Development of Needle-Punched Nonwoven Fabrics from Natural Fibers for Sound Absorption Behavior.

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Abstract: The natural fibers prepared from plant waste have parameters like fiber strength, length, and chemical composition which are suitable to fabric and the fibers into nonwoven. The selected plants were identified from their botanical names by comparing the collected samples with those of known identity in the herbarium of a botanical survey in India with their names as *Sesbania grandiflora*, *Muntingia Calabura*, and *Bauhinia Purpurea*. A novel Portable multi-fibre decorticator machine was fabricated and used to extract the fibers from the plant stem and barks. The extracted fibers are done physical characterization and their properties are investigated. The extracted fibers are blended with other natural fibers like jute and flax in appropriate proportions 45:45:10 and nonwoven fabrics were prepared by the needle-punching method. Three and four-layer nonwovens are produced using a needle punching machine. The developed nonwovens are tested using standard apparatus and the effect of natural fibers in areal density, thickness; bulk density, porosity, and air permeability are analyzed. In addition, thermal conductivity and sound absorption behaviour are also investigated. The sound absorption property increases concerning areal density and fabric thickness. The thermal conductivity increased by increasing the fiber layer in the fabric to evaluate its potential as a protective barrier material in non-woven face masks.

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1. INTRODUCTION

Technical textiles were developing in many different directions with varying speed and level of success for long years. Technical textiles are becoming one of the most important elements of modern technology and lifestyle and it is present everywhere. Their end-uses ranges from simple products such as filters to acoustic and thermal insulation for domestic/industrial applications.

1.1 *Sesbania Grandiflora* (NSG)

Sesbania Grandiflora is a medicinal plant that belongs to the family Leguminosae. The plant contains rich in tannins, flavonoids, coumarins, steroids, and triterpenes. NSG is a thin small erect, fast-growing, and sparsely branched tree that reaches 10 m in height. The bark of this species is light grey, corky and deeply furrowed and the wood is soft and white. All *Sesbania* species have compound leaves where each leaf is divided into multiple leaflets

which can be up to 30 cm long with 5-15 paired leaflets that are oblong to elliptic in shape and about 3 cm in length. The flowers of *Sesbania Grandiflora* are large (7–9 cm long) shown in Plate Ia.

1.2 *Muntingia Calabura*-NMC

Muntingia Calabura is a fast-growing tree of slender proportions, reaching a height of approximately 7.5-12m within early horizontal spreading branches. NMC is evergreen approximately 5-12.5 cm long, alternate lanceolate or oblong, long-pointed at the apex, oblique at the base with dark green colour and minutely hairy on the upper surface, grey-or brown hairy on the underside and irregularly toothed. The flowers are approximately 1.25-2cm wide. The fruits are abundant, in round shape; approximately 1-1.25cm wide, with red or yellow, thin, smooth, tender skin and light brown, soft, juicy pulp, with very sweet, musky, fig-like flavour, and filled with exceedingly tiny, yellowish seeds were shown in Plate Ib.

Plate 1a.

Plate 1b.

Plate 1c.

Plate 1d. Decorticator Machine

Plate 1e. NSG Fiber

Plat 1f. NMC Fiber

Plate 1g. NBP Fiber

Plate 1. Extraction of fibers from different plants

1.3 Bauhinia Purpurea-NBP

Bauhinia Purpurea is a flowering plant species belonging to the family Leguminosae, commonly found in Southeast Asia. Different parts of this plant have been used in traditional medicine to cure a host of illness such as body pain, rheumatism, fever, dropsy, stomach tumour, skin diseases, septicemia, and diarrhoea. The leaf, bark, and root of this plant have shown sign of analgesic, anti-inflammatory, antipyretic properties were shown in Plate 1c.

1.4 Cutting and Blending of Fibers

Sesbania Grandiflora, Muntingia Calabura, and Bauhinia Purpurea are blended with fibers jute and flax (6) in different percentages which will enhance

the performance and improves the aesthetic qualities of the fabric as cited in (www.fabric.link.com/blends.html). The ratio of the needle-punched nonwoven process is presented in Figure 1.

