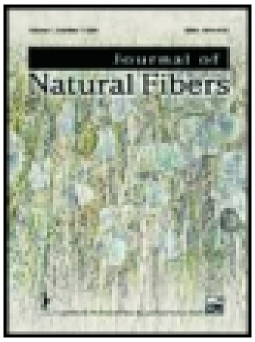

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Investigating the Properties of Wet-Laid Nonwoven Made from Mechanically Fibrillated Jute Fiber

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ABSTRACT
The jute fibers have been mechanically fibrillated, and the wet-laid non-woven fabrics have been manufactured using these fibers at two different concentrations of binder. The mechanically fibrillated states from non-fibrillated and partially fibrillated to highly fibrillated are considered at different lengths of fibers such as 5 and 10 mm to 15 mm. The tensile strength, air permeability, and the acoustic property of formed web are analyzed. There is no significant effect of fiber fibrillation found on the tensile properties of the manufactured wet-laid web, while there is an effect of fiber fibrillation observed on air permeability.

摒要
黄麻纤维经过机械纤维化处理，并在两种不同浓度的粘合剂中使用这些纤维生产湿铺非织造布. 从非纤维化、部分纤维化到高度纤维化的机械纤维化状态被认为是在不同长度的纤维5毫米、10毫米到15毫米. 分析了成形腹板的拉伸强度、透气性和声学性能. 纤维纤颤对湿铺网的拉伸性能没有显著影响，而纤维纤颤对透气性有显著影响.

KEYWORDS
Word; jute fiber; fibrillation; wet-laid nonwoven; acoustic property

关键词
单词; 黄麻纤维; 纤维性颤动; 湿铺非织造布; 声学性能

Introduction

Nonwoven fabric is a sheet of fibrous material having a varying degree of porosity based on the techniques of manufacturing. Almost all types of fibers from natural to regenerated and synthetic are used for the production of nonwoven fabrics like the use of viscose fiber for wet-laid nonwoven (Bernt and Eckhart 2013). Among the available techniques of manufacturing nonwovens, wet-laid is one of the suitable techniques for manufacturing of the sustainable product (Berto et al. 2012) made from short natural fiber or waste fiber (Iasnicu, Vasile, and Iatan 2015). From commercial aspects, the rate of production on a wet-laid nonwoven machine is many times greater than that can be achieved in a typical woven textile line (Williams 1993), and also, the there is a provision of recycling of water.

The various sustainable materials including textile fibers can be used for insulation (Asdrubali and Alessandro 2015; Mohanty 2014) in the form of fibrous sheet. The use of natural fibers is important from a sustainability point of view, and jute fiber is one of the fibers which is finding a place at various applications in the form of nonwoven in technical applications. Natural bast fibers like flax and jute because of their multicellular structure can be fibrillated, and surface structure can be modified by mechanical beating action and chemically (Erdoğan et al. 2016; Hai, Kim, and Lee 2009) and biologically modified by using enzymes (Karaduman, Gokcan, and Onal 2013). Various studies have been carried out on properties of nonwovens, acoustic properties of needle-punched wool (Botha 2015), jute composites (Fatima and Mohanty 2011), and needle-punched nonwoven

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using luffa fibers (Thilagavathi et al. 2017). Also, in some studies, the cellulosic and modified cellulosic (Doh et al. 2013) fibers have been used as a raw material. Very few studies are available on the investigation of properties of wet-laid jute fiber. In one of the studies (Fagus et al. 2013), acoustic properties of flax wet-laid nonwoven fabric are studied to see the effect of different types of binder fibers. There is no study available on the wet-laid nonwoven made from mechanically fibrillated fiber.

During the mechanical processing and recycling of jute fiber, generally, the fibers undergo multiple beating action which may lead to the mechanical fiber fibrillation. In the present study, the fibers are mechanically fibrillated, and the corresponding properties of wet-laid nonwoven made from these fibers have been investigated. As the wet-laid nonwoven can be used in acoustic applications as a sustainable material, in the present study, the acoustic property is also characterized (Berardi, Lannace, and Gabriele 2016) using impedance tube.

