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Acoustic and Thermal Behavior of Low Density Wheat Straw Particle Board

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Abstract: ***Wheat straw being a versatile material was used to make particle boards of different densities to make its use in interior applications for thermal and sound absorption. Efforts were made to optimize the process parameters to make boards of low densities 300, 400 and 500 kg/m3 and the boards manufactured were been tested for sound absorption coefficient as per Indian standard 10420-1982 and thermal conductivity as per Indian Standard 3346-1980 .The manufactured boards were also examined for the physical properties as defined in IS: 3129-1985. The study reveals that the thermal conductivity of the wheat straw particle board increases as density increases with linear trend equation $Y = 0.0003X + 0.0177$ and coefficient of determination (R^2) 0.9982. Sound absorption coefficient values of 300kg/m3 & 400kg/m3 density boards were conforming the requirements of IS 3129. The boards of density 400kg/m3 and 500kg/m3 meets all the requirement of physical and mechanical properties of IS 3129.***

Keywords: Thermal conductivity, Sound absorption coefficient, coefficient of determination (R^2), linear trend equation

1. Introduction

There is a deficit of 61.3 million cubic meter in the supply and demand for wood, To overcome this deficit and have a sustainable development of composite industry in India, there is a need to find new replaceable agro resources and develop innovative products. The wood-based panels industries make use of forest wood as a raw material for their products. The use of other renewable resources such as agricultural residues (wheat straw, rice straw, bagasse, coir etc.) in the production of composite panels (i.e. particleboards, fibreboards) has recently been considered attractive.

Acoustic properties for absorb sound waves are so important in places such as conference halls, cinema, hospital and houses near streets and high ways. Fiber glass is the most fashionable material which used as insulation material (Liaghatii,1990) but environmental problems of these materials limit usage of them.

2. Materials and Methods

Wheat straw procured from North Karnataka Nalagund , Hubli (K) has a specific gravity of 0.55 with a moisture content of 20-25 %. Wheat straw of length 1 inch was pulverized and sieved to get required size of 2-3mm. The particles were dried in Hot air Oven at 62$\pm$2°C to get requisite moisture content of 3 to 4%. Melamine Urea Formaldehyde (MUF) resin of weight ratio 1:2 (M+U: F) was used for preparation of low density wheat straw particle board. The properties of the resin used are as shown in Table- 1

Table 1: Properties of MUF Resin.

SI No.	Particulars	Results
1.	PH of resin	8.5-9
2.	Flow time of resin in B4 cup	18 seconds
3.	Water tolerance	1:2.5
4.	Solid content	51%
5.	Gelation time	180 seconds
6.	Shelf life	One and half month

2.1 Manufacturing Process of particle board

Sixteen sets of single layered Wheat straw particle boards of dimension 300mm x 300mm x 12mm for a targeted density of 300kg/m3, 400kg/m3 and 500kg/m3 were manufactured using MUF resin adhesive . The adhesive formulation used for the manufacturing of boards is as shown in Table-2.The particles were blended with the adhesive with 10% MUF resin on dry solid basis. The glue blended particles were placed into a mat forming box with base dimensions of 330mm x 330mm. Prepressing and compression of the particles were done by pressing a matching wooden plate on the mat in the forming box by applying manual pressure. Supporting rods to control the thickness to12mm were placed on either ends of the assembly. The assembly was then loaded into a hot press of size 350mm x 350mm wherein temperature of the platens was maintained at 160 °c for particle board. Pressure of 20 kg/sq cm for compression cycle and 12 kg/cm^2 for curing cycle with requisite curing time for respective resin systems were employed. The boards were kept for stabilization 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 as per relevant specifications.

Table 2: Adhesive Formulations

SI No	*Particular*	*Quantity*
1.	Liquid MUF resin	100 grams
2.	Wax emulsion	1 gram
3.	Liquor ammonia	1 ml
4.	Hardener (ammonium chloride) water (mixed with hardener)	0.4 grams & 1.2 grams

2.2 Testing of the boards

All The test specimens were exposed to an atmosphere maintained at a relative humidity of 65 ± 5 %t and at a temperature of 27 ± 2°C until their masses are nearly constant. The test specimens were kept in this controlled atmosphere until they are required for testing.

