Feasibility and Properties of Flat-Pressed Three-layer Bamboo-Rubberwood Particleboards for Resource-Efficient Production

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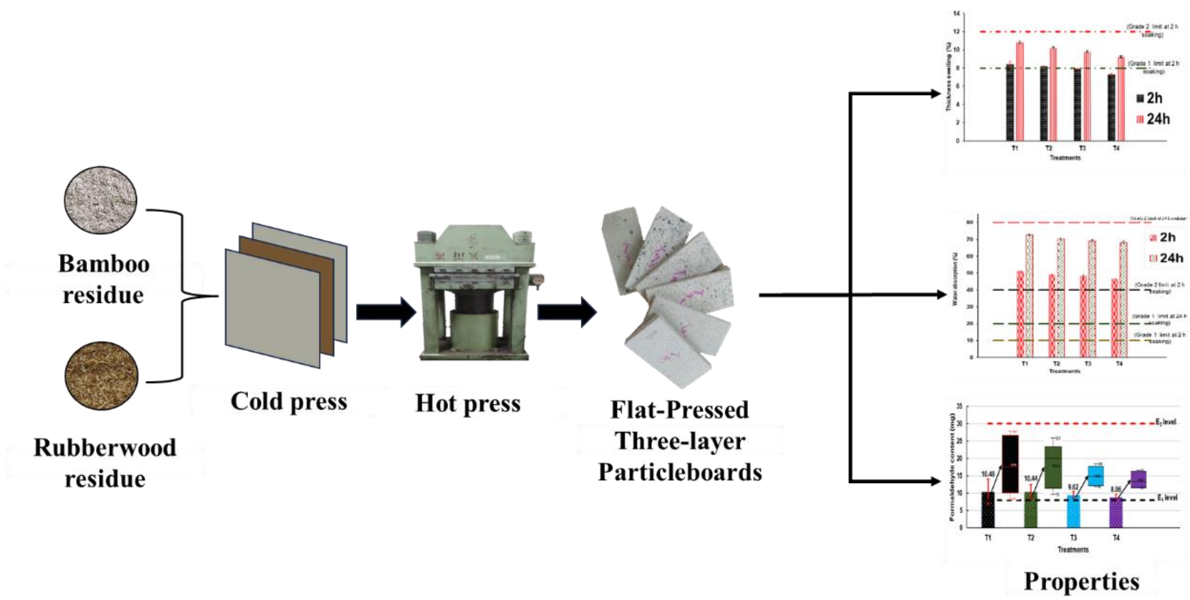
DOI: 10.15376.biores.19.4.7239-7249

GRAPHICAL ABSTRACT



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This study aimed to develop new composites and evaluate the physico-mechanical properties and formaldehyde content of flat-pressed three-layer particleboard (FPTP) made of bamboo (as a face material) and rubberwood (as a core material) residue bonded with urea-formaldehyde adhesive. Different ratios of core and face material were adopted to investigate the effects of these ratios on the properties of the particleboards. The results indicate that increasing the proportion of rubberwood particles enhanced mechanical properties. All particleboards complied with the maximum permissible thickness swelling percentage (12%) specified in IS 3087 (2005) for Grade 2 category boards. While the moduli of rupture and elasticity values increased with higher rubberwood content, the particleboards did not satisfy the IS 3087 (2005) standard overall. However, the internal bonding strength of T4 (0.5 N/mm^2) met the minimum requirement. Nail and screw withdrawal resistance of the particleboards indicated significantly higher resistance with increased rubberwood proportion. Only T4 particleboards met the minimum requirement stipulated by IS 3087 (2005) regarding screw withdrawal resistance for both Grade 1 and Grade 2 category boards. All boards met the criteria for the E_2 classification (formaldehyde content ≤ 30 mg/100 g for oven-dried boards).

DOI: 10.15376.biores.19.4.7239-7249

Keywords: Particleboard; Urea formaldehyde; Bamboo residue; Rubberwood; Formaldehyde emission

