Needle-Punched Non-Woven Jute Floor Coverings: Part III—Air Permeability and Thermal Conductivity

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In needle-punched jute non-wovens, a decrease in the ratio of reinforcing material weight to web weight decreased air permeability as well as thermal conductivity. The thermal conductivity of the non-wovens increased with decrease in thickness. The closeness of structure and rigidity of the reinforcing material decreased the air permeability.

Keywords: Air permeability, Floor coverings, Jute, Needle-punched fabrics, Non-wovens, Thermal conductivity

Needle-punched non-wovens are essentially a three-dimensional network of fibres enclosing small air pockets. The air permeability of a fabric is of fundamental significance from the points of view both of its structure and end use. Air permeability depends on a number of simultaneously varying characteristics. In non-wovens, the characteristics include weight, thickness, density, fibre and fabric structure, etc. In the case of carpets or floor coverings the effectiveness of vacuum cleaning by the formation of air pockets through which suction is applied depends greatly on the matrix structure.

The comfort property of floor coverings also depends on their thermal conductivity. In textile materials, especially needle-punched non-wovens, heat transfer can occur through their complex fibre-air-matrix structure. Heat transfer is influenced appreciably by the structural characteristics of fabrics, viz. thickness, weight, area density, etc.\(^1\)\(^-\)\(^5\)

Materials and Methods

The raw materials and preparation of the needle-punched non-wovens have been discussed by us in detail in a previous paper\(^6\).

Measurement of air permeability—A Shirley air permeability tester was used for measuring the air permeability of non-wovens. The results being expressed in units of volume of air in millilitres passed per second through 1 cm\(^2\) of fabric at a pressure difference (\(\Delta p\)) of 1 cm head of water. But for some cases, the high rate of flow required for a pressure difference (\(\Delta p\)) of 1 cm head of water could not be covered by the range of rotameter available. For such samples, the rate of flow at \(\Delta p\) of 1 cm water was arrived at through extrapolation by using the method suggested by Clayton\(^7\).

The air permeability, as calculated above, was multiplied by the mean thickness of needle-punched fabrics to obtain the sectional air permeability of the fabrics.

Measurement of thermal conductivity—The thermal conductivity of needle-punched non-wovens was measured by the Lees disc method. The apparatus consists of a circular metal slab of copper suspended with strings; on this rests the specimen disc (non-woven) of the same radius (\(r\)) and a hollow cylinder over the fabric specimen through which steam was passed by side tubes. One thermometer was inserted in the hole of the top hollow cylinder and another in the hole of the bottom metal slab.

The thermal conductivity of the fabric is given by the expression:

\[
K = \frac{MSD}{\pi r^2 (\theta_1 - \theta_2)} \left( \frac{d\theta}{dt} \right)_{\theta = \theta_2} \text{cal deg}^{-1} \text{cm}^{-1} \text{s}^{-1}
\]

where \(\theta_1\) and \(\theta_2\) are the thermometer readings of the top hollow cylinder and the bottom metal slab respectively in the steady state; \(D\) is the thickness of the fabric disc; \(M, r\) and \(S\) are the mass, radius, and specific heat of the bottom metal slab respectively; and \(\left( \frac{d\theta}{dt} \right)_{\theta = \theta_2}\) is the rate of fall of temperature of bottom metal slab at \(\theta = \theta_2\) when the lower and the side surfaces of the metal slab are exposed to air.

Results and Discussion

Air Permeability

Effect of batching oil emulsion treatment—The air permeability and sectional air permeability of non-wovens made of emulsion-treated jute show little or no difference from those of the untreated ones (Table 1). The fabric densities are only marginally different.
being 0.15 and 0.16 g/cm³ for untreated and treated fibres respectively.