Physical and mechanical properties of the boards: Modulus of rupture, Internal bond strength, and thickness swelling were tested as per IS: 2380 and compared with values prescribed in IS: 3129.Sound absorption coefficient was calculated by the method followed for testing of acoustic Pulse tester as per IS: 10420-1982 (Determination of sound absorption coefficient of timber by standing wave method). Three sets of samples of diameters 100 mm and 30 mm were prepared for studying acoustic properties for frequencies ranging from 125 Hz to 1500 Hz and 1500 Hz to 5000 Hz respectively. The sound absorption coefficient of the samples was recorded. The average values of three sets were noted for all the three (300, 400 & 500 kg/m3) density samples. The noise reduction coefficient (NRC) was also calculated as the average of the absorption coefficients at 250, 500, 1000 and 2000 Hz frequencies.

Thermal conductivity of the samples were determined by the method specified in IS 3346. The samples were subjected for thermal conductivity test using computerized thermal conductivity apparatus which works on the principle of guarded hot plate method and uses an absolute method for the determination of thermal conductivity. Considering the Indian extreme conditions at summer season, the temperature of hot plate and cold plate were set at 50°C and 30°C respectively for determining thermal conductivity of manufactured boards. Three sets of samples from all three densities (300, 400 & 500 kg/m3) of cross sectional area 300 x 300 mm were prepared to determine thermal conductivity. The thermal conductivity of samples was recorded after steady state condition was observed and the temperature differential between the guarded metered hot plate and the primary guard as well as the auxiliary cold plate was within 0.5°C. Also, this difference was stable for a four consecutive periods of half an hour each. During testing of samples, readings were taken only after steady state condition

The thermal conductivity is computed by the equation as given below:

$$k = \frac{Q\,D}{\{A\,(\Delta T)\}}\text{, in W/m-K}$$

Where:

Q is the heat supplied through a medium, in W

A is the cross-section of the sample, in m^2

ΔT is the temperature differential across the medium, in ^oK

D is the length of the medium through which heat flows (thickness of sample), in m

k is the thermal conductivity of the medium, W/m-K

3. Results and Discussion

The average density of the wheat straw particle boards manufactured were found to be 306kg/m3, 409kg/m3 and 520kg/m3 respectively. The Moisture content, MOR and thickness swelling due to surface absorption values are reflected in Table-3. The average Moisture content values were found to be 5.56 -6.87 % for the three targeted density boards of 300, 400, 500 kg/m3. MOR value for the density 400 kg/m3 & 500 kg/m3 were meeting the requisite value of Indian standard (IS) 3129. However the board A showed MOR of 0.9 N/mm2, which does not conform to the IS: 3129. Swelling due to surface absorption of 400 & 500 kg/m3 boards were conforming to the requirement and 300 kg/m3 board was showing higher thickness swelling .Generally there will be more space available for the water to move in a lower density particle board due to the lack of bonding between the particles and resin. Further the wheat straw contains 6 -8% of silica which further hinders the interaction of the polymer.

Table 3: Average test results of Moisture content, MOR and Swelling due to surface absorption.

SI No	Properties	Prescribed Value as Per IS: 3129-1985	A(300 kg/m^3)	B(400 kg/m^3)	C(500 kg/m^3)
1	Moisture content, %	Max 16	6.87	6.04	5.56
2	Modulus of rupture (N/mm^2)	Min. 1.5	0.9	1.7	3.1
3	Swelling due to surface absorption (after 2 hours soaking) %	Max 5	6.85	4.7	3.6

