Determination of thermal conductivity of Areca husk fiber by Lee's disc method

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Abstract

Natural fibers are often used as reinforcing materials in various mechanical and industrial applications due to their eco-friendly and degradable properties. Areca Husk Fiber (AHF) has a high fiber density with good thermal insulating property. However, due to poor utilization of the husk, it is being discarded as an agricultural waste.

The present study determines the thermal conductivity of the areca husk fiber collected from the western ghat region of Karnataka. The thermal conductivity was determined by Lee's disc method and crystallinity of the material was analysed by Segal's method. The study showed that the thermal conductivity of the AHF was 0.021 W/mK. In comparison with the other known thermal insulators, AHF exhibited a low thermal conductivity. Detailed study on AHF may result in a good eco-friendly thermal insulating material.

Keywords: Areca husk fibers, Lee's disk method, thermal conductivity.

Introduction

The world is facing many problems on environmental issues due the usage of non-degradable plastics. Natural fiber-based composites the potential alternatives for plastic based materials. The light weight, strong, flexible, bio-degradable and cost-effective advantages of natural fibers could be the good replacement in many fields. Areca husk fiber (AHF) is one such natural fiber having high fiber density, short length and abundantly available as agricultural by product. India is one of the largest producers of Areca. Karnataka (40%), Kerala (25%), Assam (20%), Maharashtra, Tamilnadu, Meghalaya and West Bengal are the states contributing the major part of Areca production in the country.

Areca is mainly cultivated as commercial crop and used across the country for pan masala industry, chocolate industry and medicinal industries[1]. Areca is being cultivated in thousands of hectare land generates a massive amount of husk.

However, poor utilization of these husks is being discarded as agricultural waste. Areca husk constitutes about 60-80% of the total volume and 50% weight of the whole Areca fruit. The AHF is composed of cellulose with varying proportion of hemicellulose (35-64.8%), lignin (13-26%), pectin and propectin.[2,3] An average length of the fiber is 4cm and it is a combination of two types of filamented fibers, one is very coarse and another is fine. The coarse part is nearly ten times as coarse as jute fibers and fine filament is as fine as jute fibers. The AHF could be used to fabricate boards, fluffy cushions and thermal insulators[4].A small amount of dry husk is used as fuel in areca nut processing.

Although, due to its high thermal stability boiler container used while areca processing may get corrode. This would be the major cause of not practicing areca husks as burning fuel in domestic applications. The unutilized wet husks left on the field, cause an awful odour and the slow decay result in several problems[5].An intense research is required to fabricate these unmanaged husks as structural material along with superior physical, chemical and thermal properties. Many researchers have studied these aspects of areca husk and could not succeed in designing areca husk as a useful material.

However, there are no such articles on thermal conductivity of AHF and it is necessary to understand the thermal conductivity of AHF to utilize discarded material as a valuable material. The present work emphasizes the determination of thermal conductivity AHF to show it as a good thermal insulator. The thermal conductivity of areca husk fiber was measured using Lee's Disc method and the obtained result is compared with other known thermal insulators. The determination of thermal conductivity gives enough evidence of the thermal insulation nature of AHF.

Material and Methods

Materials:

Areca Husk: Unripen areca fruit husks were collected from the G.R.S. Farm, Hurali, Thirthahalli, situated in the western ghat region of Karnataka.

Binding Agent: Wheat flour was used as an organic binding agent for AHF Disc preparation. (The external binding agents obtained from biological starch are regulated in EN14961-2[6]).

Thermistors: W1209 50-100 digital temperature controller thermostat was used to measure the temperature in Lee's Setup.

Methods:

Fiber Extraction: The fibers were extracted through Retting process. Impurities were separated from collected husks and soaked in water for 140 hrs[7]. Soaked husks get loosen the fiber content and were extracted manually washed with distilled water and dries at 70 °C for 24 hrs[8]. Extracted AHF were kept inside a polythene bag and stored at room temperature.

Fig. 1: Extracted Areca husk Fiber

Optical and morphological study: The surface morphology analysis of AHF carried over using Zeiss Scanning electron microscope. The fiber surface was examined in different regions and angles.