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INTRODUCTION

The scarcity of natural resources and the need for sustainable management of lignocellulosic residue materials have driven increased interest in technologies for the sustainable manufacturing of new products (Brito *et al.* 2020). A prime example is the recycling of wood residues from construction and residue from wood processing industries, which are then used to produce engineered wood products, nanomaterials, biofuels, and animal bedding (Shibu *et al.* 2023). Furthermore, lignocellulosic materials other than wood are being increasingly used to produce composites, energy, and chemicals, highlighting the growing importance of lignocellulosic residue valorization (Blasi *et al.* 2023). These practices not only reduce the demand for virgin natural resources, but they also minimize environmental liabilities (Brito *et al.* 2020). The current viability and potential for utilizing lignocellulosic residual resources, coupled with new technological innovations, offer the opportunity to harness these resources to produce novel products (Wang *et al.* 2018). The depletion of solid wood resources has spurred the production of engineered wood products, particularly particleboard. To address the continuing demand for wood-based materials, the wood industry is actively investigating the utilization of alternative lignocellulosic materials (Mohd Ghani *et al.* 2024). Lignocellulosic materials offer a diverse range of materials for particleboard production, including sugarcane bagasse, rice husk, cotton stalks, bamboo, and rice straw (Pędzik *et al.* 2021; Lee *et al.* 2022). Traditionally, the particleboard industry relies on wood fibers and particles as its primary raw materials.

Similar to wood, bamboo and its residual products hold significant promise as a lignocellulosic resource for the production of particleboard. Bamboo has several advantages, including fast growth, good flexibility, and a high strength-to-weight ratio (Li *et al.* 2020). This unique material, with its porous structure, is used in construction works (Mao *et al.* 2023). Bamboo is also versatile and can be processed into various products such as panels, crafts, and tableware. The bamboo processing industry is environmentally conscious, as leftover materials are recycled into particleboard and fiberboard (Huang *et al.* 2019). India, boasting a natural bamboo habitat spanning 13.96 million hectares and harboring 136 species, is the world's second-largest bamboo producer (Jyoti Nath *et al.* 2009). A growing body of research explores the production of bamboo particleboards, utilizing either bamboo alone or combined with various lignocellulosic materials (Biswas *et al.* 2011; Widyorini *et al.* 2016; Nakanishi *et al.* 2018; Nakanishi *et al.* 2019; Brito *et al.* 2020; Karlinasari *et al.* 2021).

Rubberwood, particularly in Malaysia and India, has been extensively used for particleboard production (Amini *et al.* 2013; Shukla *et al.* 2019). In India, Kerala holds a near monopoly on natural rubber production, contributing 90% of the country's total output and occupying 78% of the land under cultivation (Anuja *et al.* 2012). These rubber plantations significantly impact the economic and social well-being of the people in Kerala. Rubberwood plantation timber lops and tops, rubberwood sawdust and other mill residue are the basic raw materials for the particleboard industry (IWST 2021). However, growing pressure on slow-growing forests and tree plantations, coupled with declining productivity, has spurred research into new, environmentally friendly materials for particleboard production (Nakanishi *et al.* 2018). Numerous studies have demonstrated the potential of single-layer particleboards made from bamboo and rubberwood bonded with various polymer binders (Biswas *et al.* 2011; Amini *et al.* 2013; Sun *et al.* 2020; Karlinasari *et al.* 2021), but multilayer particleboards have received less research attention. Multilayer particleboards can possess superior physical and mechanical properties due to their structure, which incorporates outer layers (core) and an inner layer (face) with distinct particle sizes and adhesive content (Nakanishi *et al.* 2018). This study addresses the challenge of resource scarcity in the particleboard industry. It investigates the physico-mechanical properties, formaldehyde content, and feasibility of fabricating flat-pressed three-layer particleboards (FPTPs) using bamboo and rubberwood bonded with urea-formaldehyde adhesive. A consistent adhesive amount (10% dry weight of raw materials) was employed for both the core and face layers. The particleboards were produced using fine bamboo particles for the face and coarse rubberwood particles for the core. The physical and mechanical properties of the particleboards were tested according to IS 2380 (1997). The average values were compared to the requirements of IS 3087 (2005).

EXPERIMENTAL

Materials

Rubberwood coarse particles and bamboo fine particles were used to produce the FPTPs. The bamboo (*Dendrocalamus asper*) residue was sourced from Rain Forest Research Institute (Assam, India). Rubberwood (*Hevea brasiliensis*) residue was collected from the Puthenppurackal wood industry (Kerala, India). Urea-formaldehyde (UF) adhesive with 60% solid content was prepared at the Institute of Wood Science and Technology, Kolkata field station (West Bengal, India). UF adhesive was prepared with a molar ratio (F/U) of 1:1.8 at pH 8 to 8.5. Ammonium chloride was used as a hardener, and ammonium liquor was used as a pH buffer. 1% (dry weight of raw materials) paraffin was used as a hydrophobic agent.

Experimental Design and Data Analysis

The experimental design adopted for manufacturing boards was a completely randomized design (CRD) and consisted of four treatments. The different compositions (in weight) of raw materials were used to produce the FPTPs, as presented in Table 1. Five replicates were prepared for each treatment. A total of 20 experimental boards were made. Subsequently, a comparison between the averages was realized using the Tukey test ($p < 0.05$), adopting a significance level of 5%. R-studio software was used to analyse the results.