Table 4: Average values of Sound absorption coefficient and NRC

SI No	Frequency (Hz)	Minimum prescribed value as per IS:3129	A (300) kg/m^3	B (400) kg/m^3	C (500) kg/m^3
1	125	0.05	0.07	0.06	0.03
2	250	0.1	0.13	0.12	0.08
3	500	0.2	0.28	0.22	0.15
4	1000	0.3	0.38	0.32	0.22
5	1500	-	0.54	0.46	0.37
6	2000	0.5	0.57	0.51	0.43
7	2500	-	0.42	0.38	0.32
8	3000	-	0.33	0.27	0.24
9	3500	-	0.31	0.24	0.20
10	4000	-	0.30	0.23	0.19
11	4500	-	0.29	0.25	0.19
12	5000	-	0.29	0.26	0.20
NRC			**0.34**	**0.29**	**0.22**

The absorption coefficient is a common quantity used for measuring the sound absorption of a material and is known to be the function of the frequency of the incident wave. It is defined as the ratio of energy absorbed by a material to the energy incident upon its surface. Sound absorption coefficient of all three densities boards was measured till 5000 Hz.

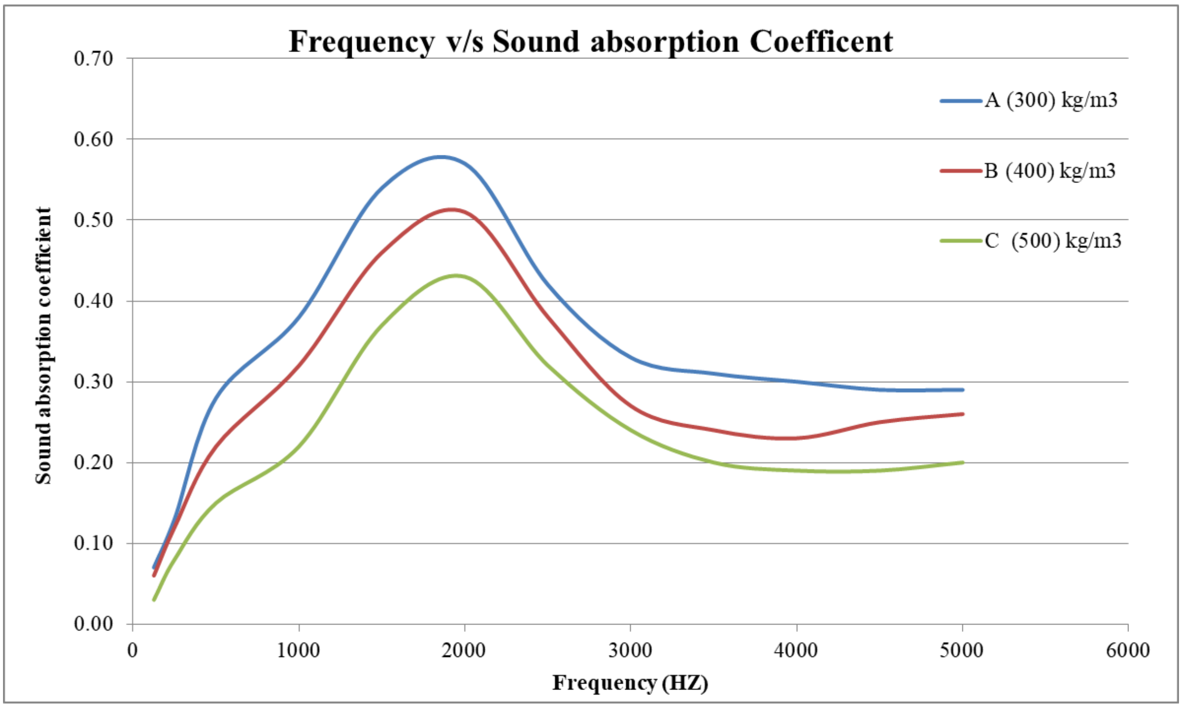

Figure 1: Sound absorption coefficient of all three density boards

Table-4 shows the average values of Sound absorption coefficient & NRC. and Table-5 indicates the Average values of Thermal conductivity with Standard deviation and coefficient of variation From Fig -1, it can be seen that the values of all three boards increased with increase in frequency up to 2000 Hz and gradually the values decreased for higher frequencies starting from 2000 Hz to 5000 Hz. This increase and decrease was due to the specific characteristic of straw or low density material. As the frequency increases above 2000, sound absorption decreases , this could be due to the limiting factors of wheat straw , an porous material which allow the passage of the wave with greater or lesser efficiency sound absorption. The porosity of any panel depends on the raw material used, density of the composite and also the empty spaces between them, which opposes the air