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Fabrication and characterization of bio composite fiber boards from areca leaf sheaths

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Abstract

Bio composite fiber boards were fabricated by utilizing the areca leaf sheaths. Areca leaf sheaths were obtained from areca nut tree and these leaf sheaths have fewer applications. Usually, these areca sheaths were decomposed in the soil without much utilization for practical applications. Bio composite fiber boards were fabricated by following the suitable methodology. The pulp consistency of the prepared pulp was determined by varying the different parameters. The pulp consistency of the fiber was found to be best suitable for manufacturing of bio composite medium-density fiber boards. The effect of NaOH on the fiber boards was also studied for different concentrations of NaOH and for different soaking times. The density of the Bio composite fiber boards was studied by varying the different parameters during the fabrication methodology. Surface roughness (Sa) and Profile roughness (Ra) of the fabricated fiber boards were studied using NANOVEA ST400 USA-made 3D non-contact profilometer. It was found that the Surface Roughness value and Profile Roughness value of the fabricated materials are almost similar to the commercially available fiber sheets.

Keywords: Bio composites, Natural fibers, Areca sheath, Pulp consistency, Bulk density, Surface Roughness

1. Introduction

Natural fibres are obtained from renewable sources. This material has got many positive advantages compared to artificial materials. Natural fibres generally have a less environmental impact than synthetic fibres because natural fibres do not use so many chemicals during the production process. In addition to this, burning natural fiber causes less environmental damage compared to artificial fibers [1, 2]. Also, it has low weight and abundant availability of raw materials making it low-cost and user-friendly. Bio composite materials fabricated using natural fibers have very huge applications in recent decades. These bio composites can substitute many of the harmful artificial composites. For our day-to-day applications, we depend upon artificial materials and mainly we depend upon plastic materials. These plastic materials are obtained from artificial compounds and are very harmful when disposing them [3-5]. The only possible way is to minimize the usage of plastics by substituting the place of plastics using the bio composite materials to some extent. By doing so, we can substitute the use of plastic over at least 85% in near future [6]. In this intention, we have planned to substitute the plastics by using natural reinforced bio composites for some of the substitutions of plastics. In our study, we have fabricated the bio composite fiber board materials by using the areca leaf sheath fibers. The main raw materials we have used for the fabrication of bio composite fiber board material are areca leaf sheath fibers [7].

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India is the largest producer of Arecanut followed by China and Bangladesh. In India, around 3Lakh hectares of land are cultivated with areca nut plants. Over six million people in India are engaged in arecanut cultivation, processing, and trade. In a year each plant sheds around 5-6 leaves. So, millions of leaf sheaths are available and extracting fibers and developing in to a product through mechanical studies gains the prime importance [8, 9]. Only 20% of these are used for areca sheath food plates and the remaining areca sheaths are becoming waste as waste material. Also, it takes more months to biodegrade in the soil completely compared with some other natural leaves [10]. So, we thought it was best to utilize Areca fiber sheaths as a natural raw material for the fabrication of the bio composite materials. It is also not only environmentally friendly, but it will help to improve the economic condition of the farmers. Using the areca sheath fibers and without using the adhesives the bio composite materials are not manufactured so far.

2. Method of fabrication

Areca Sheaths were collected from the Mangalore region of Karnataka, India. Collected areca sheaths were washed with fresh water. Then these sheaths were cut into small pieces of 10mm x 10mm dimensions. Then these pieces were soaked in fresh water for about 48 hours. As well as these pieces are soaked in NaOH solution of different concentrations [11].