Table 1. Experimental Design of the Study

Name	Fine Bamboo Particle (wt%) Face	Coarse Rubberwood (wt%) Core	UF Adhesive	Ammonium Chloride	Paraffin
T1	100	0	10% dry weight of raw material	5% solid content of resin	1% dry weight of raw material
T2	70	30			
T3	50	50			
T4	30	70			

Preparation and Characterization of FPTPs

FPTPs were manufactured in the Institute of Wood Science and Technology, Kolkata field station (West Bengal, India), with a targeted density and nominal thickness of 600 kg/m³ and 1.5 cm, respectively. FPTPs were manufactured using fine bamboo particles as face material and coarse rubberwood particles as core material. Rubberwood particles that passed through 4 mm sieve and bamboo particles that passed through 50 mesh (0.297 mm) sieve were used. Both particles were dried separately in an oven at 60 °C for 24 h to reach a 6 to 8% moisture content.

10% UF were sprayed separately on the bamboo and rubberwood particles and were manually blended for 10 to 12 min. Then, the sprayed particles were formed into 3 layers into a wooden box of 60 cm x 60 cm prior to cold pressing. The mattress was then hot-pressed at 170 °C at 44 kg/cm² for 15 min. The boards were first conditioned at room temperature and then trimmed.

Indian Standard IS 2380 (1997) was employed to assess the physical and mechanical properties of bamboo-rubberwood-based FPTP. Five specimens were extracted from each combination board for the determination of physical (density, moisture content, water absorption, and thickness swelling) and mechanical properties (modulus of rupture, modulus of elasticity, tensile strength parallel to the surface, tensile strength perpendicular to the surface (internal bonding) and nail and screw withdrawal resistance).

Formaldehyde Content (Fc)

The Fc of the boards was measured by using an extraction method called perforator method according to the procedures outlined in the Indian standard IS 13745 (1993). The measured values were then compared to the maximum permissible formaldehyde content specified in Indian Standard IS 3087 (2005) for oven-dried boards.

RESULTS AND DISCUSSION

Physical Properties

Table 2 summarizes the average density and moisture content of the bamboo-rubberwood-based FPTPs. The particleboard exhibited a medium density of 673 kg/m³, which falls within the acceptable range according to IS 3087 (2005), ABNT (2013), and NBR (14810) (Brito *et al.* 2020). An increase in the density of treatment boards (T1 to T4) was associated with the incorporation of higher proportions of rubberwood particles. The average moisture content of the boards was 10.5%, complying with the requirements outlined in IS 3087 (2005). This standard permits the commercialization of particleboard with a moisture content between 5 and 15%.

Table 2. Density and Moisture Content of Particleboards

Treatments	Density (kg/m^3)	Moisture Content (%)
T1	613.6^d (2.70)	10.4^b (0.01)
T2	649.6^c (1.65)	10.5^a (0.11)
T3	686.0^b (4.27)	10.6^a (0.04)
T4	745.5^a (4.12)	10.6^a (0.09)
Overall mean	673.7	10.5
CV (%)	0.5	0.7
Minimum requirement (IS 3087 2005)	(±10) 500-900 kg/m^3	5-15 %

The thickness swelling and water absorption of the boards exhibited decreasing trends as the amount of rubberwood particles increased (Fig. 1). Only the T3 and T4 boards complied with IS 3087 (2005), which specifies a maximum permissible thickness swelling of 8% for Grade 1 category boards after a 2 h thickness swelling test. However, all boards remained within the maximum permissible thickness swelling of 12%, which categorizes them as Grade 2 particleboards. T1 and T2 treatment boards exhibited higher thickness swelling percentages, which was likely due to the higher proportion of bamboo and the non-homogeneous distribution of wax and adhesive. The maximum permissible thickness swelling at 24 h soaking is not stated in Indian standard IS 3087 (2005). However, the results of the 24 h thickness swelling test showed that the treatment boards did not meet the recommended maximum permissible thickness swelling value of 8% provided by ANSI/A208 (1-1999) for general-purpose particleboards (Mirindi *et al.* 2021). Consequently, these particleboards may not function effectively when exposed to moisture.