The arrangement of the fibers and their orientation distribution are related to the mechanical structure of the web. Fiber orientation has a big influence on the tensile strength of the nonwoven material.

Uneven distribution in fiber orientation results in anisotropic behaviours in mechanical properties. Plate 2 (a, b, c, and d) shows the photo images of the instruments used for the needle-punching process.

F-Flax; J-jute, NSG- *Sesbania Grandiflora*; NMC-*Muntingia Calabura*; NBP- *Bauhinia Purpur*

Figure 1. The blending ratio of the needle-punched nonwoven process

(a) Conveyor Belt

(b) Web layer

(c) Needle punching

(d) Nonwoven Fabric

Plate 2. Needle-punching process

1.5 Fiber Carding

Carding is a mechanical process that starts with the opening of fibres which are blended and conveyed to the next stage. The tuft is fed into the card teeth. The toothed roller interacts to produce the separation of fiber. The web can be parallel-laid, where most of the fibers are laid in the direction of web travel. Each web was processed through the carding machine and needle-punching (two times) to develop the complete nonwoven

1.6 Needle-punching process

After the web formation, the webs were laid one upon another. The laying process was carried out to increase the thickness of the web. Whenever it is required, the thickness can be obtained for the end product. The produced web was needle-punched using DILO needle-punching machine. The web layer was compressed to form flexible nonwoven. Needle punching is the processes of bonding nonwoven web structures by mechanically interlocking the fibers through the web. 1200 barbed felting needles are punched vertically through the web to hook and entangled tufts of fibers. Needles punched non-woven resemble felt in appearance barbed needles mounted on a punch fiber into the web and then withdraw leaving the fibers entangled by varying the stroke per minute, the advance rate of the web, and the degree of penetration of the needles, a wide range of fabric densities can be achieved. The nonwoven fabrics were developed at 300 punches/sq.cm speed of 257 cycles/min and at 11mm needle penetration depth using a barbed needle.

Figure 2. Schematic diagram of the needle-punching process

2. TESTING METHODS

2.1 Sound Absorption Coefficient Measurement

The sound absorption test was carried out at the Indian Institute of Technology, Chennai, Tamilnadu, India using Standing Wave Apparatus. The acoustic test unit composed of a loudspeaker, amplifier, and impedance tube, microphone probe, oscilloscope, and waveform generator as shown in Figure 3.

Figure 3. Schematic representation of standing wave apparatus

A loudspeaker produces an acoustic wave that travels down the pipe and reflects from the test sample. The phase interference between the waves in the pipe which are incident upon and reflected from the test sample result in the formation of a standing wave pattern in the pipe. The required frequency is generated using a waveform generator; the microphone attached to the microphone car was moved back and forth to measure the minimum and maximum sound pressure levels. If 100% of the incident wave is reflected in the incident and reflected waves have the same amplitude; the nodes in the pipe have zero pressure and the antinodes have double the pressure. If some of the incidents sound energy is absorbed by the sample, then the incident and reflected waves have different amplitudes; the nodes in the pipe no longer have zero pressure. The pressure amplitudes at nodes and antinodes are measured with a microphone probe attached to a car that slides along a graduated ruler.

The ratio of the pressure maximum (antinode) to the pressure minimum (node) is called the standing wave ratio (SWR). Plate-IX images of standing wave apparatus. The absorption coefficient was calculated as the average value of three cylindrical foam pieces of dimension 90mm in diameter and 15mm thick for different frequencies in the range from 100 to 2000 Hz. Sound absorption Coefficient (α) can be defined as the ratio of energy absorbed by a material to the energy incident upon its surface.

$$\text{Thus SWR} = (A + B) / (A - B) \quad (1.7)$$

Where $A+B$ is pressure maximum, $A-B$ is pressure minimum.

The reflection coefficient R is defined by

$$R = B/A = (SWR + 1) / (SWR - 1) \quad (1.8),$$

The sound absorption coefficient,

$$\alpha = 1 - R^2 = 1 - (SWR - 1)^2 / (SWR + 1)^2 \quad (1.9)$$

$$\text{Absorption coefficient is } \alpha = 1 - R^2 \quad (1.10)$$

A loudspeaker produces an acoustic wave that travels down the pipe and reflects from the test sample. The phase interference between the waves in the pipe that are incident upon and reflected from the test sample result in the formation of a standing wave pattern in the pipe.