2.1. Treatment of Areca Fibres with NaOH

It was confirmed from the literature review that treating natural fibers with chemicals will alter the properties of the fibers. Treatment with NaOH causes an irreversible mercerisation effect, which increases the amount of amorphous hemicellulose at the expense of crystalline cellulose. The mercerization treatment enhances the surface adhesive properties of the fibers by removing natural and artificial impurities, resulting in a roughed surface topography. [12, 13]. At 32 ˚C, Areca sheath fibers were soaked with 5%, 10%, 15%, 20%, and 25% of NaOH solution for 24 hours, 48 hours, and 60 hours, respectively. After the respective soaking time, these areca sheath pieces are washed with fresh water. These pieces of sheath were then washed with acetic acid, and it is eventually washed again with fresh water. This chemical treatment is done mainly to increase the strength of the fibers and it will also smoothen the sheath pieces for grinding purposes for making the sheath pulps [14]. Figure1 shows the areca leaf sheath pieces which are kept for soaking.

Fig. 1. Soaking of areca leaf sheath pieces

2.2. Preparation of Areca Sheath Pulp and Bio composite sheaths

The term pulp refers to a fibrous lignocellulosic material that is produced by chemically or mechanically separating wood cellulose fibers, fiber cultures, or wastepaper. It is blended with water and other chemical or plant-based additives. Pulp is the most important raw material used in the production of paper products as use of other existing biodegradable fibres are consistent in reaching the reinforcement mechanisms [15,16]. Areca sheath pieces which are soaked in fresh water and soaked in a NaOH solution are taken to make the pulp.

Panasonic grinding machine having 25000 rpm is taken for grinding purposes [17]. The soaked areca sheath pieces were ground by varying the grinding time. Different samples were ground by keeping the grinding time at 4, 8, 12, and 16 minutes. Finally, we obtain areca leaf sheath pulp with different pulp thicknesses. Pulp consistency is calculated as per the standards. Figure 2a shows the pulp sample prepared from areca leaf sheath pieces. The wooden frame is prepared to have dimensions of 200 mm x 180 mm x 30 mm. A corresponding metallic weight holder is taken. Inside the wooden frame, the pulp is poured and covered with a weight holder. Mechanical pressure of 25 KPa is applied manually to the pulp [18, 19]. Pressure is applied for about 24 hours. After the curing time, the weight holder is removed, and the pulp sheath is separated from the frame. Finally, the fabricated bio-composite fiber sheath is removed from the frame and it is dried in air for 72 hours or kept in the oven at 100 degrees for about 4 hours [20]. Figure 2b shows the final bio composite sheath prepared from the areca leaf sheath pulp.

(a) (b)

Fig. 2. (a) Pulp sample and (b) Bio composite board prepared from areca leaf

3. Characterizations

3.1. Pulp Consistency

Pulp uniformity surveillance is the most fundamental and important measure in the pulp industry. It is practically impossible to control pulp and paper production without uniform pulp consistency [21]. It is not only important to be able to detect inconsistencies but also to determine the absolute value of consistency [22,23]. Pulp consistency is determined by varying the NaOH concentration as well as soaking time by keeping the medium grinding time at 10 minutes in a 25000 rpm grinding machine. The calculation is based on the formula below [22]

$$C = \frac{F}{W} \times 100\%$$

Where, C = consistency of pulp in percentage

F = total weight of dry fibrous material in the sample

W = total weight of the pulp

Details on consistency measurements for different samples are given in Table 1.

Table 1. The details for consistency measurements for different samples

Sample Specifications*	Pulp Consistency (%)			
	After 24 Hrs	After 48 Hrs	After 60 Hrs	Average
A-0	6.5	6.3	6.3	6.4
A-5	7.2	7.2	7.3	7.3
A-10	7.3	7.5	7.5	7.4
A-15	7.7	7.7	7.8	7.7
A-20	7.7	8.0	8.0	7.9
A-25	8.2	8.3	8.3	8.3

*A-0: Areca sheath pieces soaked in freshwater, A-5: Areca sheath pieces soaked in 5% NaOH solution,
A-10: Areca sheath pieces soaked in 10% NaOH solution, A-15: Areca sheath pieces soaked in 15% NaOH solution,
A-20: Areca sheath pieces soaked in 20% NaOH solution, A-25: Areca sheaths soaked in 25% NaOH solution