The results of the water absorption test at 2 h showed that the treated boards did not meet the maximum permissible water absorption value for either Grade 1 (10%) or Grade

2 (40%), as specified in IS 3087 (2005) for general-purpose particleboards. This highlights a significant issue with the material's water resistance in short-term exposure. However, all boards fell within the Grade 2 limit (80%) at the 24 h soaking. In other words, while the boards failed to meet the stricter Grade 1 requirements, they complied with the Grade 2 water absorption standards at 24 h soaking (Fig. 1). This suggests that they may be suitable for applications with moderate water resistance but unsuitable for those demanding high water resistance.

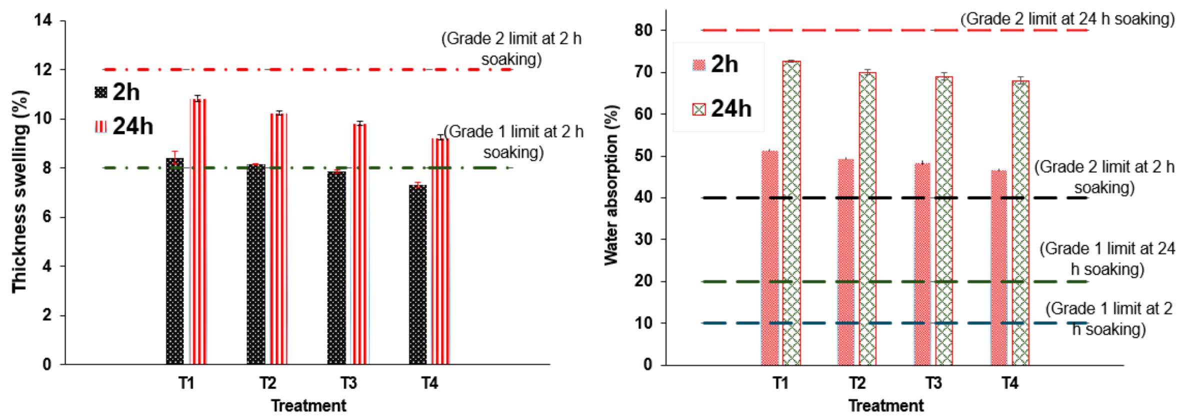

Fig. 1. Thickness swelling (left) and water absorption of particleboards: T1 (Bamboo (BM) 100% + Rubberwood (RW) 0%), T2 (BM 70%+RW 30%), T3 (BM 50%+RW 50%), and T4 (BM 30%+RW 70%)

Mechanical Properties

Table 3 summarizes the mechanical properties of the FPTPs. As defined by IS 3087 (2005), the minimum modulus of rupture (MOR) for Grade 1 and Grade 2 FPTPs is 13 and 10 N/mm², respectively. Unfortunately, none of the treatments achieved the minimum MOR. However, treatment T4 exhibited a MOR of 9.4 N/mm², coming close to the minimum requirement for Grade 2 FPTPs. The observed increase in bending resistance for specimens containing a higher proportion of rubberwood particles can be attributed to the higher density (540 kg/m³) of rubberwood compared to bamboo (460 kg/m³). Additionally, sufficient UF adhesive coverage on rubberwood particles, compared to bamboo, may contribute to enhanced bending resistance. The high volume and large surface area of the fine bamboo particles limited the ability of the available UF resin to coat and distribute evenly throughout the particles (Benthien *et al.* 2022). This resulted in a weakened bond formation, ultimately leading to the lower MOR values observed in treatments T1 and T2.

Urea, phenol, and melanin adhesives rely on mechanical interlocking and pore filling for bonding, but bamboo has no rays and smaller pits, which hinder adhesive penetration. Bamboo has 24 times lower adhesive penetration than wood; the low penetration of adhesives and small pits of bamboo leads to low bonding (Nkeuwa *et al.* 2022). Furthermore, the presence of epidermal content within the bamboo hinders optimal resin penetration, further compromising the strength of the bonds (He *et al.* 2022). Similar to the MOR results, the modulus of elasticity (MOE) values exhibited an increasing trend with increasing rubberwood content. It is generally observed that materials with higher density tend to have greater stiffness or rigidity. This increase in MOE and density from treatment T1 (283.9 N/mm^2) to T4 (1662.5 N/mm^2) can be directly attributed to the incorporation of rubberwood particles (Lee *et al.* 2014). In the study, Lee *et al.* (2014) produced a three-layer particleboard with rubberwood particles as face and oil palm trunk

(OPT) particles as core. It was reported that OPT with lower density is softer and weaker and the resulting three-layer particleboard had inferior mechanical properties compared to that of pure rubberwood particleboard. However, similar to the MOR values, the MOE values did not meet the requirements of IS 3087 (2005).