Materials and methods

The sample preparation

The jute fibers are considered as the raw material for the preparation of wet-laid nonwoven. The fibers are cut into the lengths of 5, 10, and 15 mm, and the fibers of each category of length are mechanically fibrillated separately in laboratory scale using a rotating blade in a moist condition. The structure of fibers is observed after beating the fiber in the beater at different speeds of rotation at different times. Finally, the speeds are optimized for each fibrillation stage, which are 1100 rpm for partial fibrillation and 1400 rpm for high fibrillation for the duration of 1 min. The mechanical beating action results in the fibrillation of the fibers, the partially beaten up fibers state where the cells are just started to come out of the surface, and highly fibrillated state where the cells have come out to maximum possible extent out of the parent fiber.

The slurry is prepared by gradually mixing jute fibers and stirring while maintaining dilution of 0.5 g of fibers per liter of water. The slurry is passed through the slice opening of the headbox on to a polyester fabric screen as shown in Figure 1. The headbox movement is kept constant to maintain the web uniformity.

The styrene acrylic binder sprayed over the surface just after web formation and afterward dried in oven at a temperature of 90° for 1 h; the fiber deposited on screen; and the dried sample is as

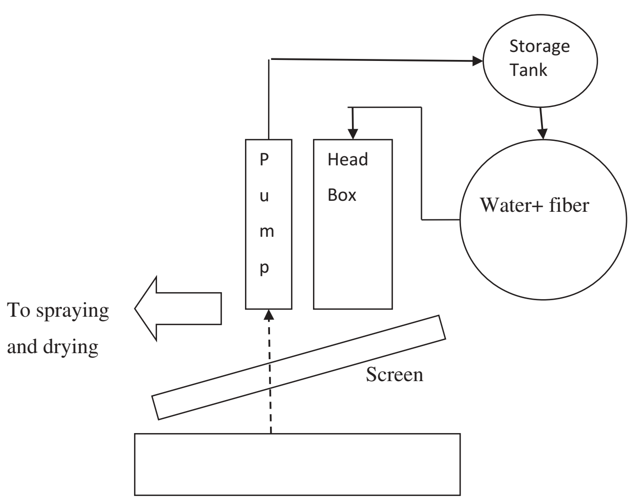

Figure 1. Schematic diagram of wet-laid fabric formation setup.

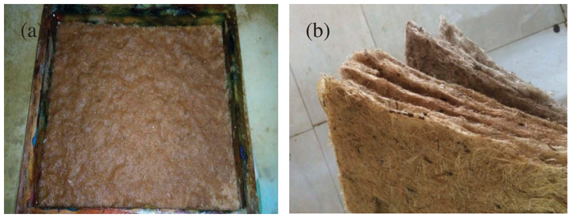

Figure 2. Wet-laid nonwoven sample formation: (a) fiber deposited over the polyester screen and (b) wet-laid samples after drying.

shown in Figure 2. The equal quantity of binder solution is sprayed over the surface from the front and back sides for all the samples at binder concentrations of 10 and 20 mL per 100 mL of water. The total 500 mL binder solution is spread over a manufactured web; therefore, the concentration of binder on the manufactured web is around 2.5 and 5 mL/g corresponding to binder concentrations of 10 and 20 mL per 100 mL of water. The uniformity of samples in terms of aerial density and thickness is achieved by feeding a known weight of fibers in a scullery at high dilution and uniform movement of headbox.

The variables that are considered for the preparation of fabric are shown in Table 1. The different lengths of fibers considered are 5, 10, and 15 mm obtained by cutting a long fiber strand of jute fibers. The binder concentration is kept at two levels: low (2.5 mL/g) and high (5 mL/g).

Characterization

The samples were conditioned at standard atmospheric conditions for 24 h before testing. The areal density of samples was measured (ASTM D-1910) using electronic balance, and fabric thickness was measured by digital thickness tester according to ASTM D-1777. The tensile strength of the fabric is measured by using tensometer, while the air permeability of the fabric is tested as per ASTM D-737 using air permeability tester. The acoustic property is characterized by using the impedance tube in the range of 100–6300 Hz as per ISO 10532, ASTM E-1050, as shown in Figure 3. The samples for acoustic test are prepared by cutting into a circular shape with diameter of 100 and 30 mm, where the larger sample is used for low frequency (63–1600 Hz) and small size sample is used for 800–6400 Hz frequency range.