3.2. Bulk density

Density is the proportion of mass to volume. It is required for the study of the composition, and properties of the samples. Knowledge of the density of the material makes it possible to determine the mass and volume of the material, all of which are extremely important measures in all industries [16,23]. Different density materials have different specified applications. The density of the fabricated bio composite sheath is determined in accordance with ASTM D1895 standards. The oven-dried sample is taken. The surface of the sample is polished using polishing paper [24]. Test samples are edges cut square to the surface. The length, width, and thickness of the samples are measured to an accuracy of 0.02 mm provided the dimension measured is less than 15 cm. Test specimen was exposed to an atmosphere maintained at a relative humidity of 65 ± 6 percent and a temperature of 27± 3°C until their masses become constant [16, 25]. Using the relation below, bulk density was calculated.

$$\rho = \frac{m}{v}$$

3.2.1. Determination of Bulk Density for different samples by varying soaking time

Bulk density is calculated for different samples by varying the soaking duration of the areca leaf sheath and obtained data is mentioned in Table 2.

Table 2. Variation of bulk density for different soaking duration of the sample

Sample Specifications	Density (Kg/m^3)		
	After 24Hrs	After 48Hrs	After 60Hrs
A-0	360	365	365
A-5	485	490	490
A-10	495	495	500
A-15	500	500	505
A-20	505	505	510
A-25	510	510	512

A-0: Areca sheath pieces soaked in freshwater, A-5: Areca sheath pieces soaked in 5% NaOH solution,
A-10: Areca sheath pieces soaked in 10% NaOH solution, A-15: Areca sheath pieces soaked in 15% NaOH solution,
A-20: Areca sheath pieces soaked in 20% NaOH solution, A-25: Areca sheaths soaked in 25% NaOH solution

3.2.2. Determination of Bulk Density for different grinding time

Areca leaf sheath which is soaked for 48 hours is taken and ground mechanically by varying the grinding time. The speed of the grinding machine is fixed at 25000 rpm and the grinding time is varied as 4, 8, 12, and 16 minutes. Table 3 gives the density variations with respect to grinding time. T indicates the grinding time of the sheath pieces in minutes.

Table 3. Variation of the bulk density for the different grinding times of the sample

Sample Specifications	Density (Kg/m^3)			
	T=4 Minutes	T=8 Minutes	T=12 Minutes	T= 16 Minutes
A-0	340	355	368	370
A-5	472	480	495	500
A-10	480	490	500	510
A-15	482	495	515	520
A-20	489	500	520	525
A-25	492	505	528	532

A-0: Areca sheath pieces soaked in freshwater, A-5: Areca sheath pieces soaked in 5% NaOH solution,
A-10: Areca sheath pieces soaked in 10% NaOH solution, A-15: Areca sheath pieces soaked in 15% NaOH solution,
A-20: Areca sheath pieces soaked in 20% NaOH solution, A-25: Areca sheaths soaked in 25% NaOH solution

3.3 Profilometer study of the sample

An important factor that influences the quality of wood-based materials is their surface quality which influences the different applications of the material. The surface roughness of these bio composite materials can be affected by different factors which include the composition of the raw material, strength of the fibers, quality of the pulp, etc. Surface roughness and Surface irregularities of wood-based products can be determined as numerical values using different terms employing various techniques [25, 26]. An optical profilometer is one of the efficient methods for the determination of the surface roughness of wood-based samples [25]. Surface roughness is a latent property of wood-based composite products. Unless they are exposed to high humidity conditions, they do not exhibit any significant problems [27].

Prior to roughness measurement, Temperature is maintained at 20 ˚C, and relative humidity of 65% is maintained until they reach equilibrium moisture content NANOVEA ST400 USA-made 3D non-contact profilometer was used for surface roughness measurements. It has 3D- non-contact, chromatic confocal sensors with a speed up to 200 times faster and 200mm × 150mm X-Y axis continuous scan with a speed up to 40 mm/s and 50mm motorized Z axis. It has High-speed large-area measurements with high-speed sensors. It can give 2D & 3D surface measurement imaging different roughness parameters can be calculated from the digital information.