Tensile strength, both parallel and perpendicular to the surface of treatments, is summarized in Table 3. It was observed that the tensile strength parallel to the surface of the board increased with a higher proportion of rubberwood particles used, in line with the study by Lee *et al.* (2014). However, the Indian Standard does not specify a minimum parallel tensile strength value for particleboard. The internal bonding of T4 (0.5 N/mm^2) was the only board that complied with the requirements of IS 3087 (2005). This standard stipulates a minimum internal bonding strength of 0.45 N/mm^2 for Grade 1 and 0.30 N/mm^2 for Grade 2 FPTPs. Additionally, the internal bonding of T3 was 0.2 N/mm^2, which is close to the minimum requirement for Grade 2 category particleboards.

Previous research by Karlinasari *et al.* (2021) has established particle size and geometry as critical factors influencing the mechanical properties of boards, including tensile strength and nail and screw withdrawal resistance. Studies on tensile strength in bamboo and wood particleboards have demonstrated a positive correlation with decreasing particle size (Lias *et al.* 2014; Abdulkareem and Adeniyi 2017). However, this study presents a contrasting finding, where tensile strength and other mechanical properties increased with an increasing proportion of coarse rubberwood particles. This discrepancy can be attributed to the higher density and more uniform distribution of adhesives in rubberwood coarse particles compared to the finer particles of bamboo. Low density materials tend to have a higher volume per one mass unit and therefore greater particle surface areas that require higher resin dosage for a more even distribution (Lee *et al.* 2014).

Nail and screw withdrawal resistance increased with the incorporation of rubberwood particles. A comparative analysis of nail withdrawal resistance of treatments revealed that the face nail withdrawal (FNW) resistance of T1 was 183.6 N, which is approximately five times lower than that of the T4 (886.3 N) board. Furthermore, the edge nail withdrawal (ENW) resistance of T4 was 423.1 N, which is six times higher than that of the T1 (72.6 N) board. However, the Indian Standard does not specify a minimum requirement for the nail withdrawal test. Regarding screw withdrawal resistance, T4 boards exhibited the highest values (361.8 N for face and 928.4 N for edge). As presented in Table 3, only the screw withdrawal resistance values of T4 boards conformed with the IS 3087 (2005) Standards requirements for Grade 1 and Grade 2 category boards. Also, T2, T3 and T4 satisfy the ANSI A208 (1-1999) Standards requirements for low-density boards for the FSW value, which establishes minimum values of 400 N for low-density boards (Nakanishi *et al.* 2018).

A higher density generally correlates with stronger mechanical properties, such as MOR, MOE, TS, and nail and screw withdrawal resistance. Rubberwood particles likely offer better compatibility with adhesives used in particleboard manufacturing than bamboo (Nkeuwa *et al.* 2022). The presence of the epidermis, the outer, waxy, and dense layer of the bamboo culm, acts as a water barrier due to stomata and silica cells.

Table 3. Density and Moisture Content of Particleboards

Mechanical Properties	Treatments				Mean	CV (%)	Minimum Requirement (IS 3087 2005)	
	T1	T2	T3	T4			Grade 1	Grade 2
MOR (N/mm^2)	0.8[c] (0.15)	3.3[b] (0.73)	8.9[a] (0.16)	9.4[a] (0.11)	5.6	6.8	13 N/mm^2	10 N/mm^2
MOE (N/mm^2)	283.9[c] (72.53)	551.9[c] (110.43)	1100.6[b] (114.29)	1662.5[a] (264.52)	899.7	17.6	2250 N/mm^2	1800 N/mm^2
Parallel tensile strength (N/mm^2)	1.2[d] (0.08)	1.9[c] (0.16)	3.6[b] (0.1)	4.0[a] (0.1)	2.7	4.3	Not Specified	Not Specified
Internal Bonding (N/mm^2)	0.1[c] (0.01)	0.1[c] (0.02)	0.2[b] (0.07)	0.5[a] (0.09)	0.2	24.7	0.45 N/mm^2	0.3 N/mm^2
Face nail withdrawal test (N)	183.6[d] (6.36)	500.5[c] (1.44)	678.5[b] (2.14)	886.3[d] (3.80)	562.2	0.7	Not Specified	Not Specified
Edge nail withdrawal test (N)	72.6[d] (1.44)	105.1[c] (2.49)	360.2[b] (1.21)	423.1[a] (1.04)	240.3	0.7	Not Specified	Not Specified
Face screw withdrawal test (N)	361.8[d] (5.62)	416.4[c] (3.46)	949.0[b] (2.93)	1375.1[a] (2.29)	775.6	0.5	1250 N	1250 N
Edge screw withdrawal test (N)	170.5[d] (2.99)	221.3[c] (0.46)	909.4[b] (0.83)	928.4[a] (0.81)	557.4	0.3	850 N	700 N

Treatments with means followed by the same letter in the column are not significantly different (Tukey; $p > 0.05$). Values in parentheses are the standard deviation. CV: Coefficient of variation

However, this layer also reduces gluing properties (de Sá *et al.* 2023). Therefore, the low performance of T1 and T2 boards may be due to the presence of epidermal silica in bamboo fine particles and the non-uniform adhesive distribution caused by their high surface area. To achieve the full potential of bamboo for particleboard production, further pretreatment is likely required to improve the board's mechanical properties.