pressure caused by the sound wave. $300kg/m^3$ shows a higher absorption of 0.57 at 2000 Hz and gives the best absorption compared to other two boards B & C. Sound absorption coefficient of Type A & B boards values were conforming the requirements of IS 3129. Whereas the Type C board values are not conforming the requirement of IS 3129. It clearly indicates that the absorption coefficient values decreases as the density of the board's increases.

Noise Reduction Coefficient (NRC) is an average rating of how much sound an acoustic board can absorb. It is the average values of absorption coefficients for a specific material at the octave band center frequencies of 250, 500, 1000 and 2000 Hz. From Table-4, Noise reduction coefficients (NRC) of three density boards calculated were 0.34, 0.29 and 0.22 all the three values are comparable with NRC values of coir board (12mm thick, 0.325), wadding material (30mm thick, 0.31), Fiber board (25mm thick, 0.258) and wood wool building slab (25mm thick, 0.3) (Anand Nandanwar 2017). From Fig-2, NRC values decreases with increase in density and follows linear trend line equation $y = -0.0006x + 0.5242$ with coefficient of determination 0.9857 (R^2)

The sound absorption in a material depends on the frequency of the emitted wave. Increase in frequency the lower is the wavelength and hence the waves find more difficulty in penetrating the material. Therefore, the pore size of a material may make it further difficult to control low frequency sound compared to high frequency. Hence in the figure an increase in the absorption of sound energy in the frequencies of 250-500 Hz in which the area between the curves decrease can be observed.

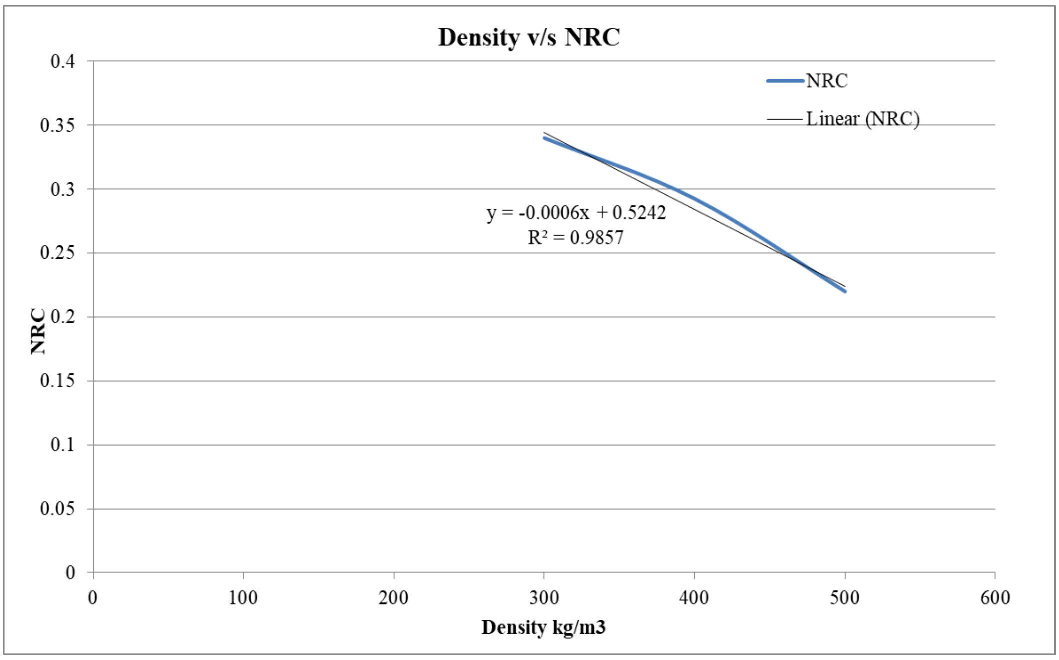

Figure 2: Density versus Noise Reduction Coefficient with linear trend equation and coefficient of determination (R^2)