Effect of reinforcing material weight to web weight ratio — The effect of the ratio of the reinforcing material weight to web weight on air permeability and sectional air permeability is shown in Fig. 1. The figure shows that as the amount of the web weight increases at a constant reinforcing material weight (jute hessian), the ability of the fibres to fill up the voids of interstices of reinforcing fabric increases, which, in turn, lowers the air permeability. Moreover, a higher web weight would also have a more number of fibres per unit area and this would increase the resistance to flow of air, causing a drop in air permeability. Similar observations were made by Newton and Kothari, who found that the air permeability is close to being directly proportional to the reciprocal of the fabric weight per unit area. This relationship holds good for both jute and woolenized jute non-wovens. The sectional air permeability of woolenized jute is slightly higher than that of jute non-wovens for a more or less similar ratio of the reinforcing material weight to web weight.

Effect of type of reinforcing material — The air permeability of non-wovens examined in the present study is very much dependent on the property of reinforcing scrim used (Table 2). The more open is the construction of the reinforcing scrim the more is the air permeability.

Effect of position of reinforcing material in the web — Table 3 shows that air permeability is higher when the reinforcing material is used at the centre of the web than at the base. The higher air permeability is possibly due to greater damage to the reinforcing fabric by the action of needles, since a more number of barbs pierce through the reinforcing fabric while it is placed at the centre of web than at its base for a given needle penetration from the bed plate.

Effect of fabric type — Air permeability and sectional air permeability of jute non-woven, woolenized jute non-woven, and jute non-woven woolenized in fabric form are given in Table 4, which shows that the higher is the density of the non-wovens, the lower is the air permeability. This is the most significant finding of several research workers like Newton and Kothari, Dent and Clayton, who concluded that the air permeability of fabrics largely depends on the fabric density.

### Table 1 — Effect of Batching Oil Emulsion Treatment of Jute Fibres on Air Permeability of Non-Wovens

<table>
<thead>
<tr>
<th>Type of fibre in fabric</th>
<th>Air permeability ml s⁻¹ cm⁻²</th>
<th>Sectional air permeability ml s⁻¹ cm⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated jute</td>
<td>68.44</td>
<td>21.35</td>
</tr>
<tr>
<td>Jute treated with batching oil emulsion</td>
<td>66.27</td>
<td>23.26</td>
</tr>
</tbody>
</table>

### Table 2 — Effect of Different Reinforcing Materials Used at the Base of Jute Web on Air Permeability of Non-Wovens

<table>
<thead>
<tr>
<th>Reinforcing material</th>
<th>Air permeability ml s⁻¹ cm⁻²</th>
<th>Sectional air permeability ml s⁻¹ cm⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jute web and jute hessian (54 ends × 48 picks/dm — 300 g/m²)</td>
<td>66.27</td>
<td>23.26</td>
</tr>
<tr>
<td>Jute web and cotton bandage cloth (120 ends × 88 picks/dm — 40 g/m²)</td>
<td>99.85</td>
<td>31.85</td>
</tr>
<tr>
<td>Jute web and cotton gauge cloth (60 ends × 50 picks/dm — 30 g/m²)</td>
<td>177.51</td>
<td>57.37</td>
</tr>
<tr>
<td>Jute web and polyethylene film (47 g/m²)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Needle-punched woolenized jute web only (288 g/m²)</td>
<td>165.88</td>
<td>53.31</td>
</tr>
</tbody>
</table>
Effect of needling density—Successive increases in the needling density increase the fabric consolidation correspondingly and thereby reduce air permeability and sectional air permeability (Fig. 2). Reduction in air permeability is usually more in woollenized jute non-wovens, which could be ascribed to the higher consolidation of fabric, less fibre rupture and less damage to the reinforcing material as compared to jute owing to its superior fibre characteristics like low flexural rigidity, high extensibility and crimp, etc. 

