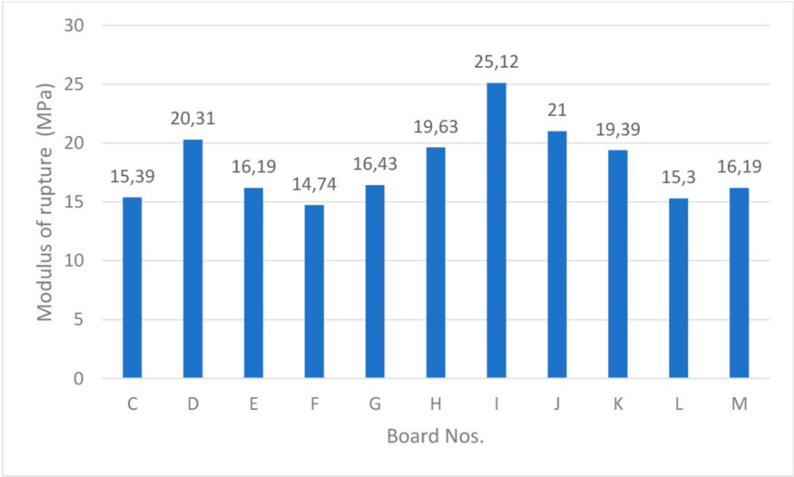

Figure 6: Modulus of rupture of rice straw particles and wood fibers.

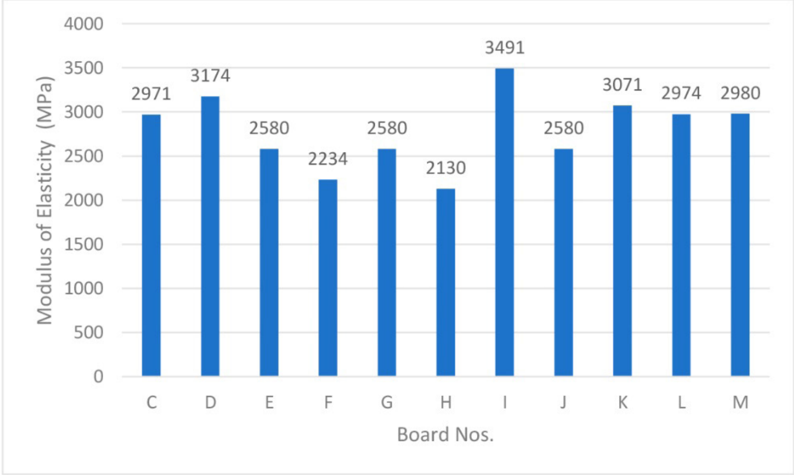

Figure 7: Modulus of elasticity of Rice straw particles and wood fibers.

Table 5 shows the effect of Replacement of wood particle in rice straw pulverized particles in the manufacture of composite boards. The chemical composition and morphology of soft wood like poplar makes it to bond easily with conventional wood adhesives. The board properties of E, F, I, J composition shows that with the increase in the percentage of wood fibers from 30 % to 50 %, the resin percentage required to achieve good bond integrity decreased to 12 % in both PCF, MUF resin. This clearly indicates that the percentage of lignin and silica in any lignocellulosic material influences on the bonding properties of boards.

The K,L and M composition of boards bonded with isocyanate resin system shows higher mechanical properties as seen in Table 5 . It is well known that curing of pH sensitive amino resins is inhibited by high pH and buffering of Rice straw. However, isocyanate resins could wet the surface of rice straw and enhance chemical bonding through hydrogen bonds with polyurethane covalent (Li *et al.* 2010). Hence in the present investigation, blocked isocyanate resins with the combination of PCF, PF and UMF was attempted to minimize the cost of resin and make simpler working conditions.

Descriptive statistics of the water absorption properties, thickness swelling, modulus of rupture, modulus of elasticity and Internal bond strength is as given in Table 5. The standard deviation for thickness swelling due to general absorption, modulus of rupture and IB strength are seen to be ±1 on the average value obtained which indicates the concurrence of those of the individual values of each test. The descriptive statistics analyzed for modulus of elasticity shows the standard deviation minimum value of ±0,84 for L composition of boards and the D composition indicated the highest of ±10,82 %. However, all the other composition of boards value did not show significant change in the standard deviation values. The coefficient of variation for all the composition boards shows less than 5%. The descriptive statistics indicate that the properties obtained for each test are consistent without much variation within the boards.

CONCLUSIONS

In this investigation, a new environmentally friendly technology by using bio-based resin has been developed for the manufacture of rice straw particleboards.

According to the research findings, increase in the percentage of wood fibers in the composition with 12% resin solids for the core layers shows improvement on the mechanical properties. The tensile strength is weak when bonded with amino resin system or conventional phenol formaldehyde resin.

The cardanol based resin system and blocked isocyanate resin combined with cardanol system shows high internal bond strength and less thickness swelling. The investigation reveals that the hinderance of bonding the siliceous nature of the rice straw can be overcome using cardanol resins.

The internal bond strength and water absorption properties of the boards made with equal composition of rice straw and wood fibers exhibits excellent properties.

The blending of rice straw with wood fibers in equal proportion improved the surface area wettability.

Regarding the thickness swelling of the boards only the H, I, J, K and M composition boards was found to meet the minimum thickness swelling requirements as per IS:3087:2005 (2005) for grade 2 particleboard.

The highest MOR and MOE value was seen in I composition boards. According to IS 3087:2005 (2005), all the boards prepared in the study meet the requirements of MOR and MOE values.

The boards made with 100% rice straw shows poor internal bond strength with increased thickness swelling and water absorption. H, I, J, K and M composition boards conforms to flat pressed three layered grade -2 particleboard according to IS: 3087-1995 (1995) particleboards of wood and other ligno cellulosic materials (medium density) for general purposes –Specification.

The descriptive statistics indicate that the properties obtained for each test are consistent without much variation within the boards .

These findings shows that the particle composition and the resin system employed for preparing the particle board using rice straw has a huge impact on thickness swelling, water absorption and the internal bond strength of the boards. The MOR and MOE properties of the boards do not have significant difference with the material composition. Therefore it was concluded that the combination of rice straw and wood fibers in equal proportion shall be maintained during particleboard production. 12 % resin solids blend with the particles exhibits superior internal bond strength.

The conclusions drawn in this study was limited to laboratory scale research findings.

AUTHORSHIP CONTRIBUTIONS

S. D.: Visualization, conceptualization, methodology, investigation, supervision, writing-original draft, writing- review & editing. M. S.: Methodology, investigation, formal analysis, validation. U. N.: Resources, methodology.

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