Figure 3. Schematic representation of standing wave apparatus

(a) Impedance tube

(b) Microphone car

(c) Functional generator

(d) Frequency analyzer

Plate 3. Standing wave apparatus

3. RESULT AND DISCUSSION

The properties of the needle punched non woven fabric samples were measured and the average value of the samples are tabulated in Table1.

3.1 Influence of Thickness on Sound Absorption

Fig.4 shows the influence of fabric thickness on sound absorption. Out of six blended samples, NSG (4L) displayed the highest thickness of 6.73 mm. Moreover, the blending of natural fibers with these nonwoven fabrics leads to more number of fibers per unit area resulting in an increased thickness of the fabrics. The sound absorption coefficient of the composites was

measured and was in the range of 0.4958 – 0.5464. The results revealed that the highest sound insulation was observed for the sample NSG (4L). This may be ascribed that when the number of fibers in the fabric increases, the fibers get closer to each other because of the lack of space between each fiber in the fabric. By increasing the fiber mass per unit area, the sound absorption coefficient of the fabric increases.

Figure 5 manifest the graph of areal density against the sound absorption of the fabrics. The areal density increases concerning the number of layers. For each fiber, the four-layered fabric exhibited higher areal density compared to the three-layered fabric. When there is an increase in the areal density there is an increase in sound absorption. The nonwoven fabric NSG (4L) showed the highest areal density of 766 g/m² resulted in the highest sound absorption coefficient of 0.5464.

The influence of bulk density on the sound absorption coefficient of nonwoven fabrics as shown in Figure 6 revealed that the sound absorption coefficient increases concerning bulk density. The NB (4L) sample showed the highest bulk density of 0.116 g/cm³ and exhibited a higher sound absorption coefficient of 0.5022. This may be due to the density and fineness of the fibers (extracted from the Bauhinia Purpurea plant) is greater than that of other fibers extracted from different plants, which increases the bulk density.

Figure 7 represents the influence of fabric porosity on sound absorption. The fabric porosity of nonwoven fabrics was in the range of 0.633 – 0.906%. Out of six fabric samples, the NMC (3L) sample exhibited the highest porosity of 0.906%. If the porosity increases, the natural fiber blended nonwoven fabrics allow more air within the structure. The sound absorption decreases as the porosity of the sample increased. The sound absorption coefficient of the NMC (3L) sample was calculated as 0.5022.

Figure 8 refers to the air permeability of NSG, NMC and NB samples. The deviation among the samples can be tested based upon the fiber type and layer of materials. The air permeability of needle-punched nonwoven samples was in the range of 41.1 - 93.7 cc/s/cm² with the sound absorption coefficient of 0.4958-0.5464. The air permeability is inversely proportional to the sound absorption. Moreover, air permeability depends on the porosity of the sample. From Figure 31, it is clear that the NMC (3L) sample showed the lowest air permeability and the highest porosity among the nonwoven samples. However, the sound absorption coefficient of NBP (3L) (0.5016) was lower than that of NSG (4L) sample.

Table 1. Physical Properties of Needle-Punched Nonwoven Fabrics

Sample	Areal Density (G/M ²)	Thickness (Mm)	Bulk Density (Kg/M ³)	Porosity (%)	Air Permeability (Cc/S/Cm ²)	Thermal Conductivity (W/Mk)	Sound Absorption Coefficient
NSG (3 L)	552	6.23	0.103	0.829	93.7	0.0565	0.5448
NSG (4 L)	766	6.73	0.113	0.817	61.2	0.0472	0.5464
NMC(3 L)	555	5.25	0.105	0.906	66.8	0.0451	0.5022
NMC(4 L)	627	5.73	0.109	0.793	41.1	0.0353	0.5048
NBP (3 L)	544	5.22	0.104	0.762	93.4	0.0412	0.4958
NBP (4 L)	656	5.61	0.116	0.633	61.1	0.0129	0.5016