Effect of needle penetration—The effect of needle penetration on air permeability and sectional air permeability is shown in Fig. 3. At lower needle penetration, for both jute and woollenized jute, the ability of the fibres to be anchored with the reinforcing fabric is lower and at the same time fibre entanglement
within themselves is also lower. This is also shown by the abrasion resistance values for non-wovens in which the fibres could be pulled out easily when the needle penetration was low. Thus at lower needle penetration, the air permeability is higher and it reduces with the higher needle penetration up to a certain limit since better entanglement of fibres as well as blinding of the open spaces in the interstices of the reinforcing fabric is caused by the fibres. Too deep a needle penetration results in fibre rupture and damage to the reinforcing fabric and also creates channels in the non-wovens as was observed visually. All these result in a higher air permeability when the needle penetration exceeds an optimum limit.

**Thermal Conductivity**

A decrease in the ratio of the reinforcing material weight to web weight (i.e. increase in the web weight for a constant reinforcing material weight) decreases the thermal conductivity (Fig. 4).

Again, decrease in the ratio means increase in the fabric thickness for unaltered needling and loom parameters. The thickness of non-woven fabrics has a decisive effect in determining the thermal conductivity as can be seen from Fig. 5, where thermal conductivity is shown to be linearly related to the inverse of the thickness of non-wovens. Similar observations with respect to woven and knitted fabrics have been made by several workers.

**Effect of fabric type**—The results of thermal conductivity tests on jute non-woven, woollenized jute non-woven, and jute non-woven woollenized in fabric form are given in Table 5. The thermal conductivity of jute non-woven woollenized in fabric form is the highest, which may be due to its higher density, arising from greater consolidation by the shrinkage of the non-woven during woollenization process, which, in turn, reduces the available air pockets in the non-woven ultimately. As air is a poorer conductor of thermal transmission than fibres, it is expected that the lower is the volume of air in the non-wovens the higher would be the thermal conductivity.

**Effect of needling density**—Fig. 6 shows the effect of needling density on the thermal conductivity of non-wovens. Thermal conductivity of non-wovens increases linearly with a corresponding increase in the needling density. It is evident that increase in needling density increases the density of the fabrics. Since increase in fabric density means lesser entrapment of air inside the non-woven matrix the thermal conductivity of non-wovens is expected to increase with increase in needling density.

**Effect of needle penetration**—The effect of needle penetration on the thermal conductivity of non-wovens is shown in Fig. 7, where thermal conductivity of non-wovens increases with increase in needle penetration. Here also, the fabric density is expected to play an important role, as the density of non-wovens increases with increase in needle penetration and thus reduces the volume of air entrapped. Because air is a poor conductor of heat, a reduction in the volume of air in the non-wovens would result in a greater thermal conduction. However, at the higher needle penet-

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**Table 5—Effect of Fabric Type on Thermal Conductivity of Non-Wovens**

<table>
<thead>
<tr>
<th>Type of needle-punched fabric</th>
<th>Thermal conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jute (909 g/m²)</td>
<td>$2.56 \times 10^{-4}$</td>
</tr>
<tr>
<td>Woollenized jute (908 g/m²)</td>
<td>$2.42 \times 10^{-4}$</td>
</tr>
<tr>
<td>Jute non-woven woollenized in fabric form</td>
<td>$3.27 \times 10^{-4}$</td>
</tr>
</tbody>
</table>
Conclusions

Air being a poorer conductor of heat than fibres, a more porous structure should act as a better thermal insulator. Again, a more porous structure should offer less resistance to the passage of air and, hence, have a higher air permeability. It, therefore, stands to reason that air permeability and thermal conductivity should be inversely related to each other and that any processing parameter which increases the fabric density should result in a material with a higher thermal conductivity but a lower air permeability. Most of the results show such a relationship with the exception of the test series in which the ratio between reinforcing material weight to web weight has been varied. Here a decrease in the web weight decreases the fabric density; air permeability, however, increases as a consequence. Thermal conductivity also increases with decrease in web weight. This seemingly anomalous behaviour is resolved in the light of the inverse linear relationship of thermal conductivity with fabric thickness. A reduction in web weight reduces the fabric thickness, resulting in a corresponding increase in thermal conductivity.

References
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