Crystallinity Index: The crystallinity index of AHF was calculated through Segal's method[9]. The XRD patterns observed using Rigaku Miniflex 600 X-Ray Powder diffractometer with Cu Kα source of wavelength 1.54 Å. The diffraction peaks were taken in the range of 5 and 80^0 (2θ angle range) at the interval of 3^0.

$$\text{Crystallinity Index } I_c = \frac{I_{200} - I_{am}}{I_{200}} \times 100 \qquad (1)$$

where I_c is the crystallinity index, I_{am} is the intensity of diffraction and I_{200} is the maximum intensity at 200 peak. Both crystallineity and amorphous regions of the AHF are represented by I_{200} and I_{am} is the regon contains only amporphous nature.

Disc Preparation: The fiber composition and amount of binding agent are two main components of a disc preparation. In this study, the randomly arranged fibers are blended with wheat flour in the weight ratio of 2:3 in presence of small amount of distilled water. Further the mixture subjected to pressed in hydraulic press of 0.9 Mpa for 15 min. Eventually concoction is kept inside a hot air oven at 120°C for 3 hrs. To get it free from water particles.

Thermal Conductivity: The thermal conductivity of AHF was determined through Lee's Disc Method. The setup was self-prepared as shown in the fig. 4. The apparatus consists of a steam chamber (6 cm depth, 5.02 cm outer diameter, 4.5 cm inner diameter), a metal disc (Lee's Disc of diameter 5.02 cm), steam chamber, 1000 W electric hot plate, steam conducting pipe, cotton threads and stand. A small hole was drilled on steam chamber and Lee's Disc to place the sensor probes. All metallic chambers and disc were made by Iron and welding work done by electric mode. The metal disc freely suspended to the stand as shown in the fig. 4a to avoid the loss of heat to neighbouring bodies.

Fig. 2: Picture of Hydroulic Compresser used for disc preparation

a. Horizontal veiw of Disc **b. Vertical view of Disc**

Fig. 3: Photograph of AHF Disc

Working Procedure:

i. The mass of Lee's Disc was measured using digital weighing machine. The diameter was measured by Vernier scale and thickness by Screw gauge. The apparatus was arranged as shown in the fig. 4b.

ii. A continuous steam was made to pass through the steam chamber, simultaneously observe the temperature of steam chamber and the Lee's disc and allow their temperature to reach steady state at least for 15 min and noted down.

iii. Soon after the steady temperature, remove the specimen and make direct contact of steam chamber and Lee's disc till a rise of 10 °C observed in Lee's Disc.

iv. The steam chamber was removed and allow Lee's disc to cool down. Note down the loss of temperature in it from steady temperature + 5 °C in the interval of 60 seconds.

v. A Graph was plotted time along at x-axis and Temperature along y-axis. A tangential slope is drawn to the steady state temperature point along y-axis.

vi. The thermal conductivity was calculated using the following equation:[10,11]

$$K = \frac{msd}{\pi r^2 (T_1 - T_2)} \frac{dT}{dt} \left(\frac{r + 2h}{2r + 2h} \right) W/mK2$$

where m: Mass of the Lee's disc in Kg, d: Thickness of the Specimen in m, s: Specific heat of Iron in J/Kg, r: Radius of

Lee's Disc in m, h: Thickness of Lee's Disc in m, $\frac{dT}{dt}$= Tangential Slope, T_1= Steady Temperature of Steam Chamber in ºC and T_2= Steady Temperature of Lee's Disc.in ºC

Fig. 4a: Lee's Disc setup used in experiment

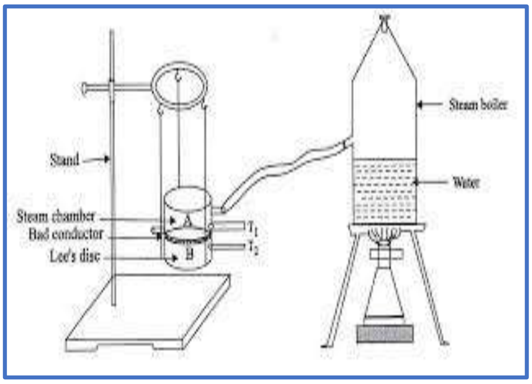

Fig. 4b: Schematic image of the setup

Result and Discussion

Morphology of AHF: The morphological view of AHF is as shown in the Fig. 5. The surface of AHF is uneven and unordered due to its different composition of matters like hemicellulose, pectin and lignin. The morphology of AHF can be modified, by altering the composition of these factors. A smooth, non-corrosive and non-broken body of AHF can play a major role in material engineering and epoxy compositions.