Table 5: Average values of Thermal conductivity with Standard deviation and coefficient of variation

SI No	Density (kg/m^3)	Thermal conductivity (W/m-K)	
1	300	Avg	**0.098**
		STD Dev	0.004
		Variation	0.036
2	400	Avg	**0.127**
		STD Dev	0.005
		Variation	0.035
3	500	Avg	**0.152**
		STD Dev	0.012
		Variation	0.081

Thermal conductivity of wheat straw boards varies from 0.098 to 0.152 W/m-K for density range 300 to 500 kg/m3. Table-5 shows thermal conductivity values of all three density wheat straw boards with standard deviation and coefficient of variation. The effect of density on thermal conductivity of wheat straw boards is as shown in Figure-3. Thermal conductivity increases as the density of the board increases and follows linear trend line relationship y = 0.0003x + 0.0177 with coefficient of determination 0.9982 (R^2).

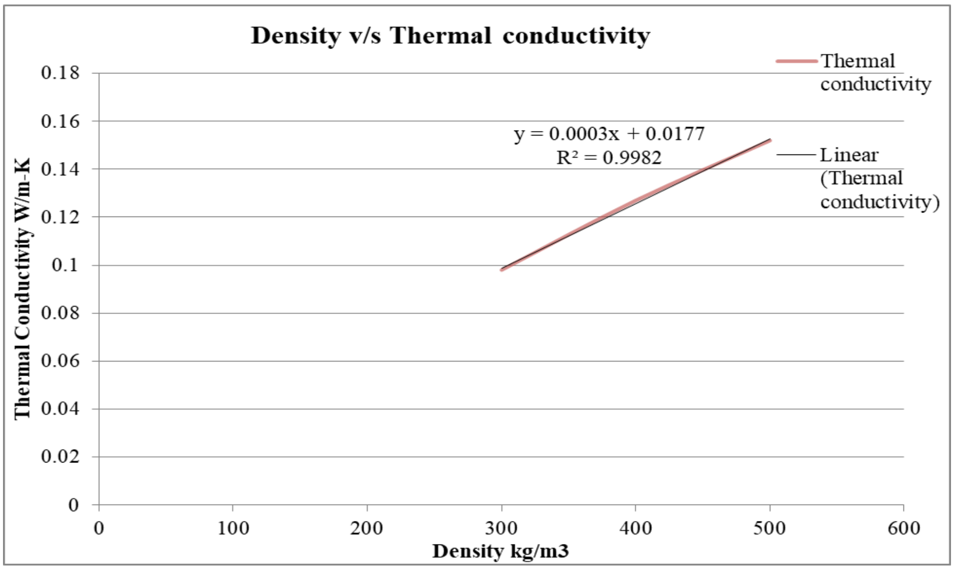

Figure 3: Density versus Thermal Conductivity with linear trend equation and coefficient of determination (R^2)

4. Conclusion

Wheat straw board manufactured for all three densities gives good sound absorption coefficient at 2000 Hz. The NRC values of all wheat straw boards are comparable with coir, wadding material, fiber material (Anand, 2017). Wheat straw of lesser density board can be used as good sound absorbing material at 400kg/m3. As the density increases the thermal conductivity of the boards will also increases, it indicates that wheat straw boards of higher densities can be used in heat sink applications and lower density boards can be used for thermal insulation applications. Wheat straw panels substantiate to be a material with potential for acoustics that range from 500 Hz to 2,000 Hz.

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