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Physio-mechanical properties of particle boards from agro-wastes

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This study presents particle boards made from low cost agro-wastes (date palm leaf and jute stick). Particle boards from jute stick, date palm leaf and their blends offered higher sound transmission loss, higher thermal insulation and lower swelling than plywood. Date palm leaf particle board showed highest strength, whereas board based on blend (1:1) of date palm leaf and jute stick gave highest impact strength.

Keywords: Date palm leaf, Impact strength, Jute stick, Particle board, Sound insulation, Swelling, Tensile strength, Thermal insulation

Introduction

Agro-wastes [date palm leaf (DPL) and jute sticks (JS)] are very cheap and mostly used for fuel purpose, and also in making particle boards with required properties[1-3] (tensile strength, impact strength, swelling, sound insulation and thermal insulation). Change in dimension due to swelling is an indicator of deterioration in board[4]. Thermal insulation is an important property for particle board when it is used as false ceiling, partition wall and wall covering in AC room.

This study presents particle boards (PBs), made from DPL and JS, and their properties have been measured and compared with plywood (PW) and PB from saw dust (SD). Also, a model has been proposed to know effect of PB thickness with sound transmission loss.

Experimental

Materials

Matured DPL, JS and SD (Table 1) were collected to prepare PB using synthetic polymer resin (urea formaldehyde). Costs of these wastes were as follows: DPL, 0.50; JS, 1.50; and SD, 4.00 Rs/kg. PW was procured from market.

Preparation of Particle Board (PB)

Matured DPLs (60 days) were air dried for 7 days. Dried leaves were cut to small pieces (1.27 cm) and then crushed in a grinding machine. Leaf particles ol were uniformly mixed with urea formaldehyde resin (10%) in an electric U-trough mixture having sigma type blade. This mixture was poured into a square mould with smooth aluminium plates on both sides and placed the whole matter in a hydraulic press. Temperature (160°C), pressure (20 kg/cm^2) and time (15 min) were set. Then pressure was released and hot PB was taken out and allowed to cool. Then PB was finished by electrical sawing and stored for conditioning. In similar way, PBs were also prepared from JS and SD. Blended PB was prepared by thoroughly mixing of DPL and JS in different ratios (75:25, 50:50, 25: 75) before application of resin.

Evaluation of Tensile Strength and Impact Resistance of Particle Board (PB)

Tensile strength was evaluated in Instron tensile tester using following values: gauge length, 50 mm; test

Table 1— Physico-chemical composition of date palm leaf (DPL), jute stick (JS) and saw dust (SD)

Properties	DPL	JS	SD
Moisture content, %	6.8	15.2	12.1
Density, g/cc	1.44	1.21	1.38
α-cellulose, %	58.00	40.80	40.43
Hemicellulose, %	20.00	31.90	30.35
Lignin, %	15.30	23.50	20.25
Ash, %	1.75	0.70	-
Others, %	3.00	3.00	8.97

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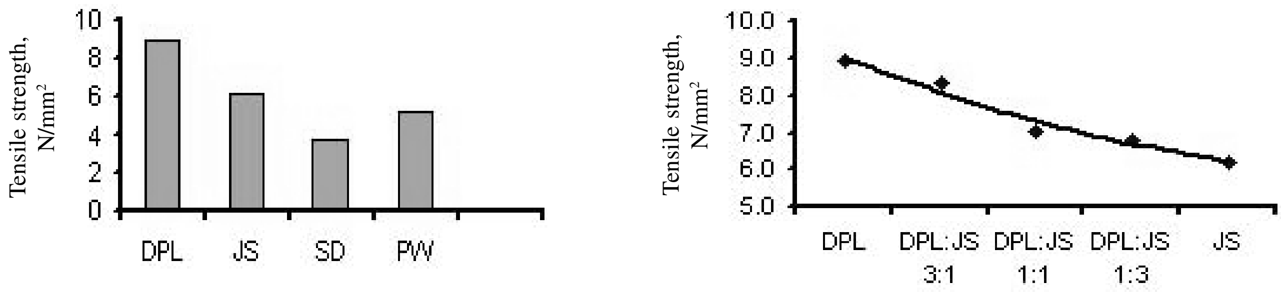


a) b)

