A preliminary investigation on kapok/polypropylene nonwoven composite for sound absorption

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The use of kapok fibre with polypropylene fibre for the development of sound absorptive nonwoven materials has been explored. Three different blend ratios of kapok and polypropylene fibres, namely 30:70, 40:60 and 50:50 have been used. The composites are characterized for their physical properties, namely thickness, density, porosity and sound absorption characteristics in the frequency range 250 - 2000 Hz. The values of sound absorption coefficient and noise reduction coefficient obtained indicate that the kapok fibre composites possess very good sound absorption behaviour in the entire frequency range. The uncompressed kapok/polypropylene nonwoven composite of 30:70 blend ratio with high bulk density and low porosity is found to give the best performance when used by providing air gap behind the composite.

Keywords: Bulk density, Kapok, Noise reduction coefficient, Nonwoven composite, Porosity, Polypropylene, Sound absorption coefficient, Standing wave

Noise refers to the irregular and chaotic sound which disturbs people’s work and impairs their health. There are several methods to decrease noise and one of them is the use of sound absorption materials. The absorption of sound results from the dissipation of sound energy, owing to the viscous friction and heat exchange when sound waves propagate through the flexible porous structure. Many authors have explained this dissipation mechanism in the past. The factors that chiefly determine sound absorption property of textile structures are fibre type, fibre size, material thickness, density, porosity and air flow resistance. Reports show that the use of nonwoven materials for noise reduction is based on inbuilt advantages such as porous fibrous structure, light weight, bulky in nature, economically low price and their versatility.

Currently, commercially available sound absorption materials for acoustic treatment consist of glass, mineral or synthetic fibres and these fibres behave alike. A composite structure with a combination of perforated panel, rubber particle, porous material, polyurethane foam and glass wool are found to demonstrate significant sound attenuation. However, when the issue of safety and health are considered, they pose interference to human health and mainly affect lungs and eyes.

Many studies have analysed the suitability of jute, hemp, banana, coir, kenaf, cotton, ramie, palm, etc. as a raw material for acoustic panel. It is reported that the characteristics of rice straw-wood particle composite boards are most suitable than wood based materials in the frequency range 500-8000 Hz, due to low specific gravity and porous nature of the boards. The industrial tea leaf fibre waste materials are also found to possess good sound absorption properties at high frequencies. Though the behaviour of few natural fibres has been investigated, the acoustical characteristic of kapok fibre is rarely studied. It has a hollow structure with central lumen comprises 77 % of total fibre volume with absolute and bulk densities of 1474 kg/m$^3$ and 384 kg/m$^3$ respectively. However, it is found that the scientific data on acoustics properties of kapok fibre composites is not available. Hence, the present study has been carried out to develop and investigate the sound absorption characteristics of kapok/polypropylene fibre nonwoven composite.

Fibres
Kapok fibres with effective length of 21.4 mm were procured from southern part of India. The polypropylene fibres with 2.2 den and 40 mm length were supplied by Zenith Fibres Ltd., India.

Preparation of Nonwoven Composite
Kapok fibres were blended with polypropylene fibre in different blend proportions as shown in Table 1 following the stack mixing method. Card laying technology was used for the web formation. Miniature carding machine (Trytex Machine Co, India), operated with process parameters such as feed rate 0.27 m/min, licker-in speed 149 rpm, cylinder speed 350 rpm, doffer speed 2 rpm and delivery...
rate 1.15 m/min, was used. The carding action was performed twice for better and random distribution of fibres. The web was thermally bonded in a hot air oven (Inlab equipments, India) at 168°C ± 2°C for 5 min and cooled under ambient conditions. Two different types of nonwoven composite samples, namely uncompressed form (UC) under zero load condition and compressed form (C) with the application of 33.33 kg/m² load were produced. This load was selected with a view to reduce the thickness of around 30% compared to uncompressed form.

Physical Characteristics

Thickness (mm) of the nonwoven composite (t) was determined using thickness gauge as per the ASTM D 5736 standard. Average of 80 observations was taken for each sample. Bulk density ($\rho_b$) was calculated using the following relationship:

$$\rho_b = \frac{W}{t} \text{ kg/m}^3$$

where $W$ is the weight per unit area, determined following the standard method ASTM D 3776.

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Blend proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kapok fibre</td>
</tr>
<tr>
<td>S1UC</td>
<td>30</td>
</tr>
<tr>
<td>S2UC</td>
<td>40</td>
</tr>
<tr>
<td>S3UC</td>
<td>50</td>
</tr>
<tr>
<td>S1C</td>
<td>30</td>
</tr>
<tr>
<td>S2C</td>
<td>40</td>
</tr>
<tr>
<td>S3C</td>
<td>50</td>
</tr>
</tbody>
</table>

UC – uncompressed, C – compressed.

Porosity ($H$) is calculated using the following equation:

$$H = 1 - \frac{\rho_b}{\rho_a}$$

where $\rho_b$ is the bulk density of nonwoven composite (kg/m³); and $\rho_a$, the weight average absolute density of fibres in the composite (kg/m³). $\rho_a$ was calculated using the following formula:

$$\rho_a = \frac{(P_{KF}D_{KF} + P_{PP}D_{PP})}{(P_{KF} + P_{PP})} \text{ kg/m}^3$$

where $P_{KF}$ and $P_{PP}$ are the % blend proportion of kapok and polypropylene fibres respectively; and $D_{KF}$ and $D_{PP}$, the absolute densities of kapok (1474 kg/m³) and polypropylene (0.900 kg/m³) fibres respectively.