Crystallinity Index: The XRD pattern of AHF obtained is shown in the figure 6. A pair of major peaks were observed around 18^0 and 22^0 which corresponds to the crystalline structure of cellulose[12].The formation of intra and intermolecular H-bonding by hydroxyl groups[13]. The free movement of cellulosic chains is restricted by the H-bonding and chains align in a formal appearance which cause the crystalline domain. These domains are embedded in the amorphous matrix components like hemicellulose, lignin and pectin this results a low crystallinity and a high amorphous nature[14]. The crystallinity index was calculated using equation 1 and overserved 40% crystallinity for AHF.

Thermal Conductivity of AHF: The experiments have been repeatedly done thrice for same sample in different weather conditions.

m = 0.216 Kg s = 450 J/Kg
d = 0.0118 m r = 0.029 m
h = 0.009 m $\frac{dT}{dt}$= 0.0047 ºC / s
T_1 = 80.866 ±0.1527 ºC
T_2 = 26.233 ±0.0577 ºC

The variation of mean temperature with respect to time is shown in fig. 7a. The slope was calculated through plotting a tangent for mean steady temperature of Lee's Disc T_2,which was 26.233 ±0.0577 ºC. An enlarged tangential slope is as shown in the fig. 7b. The thermal conductivity of AHF was calculated using the equation 2 and found to be 0.021 W/mK.

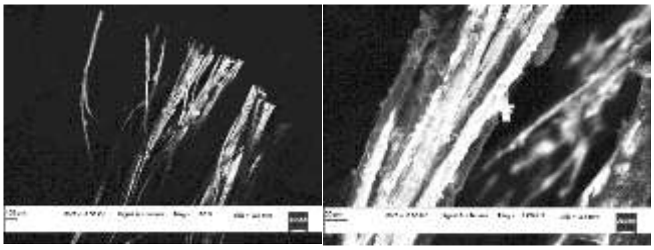

Fig. 5: SEM images of AHF

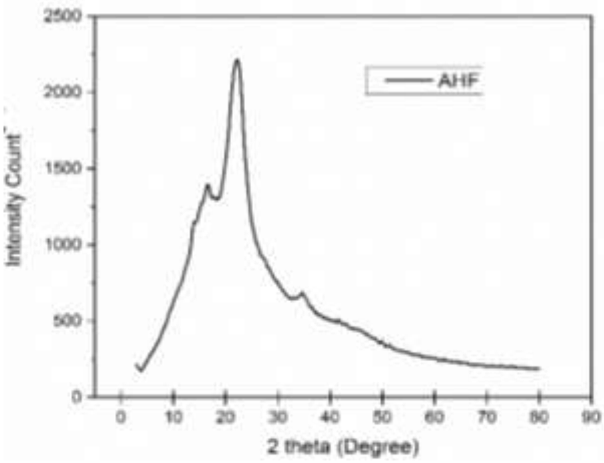

Fig. 6: XRD pattern of AHF

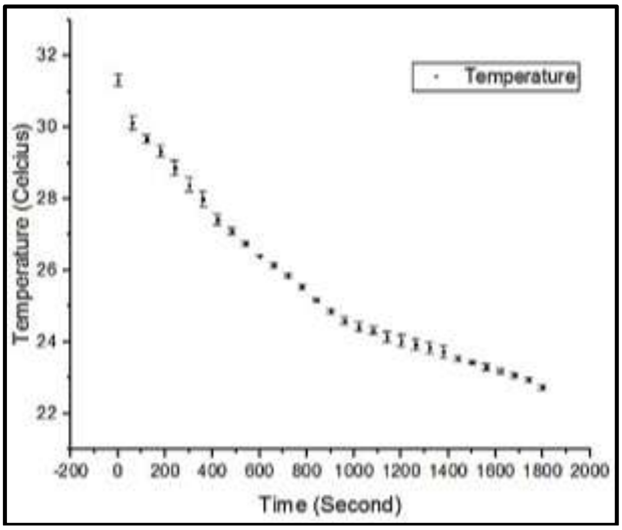

Fig. 7a: Loss of temperature graph of AHF with respect to time.