Fig. 1—Tensile strength: a) Particle boards; b) Effect of blending DPL with JS

Table 2— Statistical significance of fitted model parameters in different particle boards

Board type	Parameters	Estimate	SE	t-value	p-value
DPL	ϕ_1	15.526	0.347	44.739	7.2×10^{-10}
	ϕ_2	-0.022	0.395	-0.056	0.957
	ϕ_3	-1.482	0.089	-16.689	6.7×10^{-7}
DPL	ϕ_1	15.385	0.313	49.163	3.7×10^{-10}
	ϕ_2	-0.019	0.441	-0.045	0.966
	ϕ_3	-1.263	0.109	-11.591	8.0×10^{-6}
DPL:JS (1:1)	ϕ_1	15.480	0.608	25.436	3.7×10^{-8}
	ϕ_2	-0.035	0.751	-0.048	0.963
	ϕ_3	-1.405	0.171	-8.174	7.9×10^{-5}
PW	ϕ_1	12.939	0.026	501.462	2.0×10^{-16}
	ϕ_2	0.001	0.054	0.011	0.991
	ϕ_3	-0.902	0.022	-40.661	1.5×10^{-10}

DPL, date palm leaf; JS, jute stick; PW, plywood; SE, standard error

width, 6 mm; and cross head speed, 5 mm/min. Average tensile strength (N/mm^2) [breaking load (N) / initial cross-sectional area of specimen (mm^2)] was considered after evaluating 20 specimens. Impact resistance was evaluated in IZOD-type cantilever beam impact tester[5]. Average impact resistance was considered after evaluating 10 specimens.

Evaluation of Swelling

PB specimen (10 cm x10 cm) was taken and cut area was painted. It was kept immersed in water for 24 h. Thickness of PB before immersion in water (T_0) and after 24 h (T_1) was tested in thickness tester. Swelling is expressed as *swell* (%) = $[(T_1 - T_0) / T_0] \times 100$.

Evaluation of Thermal and Sound Insulation

Thermal insulation was tested in thermal insulation tester developed by NIRJAFT[6]. Sound loss through PB was evaluated in a sound insulation tester designed at NIRJAFT[7]. Sound of a specific decibel was created by operating control panel. Source decibel and receipt decibel were measured by two decibel meters S and R respectively without and with sample in-between. Sound reduction due to sample was calculated as dB_F = decibel reduction with sample - decibel reduction without sample $[(dB_S - dB_R)_{WS} - (dB_S - dB_R)_{WOS}]$.

Nonlinear Regression Model Building and Fitting

Non-linear model was employed to study effect of thickness on sound loss. Sound absorption gradually increases with increasing thickness and become stable after a certain thickness. Hence, a nonlinear asymptotic regression model was considered for better inferences as

$$y_i = \phi_1 + (\phi_2 - \phi_1) e^{[-\exp(\phi_3) x_i]} + \varepsilon_i \quad \ldots(1)$$

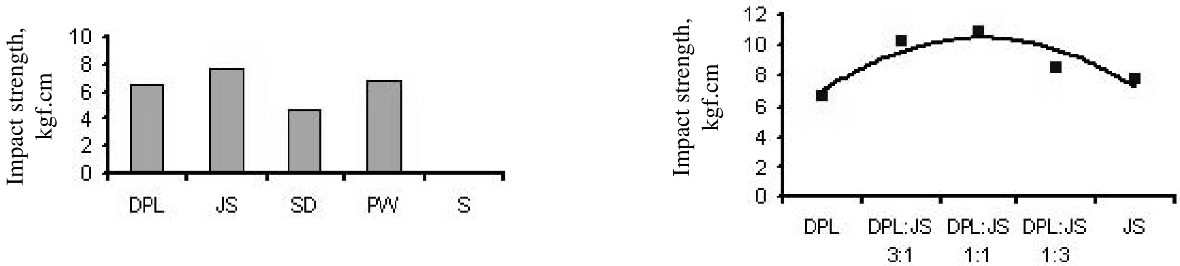
where, (y_i, x_i), i^{th} observation on sound transmission loss and thickness; ε_I, random error assumed to follow independent and identical normal distribution.; ϕ_1, maximum attainable sound loss; ϕ_2, sound absorption (%) without using any obstruction to sound wave; ϕ_3, logarithm of rate constant; and $\exp(\phi_3)$, rate of increment of sound loss with unit change of thickness.

