A Study of Physical, Mechanical and Thermal Properties for Thermal Insulation from Narrow-leaved Cattail Fibers

Thitiwan Luamkanchanaphan\textsuperscript{a}, Sutharat Chotikaprapkhan\textsuperscript{a*}, Songklod Jarusombati\textsuperscript{b}

\textsuperscript{a}Department of Physics, Faculty of Science, Kasetsart University, Bangkok 10900, Thailand
\textsuperscript{b}Department of Forest Products, Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand

Abstract

The objective of this research was to study physical, mechanical and thermal properties of insulation boards prepared from narrow-leaved cattail fibers by using Methylene Diphenyl Disocyanate (MDI) as a binder. Hot pressing was employed to produce single layered plain thermal insulation boards with the size 350x350x10 mm. The physical, mechanical and thermal properties of the boards were investigated. The test results showed that the insulation boards from narrow-leaved cattail fibers had good physical and mechanical properties tested according to the standard of TIS. 876-2547. Thermal conductivity measured in accordance with the ASTM C518 revealed that the board with a density of 200-400 kg/m\textsuperscript{3} had the thermal conductivity values ranging from 0.0438-0.0606 W/m K, which was less than that of fibrous materials and cellular materials, such as low-density wheat straw board, particleboard from mixture of durian peel and coconut coir, kenaf binderless board, expanded perlite and vermiculite with the same density range. According to the test results, it can be concluded that this insulation boards from narrow-leaved cattail fibers were an excellent insulating component for energy saving and environmentally friendly. Additionally, these insulation boards could be used to produce furniture with an advantage to help, and get rid of weeds.

Keywords: thermal insulation; narrow-leaved cattail fibers; physical property; mechanical property; thermal conductivity

1. Introduction

Since the energy consumption and global warming problem is getting more and more of an issue.
Researchers presented many processes in order to save energy in accommodations and building. As the largest building, heat from the sun affect on air conditioning. For these reasons, the use of thermal insulation in building is the key tool to protect heat through the building, control the interior temperatures at comfortable levels and maintain the building temperature appropriate for a long time without having to run air conditioning for long periods of time.

One of the most examples of commercial thermal insulation is an inorganic materials especially fiberglass. Until 1996 Bureau of Environmental Health of Thailand reported that fiberglass has an effect on human health when fiberglass is handled, cut or otherwise disturbed, people can be exposed by skin and eye contact or by breathing in fibers that have become airborne. Additionally, fiberglass can cause Emphysema and lung cancer. Therefore many studies have been done on the development of thermal insulation materials from natural fibers used as environmental-friendly and renewable materials such as maize husk, maize cob, groundnut shell, coconut pith and paddy straw [1], cotton seed hulls [2], durian peel and coconut coir [3], saline jose tall wheatgrass [4], eggplant stalks [5], tamarind hulls [6] and cotton stalk fibers [7].

Narrow-leaved cattail ([*Typha angustifolia* L.]) is marginal weeds which originated in Europe and America. Overspreading in tropical area such as Thailand, Malaysia, Philippines, North America and Pacific coast. For Thailand they can even be found in ponds, marsh, paddy, watercourse and lake. Narrow-leaved cattail in marsh is growing through the year and flower from May to July. In early fall, the brown flower head pops open, letting its fluffy seeds emerge. These seeds are carried by wind or water to new places. However, cattails rapidly spread via seeds and roots. In just a few short years without management, cattails take over water areas. It is not unusual to see ponds that are completely surrounded by cattails.

Narrow-leaved cattail is weeds that have an effect on irrigation in Thailand. Naturally, narrow-leaved cattails can rapidly spreading over the areas. Thus the other crops are severely damage and not growing. Many researchers attend to study and find best ways to manage narrow-leaved cattail by production of interior partition, charcoal bars, and use for waste-water treatment. Therefore manufacturing the insulation boards from narrow-leaved cattail fibers is the interesting way to be low cost raw materials and preserve energy. The aim of this work is to study the possibility to apply narrow-leaved cattail, in the thermal insulation. The physical, mechanical and thermal properties of the insulation boards were investigated and confirmed generally as competitive with the other studies.