Sound Absorption Characteristics

Standing wave tube apparatus (Fig. 1), a facility available at Indian Institute of Technology Madras, India, was used for the determination of sound absorption coefficient (SAC) and noise reduction coefficient (NRC) in the absence and presence of air between the sample and rigid backing, following the procedure described by Russell. The air gap used is kept 20 mm. The frequency values, such as low (250 Hz), lower middle (500 Hz), upper middle (1000 Hz) and high (2000 Hz), were selected as they are harmful to human ear. After generating the required frequency using the waveform generator, the microphone probe attached to microphone car...
was moved back and forth to measure the minimum and maximum sound pressure levels. Standing wave ratio (SWR) was calculated using the following relationship:

\[ \text{SWR} = \frac{\text{Maximum sound pressure}}{\text{Minimum sound pressure}}. \]

\( \alpha \) was calculated using the following relationship:

\[ \alpha = 1 - \left( \frac{\text{SWR} - 1}{\text{SWR} + 1} \right)^2 \]

NRC was determined using the following formula\textsuperscript{20, 21}:

\[ \text{NRC} = \left( \alpha_{250 \text{ Hz}} + \alpha_{500 \text{ Hz}} + \alpha_{1000 \text{ Hz}} + \alpha_{2000 \text{ Hz}} \right) / 4 \]

**Physical Characteristics Analysis**

Table 2 shows that as the content of kapok fibre in the composite increases from 30% to 50% (from S1 to S3), the bulk density of compressed and uncompressed samples decreases. Further, it can be observed that the bulk density of compressed composites is higher than that of uncompressed composites. Increase in kapok content in the blend increases the porosity but it decreases on compression.

**Sound Absorption Characteristics Analysis**

The values of SAC and NRC for uncompressed and compressed composites obtained in the absence and presence of air between the sample and the rigid backing are given in the Table 3.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Thickness (mm)</th>
<th>Bulk density (kg/m³)</th>
<th>Porosity (H)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UC</td>
<td>C</td>
<td>UC</td>
</tr>
<tr>
<td>S1UC/S1C</td>
<td>9.21</td>
<td>6.34</td>
<td>122.69</td>
</tr>
<tr>
<td>S2UC/S2C</td>
<td>9.29</td>
<td>6.44</td>
<td>105.92</td>
</tr>
<tr>
<td>S3UC/S3C</td>
<td>9.36</td>
<td>6.45</td>
<td>75.11</td>
</tr>
</tbody>
</table>

**Performance in the Absence of Air**

**Uncompressed composites**

The increase in the kapok content in the composite does not show appreciable change in SAC, at all the frequencies. These composites have good absorption behaviour towards 250 Hz and 2000 Hz and moderate to low behaviour at mid frequency levels. However, the difference in behaviour of the composites with respect to frequency levels is not reflected in its NRC.

**Compressed composites**

With respect to kapok content, these composites are found to behave like uncompressed composites. Their behaviour on sound absorption at different frequency levels are also found to be the same as in uncompressed composites, but absorptions at lower and mid frequency levels, and at high frequency level are lower and higher than in uncompressed composites respectively. The NRC values obtained are found to be almost the same as in uncompressed composites.

**Performance in the Presence of Air**

**Uncompressed composites**

The increase in kapok content in composites does not have effect at low and upper middle, and high frequencies, whereas it has a distinct effect at lower middle frequency (500 Hz). These composites have good absorption behaviour at upper middle and high frequency levels compared to that at low mid frequency. However, these effects are not appreciably reflected in the NRC values. The overall performance of these composites with respect to SAC and NRC is better than that of uncompressed and compressed samples in the absence of air.

**Compressed composites**

Kapok content in these composites does not show any effect at low and high frequency levels, whereas

<table>
<thead>
<tr>
<th>Sample</th>
<th>Absence of air gap</th>
<th>Presence of air gap</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SAC</td>
<td>NRC</td>
</tr>
<tr>
<td></td>
<td>250 Hz</td>
<td>500 Hz</td>
</tr>
<tr>
<td>S1UC</td>
<td>0.94</td>
<td>0.34</td>
</tr>
<tr>
<td>S2UC</td>
<td>0.96</td>
<td>0.35</td>
</tr>
<tr>
<td>S3UC</td>
<td>0.97</td>
<td>0.36</td>
</tr>
<tr>
<td>S1C</td>
<td>0.86</td>
<td>0.30</td>
</tr>
<tr>
<td>S2C</td>
<td>0.87</td>
<td>0.34</td>
</tr>
<tr>
<td>S3C</td>
<td>0.91</td>
<td>0.34</td>
</tr>
</tbody>
</table>

SAC—Sound absorption coefficient, and NRC—Noise reduction coefficient.
it decreases at low mid frequency and increases at high mid frequency levels. Sound absorption is found to be higher at low frequency levels compared to that at all other frequency levels. It is also found that the sound absorption of these composites is lower than that of uncompressed samples at all frequencies. In this case also, the variation with respect to absorption at different frequency levels is not found to reflect appreciably in NRC but the values obtained are lower than that of uncompressed composites.

Considering kapok content in the composites and the role of compression on the behaviour of composites in the absence and presence of air with respect to SAC at different frequency levels and NRC, it can be said that the maximum sound absorption at any given frequency between 250 Hz and 2000 Hz and maximum absorption of sound waves with varying frequency in the above frequency range can be obtained from the uncompressed kapok/polypropylene nonwoven composite of 30:70 blend ratio having high bulk density and low porosity (Table 2). This might have resulted in higher tortuosity of the composite (a desired property for sound absorption\(^20\)), in presence of air gap behind the composite. As the potential for sound absorption appears bright, further exploration in the direction of understanding the kapok fibre behaviour in the composite would certainly lead to an improved solution for noise reduction.

**References**