Nonlinear least squares[8,9] as implemented in R function non-linear least square was proposed to fit the model and results were recorded (Table 2).

Results and Discussion

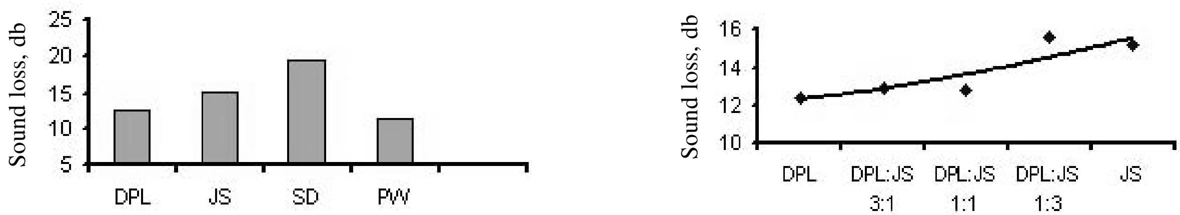
Effect of Raw Material on Tensile Strength

Tensile strength was maximum for PB of DPL and minimum for PB of SD (Fig. 1a). PBs from DPL and JS



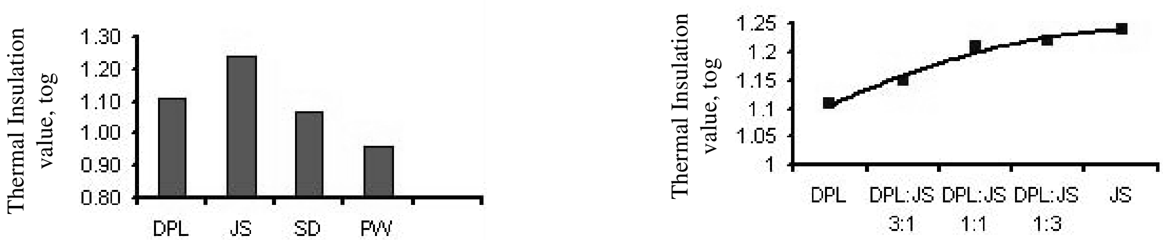
a) b)

Fig. 2—Impact strength: a) Particle boards; b) Effect of blending DPL with JS



a) b)

Fig. 3—Sound insulation: a) Particle boards; b) Effect of blending DPL with JS



a) b)

Fig. 4—Thermal Insulation: a) Particle boards; b) Effect of blending DPL with JS

showed better strength than PB of SD and PW. As DPL contains higher amount of cellulose than JS and SD (Table 1), it has better compatibility with urea formaldehyde resin, which may be responsible for higher strength. In DPL and JS blended board, with increase of JS content in the blend, strength decreased steadily (Fig. 1b). As JS contains lower cellulose than DPL (Table 1), it reduces compatibility with urea formaldehyde resin. DPL, JS and their blended boards were superior to PW in relation with strength. Tensile strength for different PBs is in the order: DPL> DPL:JS (3:1)> DPL:JS (1:1)> DPL:JS (1:3)>JS>PW>SD.

Effect of Raw Material on Impact Strength

Impact strength was maximum (Fig. 2a) for PB of JS and minimum for DPL (similar with PW and SD). In case of DPL and JS blended PBs, maximum impact strength was achieved by blend 1:1 (Fig. 2b). With increase of JS content in blend with DPL, impact strength increased up to proportion 1:1 and thereafter it decreased. Hence, blending of DPL with JS (1:1) produced PB with highest impact strength. Impact strength for different PBs is in the order: SD<PW<JS<DPL:JS(1:3)<DPL:JS(3:1)<DPL:JS(1:1).

Effect of Raw Material on Sound and Thermal Insulation

Sound loss was highest in SD board and lowest in plywood (Fig 3a) with following trend: SD>JS>DPL>PW. Effect of blending on sound loss is depicted in Fig. 3b. PB of JS had highest thermal insulation followed by PB of DPL with following trend: JS> DPL>SD> PW (Fig. 4a). As proportion of JS increases, thermal insulation value increases in a continuous manner (Fig. 4b).