The formaldehyde content (Fc) of the boards was measured according to the methods outlined in Indian Standard IS 13745 (1993). The results for Fc are presented in Fig. 2. T1 treatment boards exhibited high variability in Fc, ranging from 6.3 mg to 14.6 mg (standard deviation 3.6 mg). This variation could be attributed to the non-homogeneous distribution of adhesive within the particleboards. This may also be related to the observed lower mechanical properties of T1, which likely stem from the insufficient and non-homogeneous distribution of UF adhesive. T4 boards achieved Fc values very close to the E_1 classification ($Fc \leq 8$ mg/100 g for oven-dried boards), with the lowest Fc value (8.9 mg/100 g oven-dried boards) among the treatments. All treatments (T1, T2, T3, and T4) fell under the E_2 classification ($8 < Fc \leq 30$ mg/100 g for oven-dried boards).

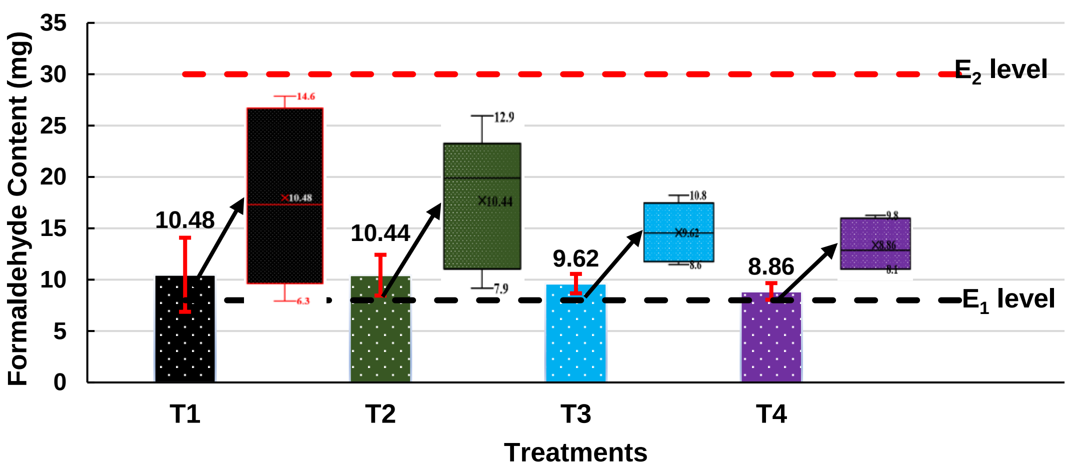

Fig. 2. Formaldehyde content (mg) of particleboards

CONCLUSIONS

1. This study demonstrated the feasibility of producing three-layer flat-pressed particleboards using a varied combination of rubberwood (core) and bamboo (faces).
2. Increasing rubberwood content led to denser boards with better dimensional stability and mechanical properties.
3. All boards met Grade 2 water resistance standards, indicating their suitability for applications requiring moderate water resistance.
4. T4 boards (30% bamboo, 70% rubberwood) achieved most Grade 2 specifications except minimum MOR and MOE.
5. All boards complied with E_2 formaldehyde content classification.
6. Further research on bamboo pre-treatment is needed to improve compatibility and potentially reach Grade 1 compliance.

ACKNOWLEDGMENTS

The authors are grateful to Kerala Agricultural University (Kerala, India), for providing financial support. The authors would like to extend gratitude to the Institute of Wood Science and Technology (West Bengal, India), Rain Forest Research Institute (Assam, India) and Central Wood Testing Laboratory (Kerala, India) under the Ministry of Commerce & Industry, Government of India for their invaluable technical support.