In this research work, Average roughness (Ra), Mean peak-to-valley (Rz), and Maximum roughness (Rmax) was used to calculate the surface of the sample. The calibration of the profilometer was done by using a standard plate every 100 measurements to make sure there is no significant variation in the values [27]. In this work, we have considered four samples. They are as follows,

- The first sample which is fabricated without treating the pulp with NaOH and having 10 mm thickness,
- The second sample which is fabricated without treating the pulp with NaOH and having 2 mm thickness.
- The third sample which is fabricated by treating the areca sheath pieces with 10 % NaOH for 48 hours and having a thickness of 6 mm.
- Finally, fourth sample Readymade commercially available cardboard having a thickness of 6 mm.

Figure 3 shows the instrument set up for the measurement of Surface Roughness.

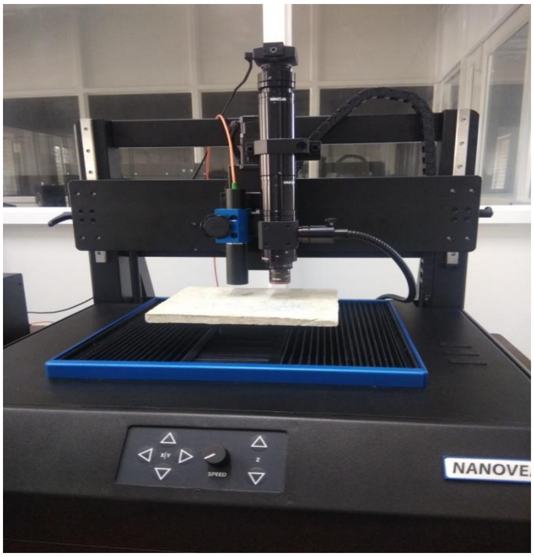
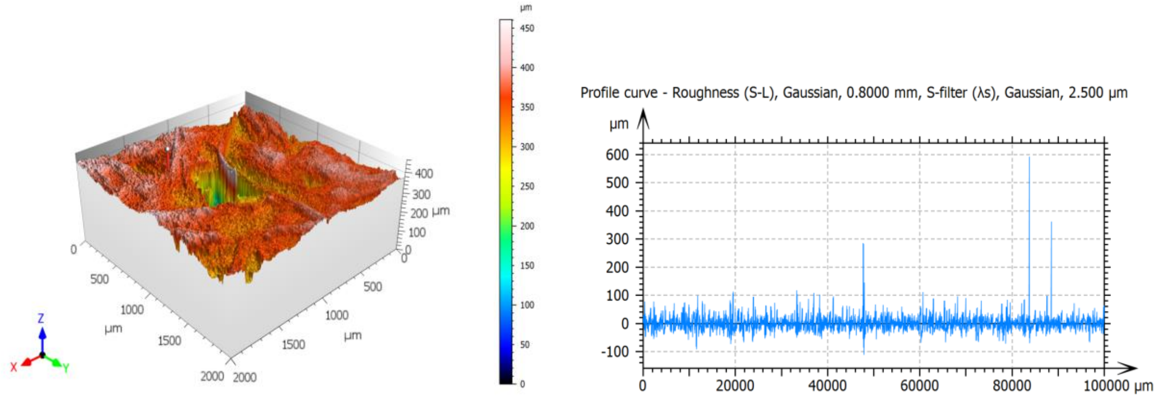
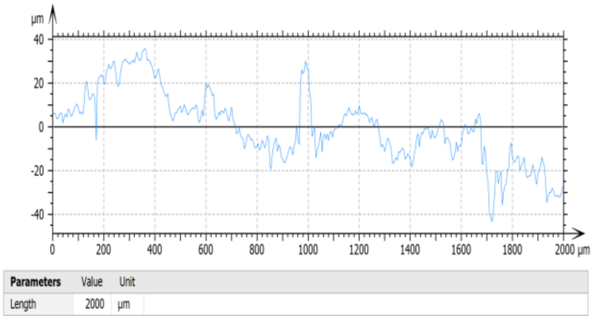