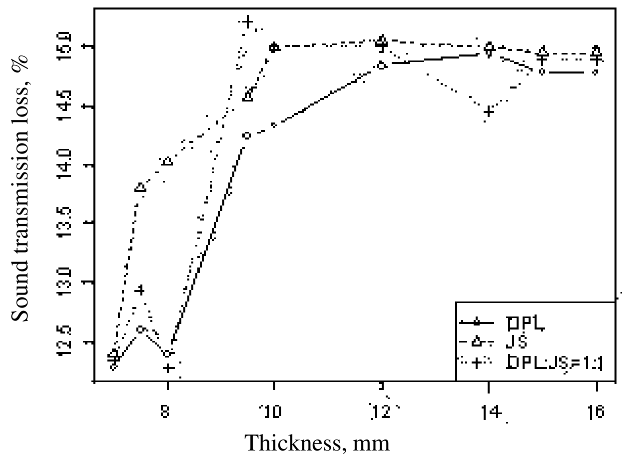


Fig. 5—Scatter plot of sound loss of different type of board

Fig. 6—Swelling: a) Particle boards; b) Effect of blending DPL with JS

Effect of Thickness on Sound Loss

Sound loss increases non-linearly with increase of PB thickness (Fig. 5). PB made of DPL:JS (1:1) exhibited somewhat more fluctuation in sound loss than that in others. Statistical significance of model parameters in Eq. (1) for different PBs (Table 2) shows that for all PBs, p-values of ϕ_1 and ϕ_3 are less than 0.0001, indicating highly significant. However, ϕ_2 is not statistically significant (p-values >0.05) for all boards and estimated values are almost near to zero. This clearly signifies that there would be almost negligible sound loss without using any PB. Fitted sound loss model proposed can now be written as

$$y = 15.526\left(1 - e^{-0.227x}\right) \quad \text{for DPL}$$

$$y = 15.385\left(1 - e^{-0.283x}\right) \quad \text{for JS}$$

$$y = 15.480\left(1 - e^{-0.245x}\right) \quad \text{for DPL:JS (1:1)}$$

$$y = 12.939\left(1 - e^{-0.405x}\right) \quad \text{for PW}$$

where y represents sound loss and x represents thickness.

Asymptotes of fitted equations for different PBs were as follows: DPL, 15.526; JS, 15.385; DPL:JS (1:1), 15.480; and PW, 12.39. Sound loss performance for various PBs was found as follows: For thicknesses < 19 mm, JS > DPL > DPL:JS (1:1)>PW; and for thicknesses > 19 mm, JS = DPL = DPL:JS (1:1) > PW.

Effect of Raw Material on Swelling

Swelling was maximum (Fig. 6a) in PB of SD and minimum in PB of DPL:JS (1:1). DPL, containing more cellulose than JS and SD (Table 1), has better compatibility with urea formaldehyde resin, resulting in low swelling. With increase of JS in blend with DPL, swelling remains almost constant up to blend 1:1 and thereafter increases (Fig. 6b). Decreasing trend of swelling of PBs was as follows: SD >PW>JS> DPL:JS (1:3)> (DPL:JS (3:1)/ DPL /DPL:JS (1:1)). Therefore, PBs of DPL and JS were more stable in water than PBs of PW and SD.

Conclusions

PBs from DPL and JS and their blends showed better strength, sound insulation and thermal insulation than PBs of PW. Blending of DPL and JS (1:1) produced PB with highest impact strength. Increase of JS in blend with DPL increased sound loss as well as thermal insulation. Sound loss increased with increase of thickness. Relationship between sound loss and thickness is nonlinear for all PBs and mathematical models were established. Sound loss reached maximum at board thickness of 19 mm for PB made other than PW (14 mm). PB of JS had highest thermal insulation followed by PB of DPL. PBs of DPL and JS were found more stable (low swelling) in water than PBs of PW and SD. Thus DPL and JS were found suitable to develop eco-friendly PBs, which can be a good substitute of conventional PBs of PW or SD.

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