Table 2. Statistical analysis of Sound Coefficient Natural Fiber Needle Punching Nonwoven Fabrics Using one way ANOVA

Variables (3L and 4L)	Source of square	Sum of square	Degree of Freedom	Mean square	F	Sig.
NSG,NMC,NBP	Between	14.582	1	14.582	43.718	.000
Thickness And sound Absorption	within Groups	3.336	10	.334		
Total		17.918	11			
NSG,NMC,NBP	Between	.002	1	.002	.259	.002
Bulk Density and sound Absorption	within Groups	.067	11	.007		
Total		.069	12			
NSG,NMC,NBP	Between	934174.753	1	934174.753	168.601	.003
Areal Density and sound Absorption	within Groups	55407.334	10	55407.733		
Total		989582.088	11			
NSG,NMC,NBP	Between	2856.658	1	2856.658	139.217	.002
Air permeability Density and sound Absorption	within Groups	205.194	10	20.519		
Total		3061.852	11			
NSG,NMC,NBP	Between	15177.847	1	15177.847	93.182	.000
Porosity and sound Absorption	within Groups	1628.834		1628.834		
Total		16806.681	11			
NSG,NMC,NBP	Between	.206	1	.206	445.381	.001
Thermal conductivity and Sound Absorption	within Groups	.005	10	.000		
Total		.211	11

Figure 4. Influence of Thickness on Sound Absorption

Figure 5. Influence of Areal Density on Sound Absorption

Figure 9 displays the influence of thermal conductivity on sound absorption. It is obvious that the areal density, thickness, and bulk density influence the thermal conductivity. The thermal insulation property varies from 0.0129 – 0.0565W/mK for fabric samples. The NBP (4L) sample showed the lowest thermal insulation property of 0.0129W/mK because of its higher bulk density. On the other hand, the NSG (4L) sample resulted in the highest thermal conductivity of 0.0565 W/mK and a sound absorption coefficient of 0.5448.

Figure 6. Influence of bulk density on sound absorption

Figure 7. Influence of porosity on sound absorption

Figure 8. Influence of air permeability on sound absorption

Figure 9. Influence of thermal conductivity on sound absorption

Figure 10. Sound absorption performance of non-woven fabrics at different frequencies

Different natural fibers have different properties especially in the consideration of surface and inner stitch bonding properties which influence the density of nonwoven fabrics, which in turn affect the sound absorption of the fabrics. Figure 10 represents the plot of frequency versus sound absorption coefficient of natural fiber stitch-bonded nonwoven fabrics. From Figure 33, it can be observed that while the frequency increases the sound absorption coefficient increased. At the highest frequency of 2000 Hz, the sound absorption coefficient values of NSG (3L), NSG (4L) NMC (3L),

NMC (4L), NB (3L), NB (4L) samples were 0.5048, 0.4958, 0.5022, 0.5016, 0.54, and 0.54, respectively. The small increase in thickness or fiber content of this nonwoven did not influence the sound absorption. The experimental results were statistically calculated by using a one-way ANOVA in SPSS software. The results revealed that there was a significant difference between the sound absorption nonwoven materials.

4. CONCLUSION

The automotive and construction interiors made up of recycled fibers are in potential market growth. The recycled fiber nonwoven as acoustic absorption materials was developed by using the fibers from the plant waste of *Sesbania Grandiflora*, *Muntingia Calabura*, and *Bauhinia Purpurea*. The sound absorption property increases concerning areal density and fabric thickness. The thermal conductivity increased by increasing the fiber layer in the fabric. The nonwoven NSG (4L) sample with a thickness of 6.73 mm showed the highest sound absorption of 0.5464. It was observed that the NSG (4L) nonwoven sample displayed the highest sound absorption coefficient in the lower and higher frequency levels. This may be ascribed that when the number of fibers in the fabric increases, the fibers get closer to each other because of the lack of space between each fiber in the fabric. By increasing the fiber mass per unit area, the sound absorption coefficient of the fabric increases. The higher porosity in the fabric tends to increase the air permeability which is one of the main parameters for sound absorption.

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