2. Materials and methods

2.1. Raw materials preparation

Raw materials for this study were Narrow-leaved cattails which were collected from Chanthaburi Province in the east of Thailand. First, their dried leaf was cut into chip about 10 cm. in length by hand and then fiberized using wood grinder machine. The moisture content of fiber was 6%.

2.2. Board preparation and evaluation

The boards were prepared with a target density of 200, 300 and 400 kg/m$^3$. The weight of fiber was measured according to their target board densities before the fibers were sprayed a binder of MDI. The fibers were shaped using a forming box with 350 mm. in length, 350 mm. in width and 10 mm. thickness. After forming, the boards were prepared in a hot pressing machine with the pressure of 40 kg/cm$^2$, the temperature of 140 °C and the pressing time of 3 min. The target board thickness was controlled by distance bar. After pressing, the boards were stored in conditioning room for one week and then they were
cut into various test samples following the Thai Industrial Standard (TIS 876-2547) [8].

2.3. Physical property

The physical property of boards were carried out in accordance with the TIS. 876-2547. Forty-five samples were prepared for moisture content (MC) test. The moisture content of samples are determined by the following the equation (1),

\[ MC(\%) = \frac{m_1 - m_2}{m_2} \times 100 \]  

where \( m_1 \) is mass of sample before drying (g) and \( m_2 \) is mass of sample after drying (g).

2.4. Mechanical Properties

The mechanical properties were evaluated following the TIS. 876-2547. Twenty-seven samples were prepared for the Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) test and forty-five samples were prepared for tensile strength perpendicular to surface test. All properties were calculated from the equations (2), (3) and (4) respectively. Each sample’s results were compared with the standard of insulation board [9].

\[ \text{MOR} = \frac{3F_{\text{max}} l_1}{2bt^2} \]  

where \( F_{\text{max}} \) is the maximum load (N), \( l_1 \) is the span (mm), \( b \) is the width of the test sample (mm) and \( t \) is the thickness of the test sample (mm).

\[ \text{MOE} = \frac{l_1^3(F_2 - F_1)}{4b(t^3)(a_2 - a_1)} \]  

where \( F_2 - F_1 \) is the increasing load in the range of linear line of graph (N) and \( a_2 - a_1 \) is the increasing bending distance in the range of linear line of graph (N).

\[ \text{Tensile strength} = \frac{F_{\text{max}}}{W \times L} \]  

where \( W \) is the width of the test sample (mm), and \( L \) is the length of the test sample (mm).

2.5. Thermal Property

In order to determine the thermal conductivity (k) of the samples, the measuring was based on the American Society for Testing Material (ASTM C518) [10] by using a heat flow meter (HC-074-200). HC-074-200 is a microprocessor-based instrument for testing materials in the conductivity range of 0.005-0.800 W/m K. The thermal conductivity of a sample is determined by following the equation (5)

\[ k = \frac{Q_U + Q_L}{2} \times \frac{D}{\Delta T} \]
where $Q_U$ is the output of the upper heat flux transducer, $Q_L$ is the output of the lower heat flux transducer, $D$ is the thickness of the sample and $\Delta T$ is the temperature difference between the surfaces of the sample.

3. Results and discussions

3.1. Effect of board density on the moisture content

The results of the moisture content tests are shown in Fig. 1.

![Fig. 1. Effect of board density on the moisture content.](image)

Fig. 1. Effect of board density on the moisture content.

The moisture content trends to increase with an increasing of board density. Due to the fact that the higher density board has more condense fibers and resin content. After blending MDI, the moisture content in high density board is higher than low density board. According to the standard of TIS. 876-2547, the average of moisture content values must be range from 4 to 13%. The experiment indicated that the moisture content of the board with a density of 200, 300 and 400 kg/m$^3$ are 11.22, 11.94 and 12.91% respectively, that are agreed with TIS. 876-2547.

3.2. Effect of board density on MOR and MOE

According to the TIS. 876-2547 and the standard of insulation board, the MOR and MOE were measured [10]. The results are shown on Fig. 2.

![Fig. 2. Effect of board density on the Modulus of Rupture (MOR) and the Modulus of Elasticity (MOE).](image)

Fig. 2. Effect of board density on the Modulus of Rupture (MOR) and the Modulus of Elasticity (MOE).