Fig. 3. Instrumental setup for Surface Roughness measurement

Figure 4 and Figure 5 show the 3D image of sample 1 and sample 3. It indicates the x-y-z variations of the surface. The four graphical representations show the Profile curve for the 4 samples as mentioned above. Profile curve consists of a variation of the surface irregularities. Along the x-axis, y-axis, and length are measured in terms of micrometers. Figure 6 (a) & (c) Profile curve for Sample 2 & 4, (b) Surface Roughness (Sa) of the third sample.

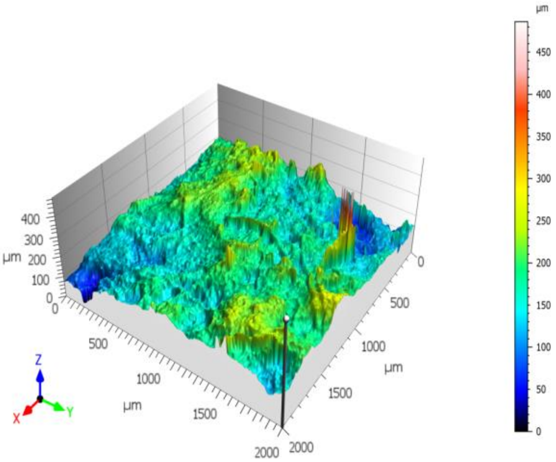


(a) (b)

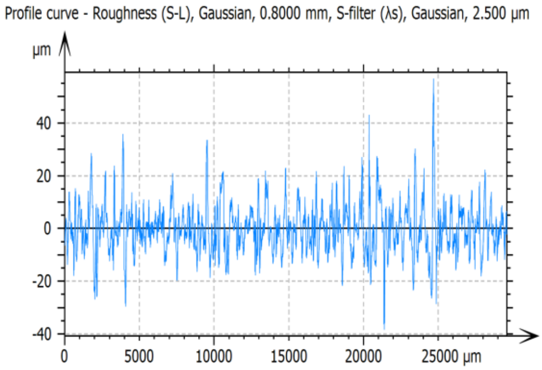


(c)

Fig. 4. (a) 3D Image, (b) Profile curve and (c) Surface Roughness (S_a) of the first sample

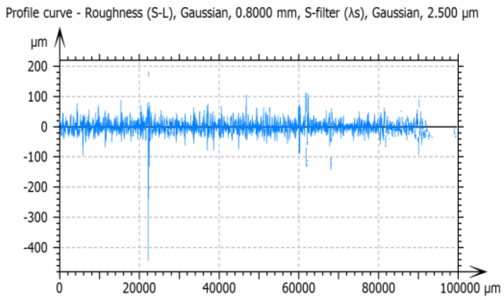


a) 3D Image

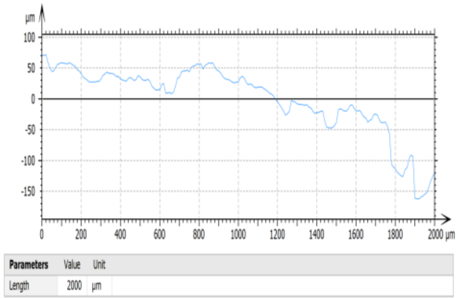


b) Profile curve

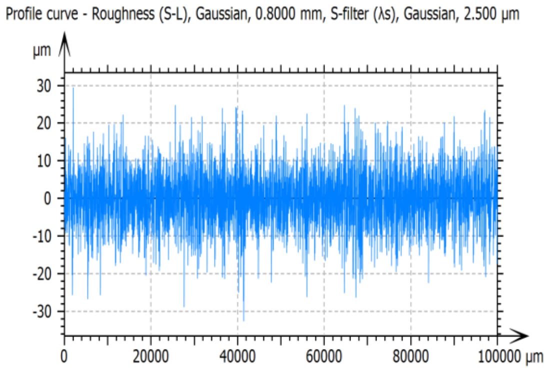
Fig. 5. (a) 3D Image and (b) Profile curve