REFERENCES CITED

Abdulkareem, S., and Adeniyi, A. (2017). "Production of particle boards using polystyrene and bamboo wastes," *Nigerian Journal of Technology* 36(3), 788-793. DOI: 10.4314/njt.v36i3.18

Amini, M. H. M., Hashim, R., Hiziroglu, S., Sulaiman, N. S., and Sulaiman, O. (2013). "Properties of particleboard made from rubberwood using modified starch as binder," *Composites Part B: Engineering*, 50, 259-264. DOI: 10.1016/j.compositesb.2013.02.020

Anuja, A. R., Kar, A., Mathur, V. C., Jha, G. K., and Kumar, P. (2012). "Economic Scenario of Natural Rubber Production and Marketing in Kerala," *Economic Affairs* 57(4), 403-413.

Benthien, J. T., Sieburg-Rockel, J., Engehausen, N., Koch, G., and Lüdtke, J. (2022). "Analysis of adhesive distribution over particles according to their size and potential savings from particle surface determination," *Fibers* 10(11), article 97. DOI: 10.3390/fib10110097

Biswas, D., Kanti Bose, S., and Mozaffar Hossain, M. (2011). "Physical and mechanical properties of urea formaldehyde-bonded particleboard made from bamboo waste," *International Journal of Adhesion and Adhesives* 31(2), 84-87. DOI: 10.1016/j.ijadhadh.2010.11.006

Blasi, A., Verardi, A., Lopresto, C. G., Siciliano, S., and Sangiorgio, P. (2023). "Lignocellulosic agricultural waste valorization to obtain valuable products: An overview," *Recycling* 8(4), article 61. DOI: 10.3390/RECYCLING8040061

Brito, F. M. S., Bortoletto Júnior, G., Paes, J. B., Belini, U. L., and Tomazello-Filho, M. (2020). "Technological characterization of particleboards made with sugarcane bagasse and bamboo culm particles," *Construction and Building Materials* 262, article 12050. DOI: 10.1016/j.conbuildmat.2020.120501

de Sá, A. D., Kadivar, M., Barbirato, G. H. A., Tarverdi, A., Kadivar, S., do Amaral, L. M., and Savastano Júnior, H. (2023). "Influence of the outer skin on the flexural properties and thermal conductivity of densified *Dendrocalamus asper* bamboo," *Advances in Bamboo Science* 5, article 100041. DOI: 10.1016/j.bamboo.2023.100041

He, L., Chen, L., Shao, H., Qi, J., Jiang, Y., Xiao, H., Chen, Y., Huang, X., and Xie, J. (2022). "Microstructure and physicochemical properties of the anisotropic moso bamboo (*Phyllostachys pubescens*) surface," *European Journal of Wood and Wood Products* 80(2), 277-288. DOI: 10.1007/s00107-021-01750-x

Huang, Y., Ji, Y., and Yu, W. (2019). "Development of bamboo scrimber: A literature review," *Journal of Wood Science* 65(1), 1-10. DOI: 10.1186/s10086-019-1806-4

IS 13745 (1993). "Method for determination of formaldehyde content in particle board by extraction method called perforator method," Indian Standard, India.