The sound absorption coefficient (α) which is the ratio between intensities of reflected and incident waves is calculated from the transfer function (ASTM E-1050) as follows:

$\alpha = 1 - r^2$, where r is the sound pressure reflection factor

$$r = [H_{12} - H1/H_R - H_{12}]\, e^{2jk_0 x_1}$$

where H_{12} is the complex transference function = $p2/p1$ further, and $p1$ and $p2$ are the complex sound pressures at the two microphone positions,

Table 1. Variables considered for manufacturing wet-laid nonwoven samples.

Factor	Levels
Fibrillation state*	H,P,N
Fiber length	5 mm, 10 mm, 15 mm
Binder concentration	Low, high

*H – highly fibrillated, P – partially fibrillated, and N – non-fibrillated.

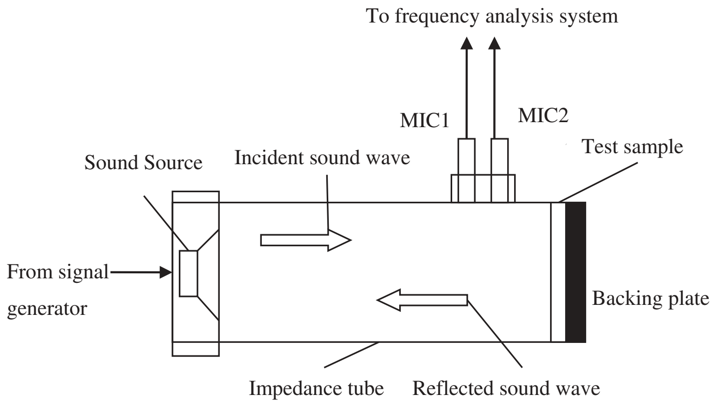

Figure 3. Schematic diagram of impedance tube setup.

x_1 and x_2 are the distances between the two microphone positions from the reference plane ($x = 0$),

H_R = transference function from the reflected wave,

k_0 = complex wavenumber,

x_1 = distance between sample and microphone.

Results and discussion

The samples of nearly same aerial density and thickness have been prepared by considering the variables fiber fibrillation state, fiber length, and binder concentration, and afterward, the tensile strength and air permeability are measured as shown in Table2. Also, the acoustic properties of the selected samples are characterized as shown in Figure 6.

The samples have been analyzed under the microscope, and the images obtained are shown in Figure 4, where the variation in the fiber fineness as a result of fibrillation can be seen. The average fiber diameter obtained for non-fibrillated fiber sample is 0.089 mm (cv = 17.4%), for partially

Table 2. Wet-laid fabric sample specifications with tensile property and air permeability of samples.

Sr. No.	Fiber length (mm)	Binder concentration	Fibrillation state	Fabric thickness (mm)	Areal density (g/m^2)	Tensile strength (N)	Air permeability cm^3/cm^2/s
1	5	High	H. Fibrillated	3.43 (2.35%)	159	52.61 ± 5.23	98.45 (2.56%)
2	5	High	P. Fibrillated	3.21 (3.46%)	156	50.44 ± 4.98	94.88 (3.57%)
3	5	High	N. Fibrillated	3.72 (3.47%)	158	50.73 ± 4.55	107.01 (3.26%)
4	5	Low	H. Fibrillated	3.65 (3.52%)	152	48.21 ± 3.87	115.21 (3.96%)
5	5	Low	P. Fibrillated	3.75 (3.63%)	158	43.53 ± 3.20	105.22 (3.02%)
6	5	Low	N. Fibrillated	3.81 (3.4%)	150	45.45 ± 5.06	118.78 (2.66%)
7	10	High	H. Fibrillated	3.65 (3.57%)	158	60.91 ± 3.99	104.51 (3.82%)
8	10	High	P. Fibrillated	3.49 (3.56%)	160	59.89 ± 4.21	121.27 (2.37%)
9	10	High	N. Fibrillated	3.82 (4.11%)	162	57.75 ± 5.11	128.41 (3.22%)
10	10	Low	H. Fibrillated	3.91 (2.9%)	156	57.58 ± 5.70	122.34 (2.19%)
11	10	Low	P. Fibrillated	3.56 (4.02%)	157	55.79 ± 4.86	128.41 (2.65%)
12	10	Low	N. Fibrillated	3.56 (3.63%)	160	55.31 ± 5.80	141.25 (2.16%)
13	15	High	H. Fibrillated	3.91 (4.94%)	163	62.49 ± 5.55	121.27 (3.86%)
14	15	High	P. Fibrillated	3.82(3.45%)	156	60.35 ± 3.23	140.18 (3.23%)
15	15	High	N. Fibrillated	3.73 (4.08%)	158	59.66 ± 3.99	155.52 (2.56%)
16	15	Low	H. Fibrillated	3.76 (3.91%)	157	59.38 ± 2.61	133.04 (2.56%)
17	15	Low	P. Fibrillated	3.91 (3.42%)	162	57.73 ± 4.41	142.68 (4.12%)
18	15	Low	N. Fibrillated	3.80 (3.69%)	160	57.53 ± 4.20	158.01 (2.29%)

Values in parentheses indicate the standard deviation.