The higher density boards were stronger than the lower density boards. The average of MOR of the board with a density of 200, 300 and 400 kg/m$^3$ are 106.896, 293.349 and 524.074 psi respectively (1 psi = 6.894 x $10^3$ Pa). The MOE has the same trending as the MOR. The MOE increased when the density of the board increased. The averages of MOE of the board with a density of 200, 300 and 400 kg/m$^3$ are 11.40, 29.09 and 47.46 ($10^3$psi) respectively. According to the standard of insulation board, the average of MOR values ranging from 200 to 800 psi and the average of MOE values ranging from 25 to 125 ($10^3$psi). From Fig. 2 it was found that only the lowest density board did not pass in the standard of insulation board.
3.3. Effect of board density on tensile strength

Tensile strength of the boards increased as the density increased. In order to produce a lower density boards, the less mass of the fiber and resin content was used. This results the lower tensile strength as shown in Fig. 3.

Since the thickness of all the boards are equal to 10 mm. The voids in the boards with the higher density are less. This results the stronger adhesive between fibers. According to the standard of insulation board, the average of tensile strength values is between 10 to 25 psi. The experiment shows that the averages of tensile strength of the board with a density of 200, 300 and 400 kg/m$^3$ are 4.49, 13.24 and 14.78 psi respectively. Only the board with density 200 kg/m$^3$ is not agreed with the standard of insulation board.

3.4. Effect of board density on thermal conductivity

The thermal conductivity of all boards was tested in accordance with the American Society for Testing Materials (ASTM C 518). The measured thermal conductivity is plotted as a function of board density shown in Fig. 4.

Thermal conductivity testing confirmed that the thermal conductivity is directly related to the board density, where the higher board density, the higher thermal conductivity. Although the thermal insulation boards are solids, their structure contains a lot of voids. The available voids between fibers in board are increased with decreasing board density. The air within the voids leads to a lower thermal conductivity of the whole board.

Table 1 shows the comparison between the measured thermal conductivity of thermal insulation board from narrow-leaved cattail fibers to published data. It revealed that this thermal insulation board with a density of 200-400 kg/m$^3$ had the thermal conductivity values ranging from 0.0438-0.0606 W/m K, which was less than that of fibrous materials and cellular materials, such as low-density wheat straw board,
particleboard from mixture of durian peel and coconut coir, kenaf binderless board, expanded perlite and vermiculite with the same density range.

Table 1. Thermal conductivity of various materials.

<table>
<thead>
<tr>
<th>Board type</th>
<th>Density (kg/m³)</th>
<th>k (W/m K)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow-leaved cattail fiber</td>
<td>200-400</td>
<td>0.0438-0.0606</td>
<td>Present study</td>
</tr>
<tr>
<td>Wheat straw board</td>
<td>150-250</td>
<td>0.0481-0.0521</td>
<td>Zhou et al.</td>
</tr>
<tr>
<td>Cotton stalk fiber</td>
<td>150-450</td>
<td>0.0585-0.0815</td>
<td>Zhou et al.</td>
</tr>
<tr>
<td>Durian peel and coconut coir</td>
<td>311-611</td>
<td>0.0728-0.1117</td>
<td>Khedari et al.</td>
</tr>
<tr>
<td>Kenaf</td>
<td>100-250</td>
<td>0.040-0.065</td>
<td>Xu et al.</td>
</tr>
<tr>
<td>Expanded perlite</td>
<td>78-224</td>
<td>0.0477-0.0616</td>
<td>Zhou et al.</td>
</tr>
<tr>
<td>Vermiculite</td>
<td>80-200</td>
<td>0.047-0.07</td>
<td>Zhou et al.</td>
</tr>
</tbody>
</table>

4. Conclusions

The results indicated that the thermal insulation from narrow-leaved cattail fibers with a density of 200, 300 and 400 kg/m³ and a thickness 10 mm, which bonded by MDI during hot pressing process have a good physical, mechanical and thermal properties according to TIS. 876-2547, the standard of insulation board and ASTM C 518. It can be seen that the board of Narrow-leaved cattail fibers has the thermal conductivity with the range of 0.0438-0.0606 W/m K which is lower than the board of other insulation materials. This shows the Narrow-leaved cattail is a candidate raw material for an insulator of wall, ceiling and building materials for energy saving.

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References