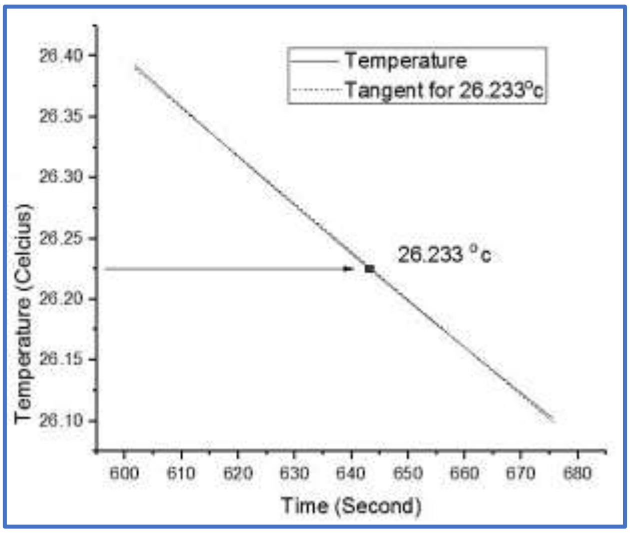

Fig. 7b: Tangential Slope for Steady Temperature of Lee's Disc T_2

Calculation of instrumental error: The instrumental error was calculated by determining the thermal conductivity of known insulators. Thermocol, Thermo-foam and Plywood are repeatedly examined three times through this setup on different weather conditions to get the accurate thermal conductivity. Measured value (O.V) are correlated with a known value (K.V) and by performing the percentage of error the instrumental error has been calculated.

$$Percentage\ of\ error = \frac{(Measured\ Value - Known\ Value)}{Known\ Value} \times 100 \quad (3)$$

The instrumental error is found to be 4.6%. The error may due to the material used to build Lee's setup, and digitization error of the thermistors and the different quality of specimen used in the experiment. The various natural fibers do exhibit the low thermal conductivity such as jute (0.427 W/mK)[17], hemp (0.05W/mK)[18], Silk (0.083 W/mK)[19], Sheep wool (0.04W/mK)[20] and etc. In comparison with known thermal insulators, AHF is showing much lower thermal conductivity with 0.021 W/mK. The XRD analysis of AHF reveals the low crystallinity index of 40%.

Table 1
Thermal Conductivity of different thermal insulators and instrumental error

S. N.	Material	M.V in W/mK	K.V in W/MK	Error in %
1	Thermocol[15]	0.044	0.047	6
2	Thermo-foam[16]	0.061	0.059	3
3	Plywood[15]	0.114	0.120	5
4	AHF*	0.021	-	-

*****Present work

The amorphous nature of Hemicellulose, lignin and pectin depress the crystallinity domain existed in the AHF matrix. The low crystallinity index and greater amorphous nature present in the AHF could be the reason for the low conduction of heat in the system. Abundancy of AHF is enough to satisfy the need of thermal insulators to the real world. The use of furnished AHF as thermal insulators be the one of the solutions for the replacement of non-degradable materials or in the least case, it lowers the usage rate of non-degradable insulators.

Conclusion

The determination of thermal conductivity of AHF by Lee's Disc method is found to be 0.021 W/mK and crystallinity index is found to be 40%. In comparison with other known thermal insulators, AHF exhibited a low thermal conductivity and can play as a good thermal insulator. Further research on AHF will result in its utilization as thermal insulation material, which is otherwise considered as a waste.

Acknowledgement

Author gratefully acknowledge the Ministry of Tribal affairs (MoTA), Govt. of India for financial support, PURSE, Mangalore university for conducting SEM characterisation and Prof. S. M. Dharmaprakash, Department of Physics, Mangalore University for assisted in XRD characterization.

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