Figure 4. Images of wet-laid samples made from (a) non-fibrillated fiber (sample 18), (b) partially fibrillated fibers (sample 14), and (c) highly fibrillated fibers (sample 16) using 15-mm fiber and (d) fibrillated fiber (sample 4) using 5-mm fiber.

fibrillated sample is 0.071 mm (cv = 25.9%), and 0.059 mm (cv = 43.34%) for highly fibrillated sample. The increase in the cv% (coefficient of variation) from non-fibrillated stage to fibrillated stage is observed. This increase in variation is because some fibers form a fibril of comparatively small diameter after beating and some fibers does not undergoes the fibrillation even after mechanical beating, which results in the fibers of varying diameters.

The tensile strength of the wet-laid fabric is increasing with the increase in fiber length of raw fiber used for preparing the fabric as shown in Figure 5, as there is a direct relation of strength with fiber length. Even though the fiber fibrillation results in fiber bundle disintegration, there is no significant effect of fiber fibrillation seen on fabric strength at both high and low binder

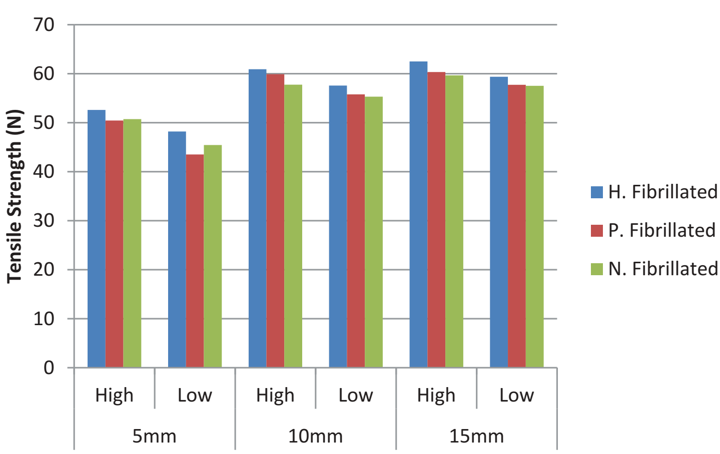

Figure 5. Effect of fiber fibrillation on the tensile strength of wet-laid nonwoven.

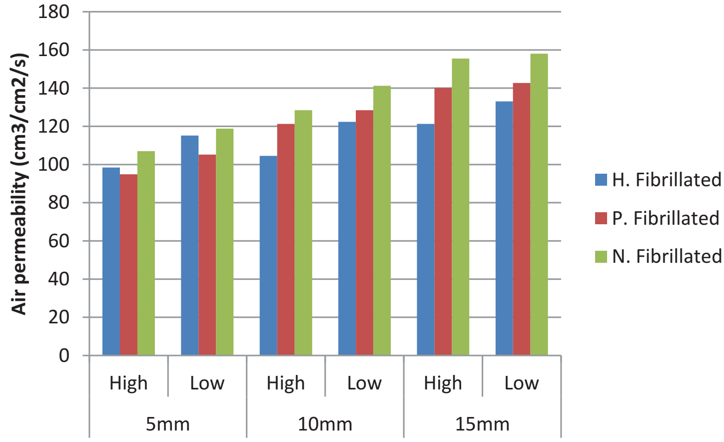

Figure 6. Effect of fiber fibrillation on the air permeability of wet-laid nonwoven.

concentrations. At higher binder concentration due to more binding of fibers, there is more strength obtained compared to lower concentration of binder.

Figure 6 shows that the air permeability is increasing with the increase in the fiber length. This may be because of the better distribution of fibers of lower length for equal fiber concentration as compared to the fibers with longer length as shown in Figure 3 and, hence, the more surface area in contact with passing air. As obvious with the increase in the binder concentration, the permeability is decreasing as shown in Figure 6, as there will be more blockage of pores with an increase in binder concentration. As far as the effect of fibrillation on air permeability is concerned, the non-fibrillated fiber samples show more permeability compared to fibrillated irrespective of fiber length because the disintegrated structure of fibrillated fiber covers more surface area and hence more resistance to the air.