IS 2380 (1997). "Methods of test for wood particle boards and boards from other lignocellulosic materials," Indian Standard, India.
IS 3087 (2005). "Particle boards of wood and other lignocellulosic materials (medium density) for general purposes-specification (Second Revision)," Indian Standard, India.
IWST (2021). "*WOOD IS GOOD: India wood sector report*," Institute of Wood Science and Technology (IWST), 15-26.
Jyoti Nath, A., Das, G., and Das, A. K. (2009). "Above ground standing biomass and carbon storage in village bamboos in North East India," *Biomass and Bioenergy* 33(9), 1188-1196. DOI: 10.1016/j.biombioe.2009.05.020
Karlinasari, L., Sejati, P. S., Adzkia, U., Arinana, A., and Hiziroglu, S. (2021). "Some of the physical and mechanical properties of particleboard made from betung bamboo (*Dendrocalamus asper*)," *Applied Sciences* 11(8), article 3682. DOI: 10.3390/APP11083682
Lee, S. H., H'ng, P. S., Lum, W. C., Zaidon, A., Bakar, E. S., Nurliyana, M. Y., Chai, E. W., and Chin, K. L. (2014). "Mechanical and physical properties of oil palm trunk core particleboard bonded with different UF resins," *Journal of Oil Palm Research* 26, 163-169.
Lee, S. H., Lum, W. C., Boon, J. G., Kristak, L., Antov, P., Pedzik, M., Rogozinski, T., Taghiyari, H. R., Lubis, M. A. R., Fatriasari, W., Yadav, S. M., Chotikhun, A., and Pizzi, A. (2022). "Particleboard from agricultural biomass and recycled wood waste: A review," *Journal of Materials Research and Technology* 20, 4630-4658. DOI: 10.1016/j.jmrt.2022.08.166
Li, Z., Chen, C., Mi, R., Gan, W., Dai, J., Jiao, M., Xie, H., Yao, Y., Xiao, S., and Hu, L. (2020). "A strong, tough, and scalable structural material from fast-growing bamboo," *Advanced Materials* 32(10), article 1906308. DOI: 10.1002/ADMA.201906308
Lias, H., Kasim, J., Atiqah, N., Johari, N., Lyana, I., and Mokhtar, M. (2014). "Influence of board density and particle sizes on the homogenous particleboard properties from Kelempayan (*Neolamarckia cadamba*)," *International Journal of Latest Research in Science and Technology* 3(6), 173-176.
Mao, A., Chen, J., Bu, X., Tian, L., Gao, W., Saiz, E., and Bai, H. (2023). "Bamboo-inspired structurally efficient materials with a large continuous gradient," *Small* 19(35), article 2301144. DOI: 10.1002/SMLL.202301144
Mirindi, D., Onchiri, R. O., and Thuo, J. (2021). "Physico-mechanical properties of particleboards produced from macadamia nutshell and gum arabic," *Applied Sciences* 11(23), article 11138. DOI: 10.3390/app112311138
Mohd Ghani, R. S., Osman, M. S., and Abdul Rani, A. I. (2024). "Exploring the potential of Nipah palm frond as sustainable raw material for eco-friendly particleboard production," *Cleaner and Circular Bioeconomy* 8, article 100092. DOI: 10.1016/j.clcb.2024.100092
Nakanishi, E. Y., Cabral, M. R., Fiorelli, J., Christoforo, A. L., Gonçalves, P. de S., and Savastano Junior, H. (2019). "Latex and rosin films as alternative waterproofing coatings for 3-layer sugarcane-bamboo-based particleboards," *Polymer Testing* 75, 284-290. DOI: 10.1016/J.POLYMERTESTING.2019.02.026
Nakanishi, E. Y., Cabral, M. R., Fiorelli, J., Santos, V. dos, Christoforo, A. L., and Savastano Junior, H. (2018). "Study of the production process of 3-layer sugarcane-bamboo-based particleboards," *Construction and Building Materials* 183, 618-625.

DOI: 10.1016/j.conbuildmat.2018.06.202
Nkeuwa, W. N., Zhang, J., Semple, K. E., Chen, M., Xia, Y., and Dai, C. (2022). "Bamboo-based composites: A review on fundamentals and processes of bamboo bonding," *Composites Part B: Engineering* 235, and 109776. DOI: 10.1016/J.COMPOSITESB.2022.109776

Pędzik, M., Janiszewska, D., and Rogoziński, T. (2021). "Alternative lignocellulosic raw materials in particleboard production: A review," *Industrial Crops and Products* 174, article 114162. DOI: 10.1016/j.indcrop.2021.114162

Shibu, C., Chandel, S., and P Vats. (2023). "Scaling up of wood waste utilization for sustainable green future," in: *Handbook of Research on Sustainable Consumption and Production for Greener Economies*, Richa Goel and Sukanta Kumar Baral (eds.), IGI Global. Hershey, USA.

Shukla, S. R., Zhang, J., and Kamdem, D. P. (2019). "Pressure treatment of rubberwood (*Heavea brasiliensis*) with waterborne micronized copper azole: Effects on retention, copper leaching, decay resistance and mechanical properties," *Construction and Building Materials* 216, 576-587. DOI: 10.1016/j.conbuildmat.2019.05.013

Sun, Y., Zhang, Y., Huang, Y., Wei, X., and Yu, W. (2020). "Influence of board density on the physical and mechanical properties of bamboo oriented strand lumber," *Forests* 11(5), article 567. DOI: 10.3390/f11050567

Wang, L., Yu, I. K. M., Tsang, D. C. W., Yu, K., Li, S., Sun Poon, C., and Dai, J. G. (2018). "Upcycling wood waste into fibre-reinforced magnesium phosphate cement particleboards," *Construction and Building Materials* 159, 54-63. DOI: 10.1016/J.CONBUILDMAT.2017.10.107

Widyorini, R., Umemura, K., Isnan, R., Putra, D. R., Awaludin, A., and Prayitno, T. A. (2016). "Manufacture and properties of citric acid-bonded particleboard made from bamboo materials," *European Journal of Wood and Wood Products* 74(1), 57-65. DOI: 10.1007/s00107-015-0967-0

Article submitted: July 8, 2024; Peer review completed: August 1, 2024; Revised version received and accepted: August 9, 2024; Published: August 19, 2024.
DOI: 10.15376.biores.19.4.7239-7249