a)



b)



c) Profile curve for Sample 4

Fig. 6. (a) & (c) Profile curve for Sample 2 & 4, (b) Surface Roughness (S_a) of the third sample

4. Results and Discussion

4.1 Pulp Consistency

The pulp consistency of the prepared areca sheath leaf increases as the soaking time increase to 48 hours and after that, it remains almost the same. For samples that are not acid treated, they showed about 6.5% pulp consistency. As the NaOH concentration increases pulp consistency also increases. It has increased from 7.2% to 8.2% with 24 hours of soaking time and 5% NaOH. So, the average pulp consistency of the fabricated bio composite having 7.5% consistency which is best suitable for the fabrication of bio composite medium-density fiber materials.

4.2 Bulk Density

The bulk density of the sample increased from 360kg/m^3 to 365kg/m^3 from soaking time 24 hours to 60 hours for samples that are not acid treated. For acid-treated samples density varied from 485kg/m^3 to 512 kg/m^3 by varying the concentration of the NaOH from 5% to 25%. Variations of the grinding time showed us vast variations in the density of the fabricated bio composite material. For non-acid-treated pulp, the fabricated bio composite showed density variation from 340kg/m^3 to 370 kg/m^3 for the grinding time of 4 minutes to 16 minutes. After that density remains the same. For acid-treated samples density varied from 472kg/m^3 to 492 kg/m^3 for 5% NaOH concentration to 25% NaOH concentration by keeping the grinding time at 4 minutes. It varied from 500 kg/m^3 to 532 kg/m^3 for 16 minutes of grinding time by varying the NaOH concentration from 5% to 25 %. After that, it remains constant even if the grinding time is varied further.

4.3 Profilometer Study

For sample.1 which is fabricated without using NaOH for soaking the sheath with 10mm thickness shows Surface roughness, Sa as 30.49 µm. Profile roughness for the same sample Ra as 8.49 µm. For sample.2 which is fabricated without using NaOH for soaking the sheath with 2mm thickness shows Sa as 25.5µm. Profile roughness Ra as 7.6 µm., For sample.3 which is fabricated by soaking the areca leaf sheath with 10% NaOH solution for 48 hours, we get Sa = 28.40 µm and Ra = 6.62 µm. Sample 4 which is readymade cardboard with a thickness of 6mm has a Surface roughness value Sa= 20 µm. Profile roughness Ra = 5.20 µm. Hence, we can fabricate the bio composite material from areca sheath fiber with a Surface roughness value Sa of around 25 µm and Profile roughness value of around 6 µm. These values are comparable with the commercially available bio composite materials which are obtained from other sources.

5. Conclusions

Natural fibers obtained from Areca sheaths are very suitable for the fabrication of bio composite materials. These areca sheath fibers have the special property of self-binding. The present study succeeded in the fabrication of Bio Composite Fiber Boards from Areca Leaf Sheaths and conducted an experimental study on Pulp Consistency, Bulk Density, and Profilometer Study on prepared composites. It's concluded that the average pulp consistency of the bio composite consistency is found to be 7.5% and for the bulk density, it is observed from the results that acid-treated samples yield higher density value than untreated samples witnessing its consideration on the need to undertake the process of treating the samples. Regarding surface roughness, it is concluded that it's possible to achieve the surface roughness value of 25 µm with profile roughness value of around 6 µm and the experimental values are comparable with the commercially available bio composite materials.

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