The acoustic property is analyzed by measuring sound absorption coefficient at different frequencies as shown in Figure 7. The samples 7, 9, and 10 have been analyzed, and these are the

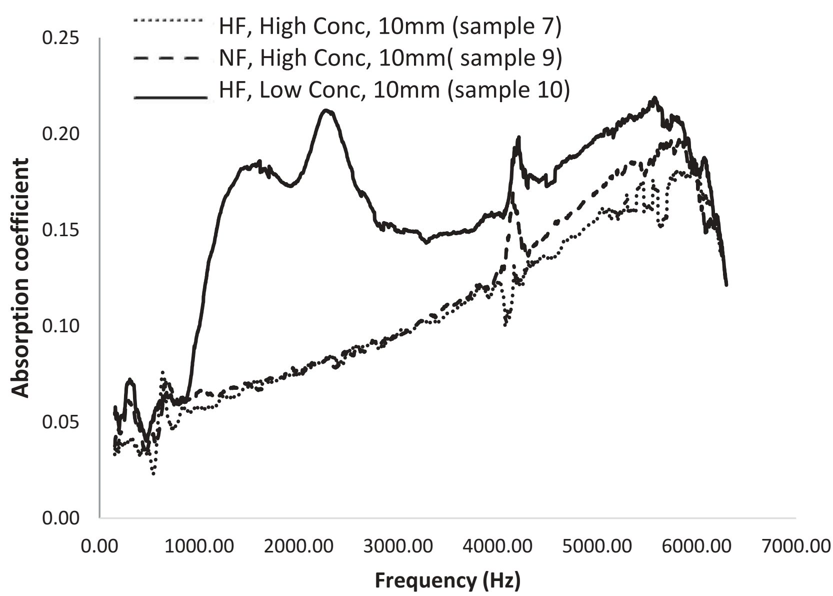

Figure 7. Plot evaluation of the absorption coefficient of wet-laid nonwovens using a fiber of 10-mm length: at high binder concentration using highly fibrillation state (sample 7) and non-fibrillation state (sample 9); at low binder concentration using highly fibrillated fibers.

samples with a fiber length of 10 mm at different concentrations and fibrillation states. Samples 7 (highly fibrillated at high binder concentration) and 9 (non-fibrillated at high binder concentration) have been selected to see the effect of fibrils on the acoustic properties. For the porous material, absorption is mainly depended on the porosity and pore size distribution. Based on this hypothesis, the fibrils which are coming out of the surface will affect the porosity and internal sound reflection path. Furthermore, to observe the effect of binder concentration on fibrillated fiber, sample 10 (highly fibrillated at low binder concentration) is also considered as the high concentration can block the pores and affect the sound absorption.

It is seen from the graph in Figure 7 that a fabric which made by fully fibrillated fibers at a lower concentration of binder (sample 10) is giving the more sound absorption than the other samples. The difference in absorption coefficient is not significant at lower frequency range 0–500 Hz, while for the range 1000–3000 Hz, there is a distinct difference observed, which may be due to the effect of porosity between fibers is more effective at this range of frequency. For samples at higher concentrations (samples 7 and 9), there is not much absorption seen, and this may be because of blocking of pores and binding of fibers by the binder at higher concentration.

Conclusion

The waste jute fiber obtained after different beating actions of varied length can be used for wet-laid nonwoven with no significant effect on fabric strength above 2.5% concentration of binder. But for the application where air permeability is the important property, the magnitude of beating, that is fibrillation state of the fiber, needs to be considered. As it has been found that the air permeability is influenced by the fiber fibrillation and binder concentration, with an increase in the fibrillation, the permeability is decreasing irrespective of binder concentration. The effect of fiber fibrillation on acoustic properties has been seen at a lower concentration. The acoustic property of wet-laid nonwoven made from the fibrillated fiber at low concentration is impressive for a given thickness of about 3.7 mm only, which is comparatively low as compared to the thickness used for sound insulating material. There is scope of using fibrillated jute fiber for the acoustic insulation by further increasing the thickness, which further needs to be investigated at different thicknesses.

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