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Particle Boards from Papyrus Fibers as Thermal Insulation

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Abstract: This work presented preliminary studies on the production and thermal property of thermal insulation produced from papyrus fiber using natural rubber latex as a binder. Thermal insulation boards, these were made by spray the pretreated natural rubber latex onto papyrus fiber to form a squared thermal insulation with the size of 20 and 1.5 cm thickness. Thermal conductivity measured in accordance with the American Society for Testing Materials standard. Test results showed that the thermal insulation produced from papyrus fiber exhibited a considerably good thermal insulation. The thermal conductivity of the thermal insulation was 0.029 W m^{-1} K^{-1} with density of 258 kg m^{-3} which closed to the commercial insulator. The success of this study shown papyrus fiber was extremely potential to instead of the synthesis fibrous insulator.

Key words: Thermal insulation, papyrus fiber, particleboard, spray process, lignocellulosic materials

INTRODUCTION

Due to global warming problem, the use of thermal insulation materials to sustain comfortable temperatures in living environments or in building has become prevalent in recent years. The use of thermal insulation is regarded as one of the most energy efficiency improvements in buildings and means of energy conservation in buildings. As the largest building component, the thermal insulation materials play an important role in achieving buildings' energy efficiency. This will result in decrease the cost of cooling as well as decrease the pollution of the environment due to using energy hard (As the air-conditioning, the energy consumption is very high). On energy consumption, both residential and commercial building have spent almost a half of primary energy resources, and trend to increase in the future (Al-Rabghi and Akyurt, 2004; Yamtraipat *et al*., 2006; Radhi, 2008; Perez-Lombard *et al*., 2008; Aktacir *et al*., 2010). The rapid growth of energy use, the fossil fuel is used consumption on each day and severe environmental impacts (ozone layer depletion, global warming, climate change, etc.) (Saidur, 2009). For these reasons, a good insulation material becomes the key tool in designing and constructing energy thrifty buildings. In fact, the insulation materials are not independent energy production or conservation systems, but part of the complex structural elements which form a building's shell. Commercial thermal insulators used generally for both residential and commercial building are made of plastic foams, glass foams, mineral wools, rock wools, etc. The plastic foam is sometimes used as the core of a structural insulated panel by being sandwiched between oriented strand boards and mineral wools that form a mat are often inserted into the airspace in walls. But the use of the commercial insulating materials has some disadvantage, due to the fact that installation of such materials is expensive and requires skilled labour and some concern in that they may be harmful to human health and body and cause environmental pollution, such as emissions of toxic gas and particle, and stick to skin (Liang and Ho, 2007). With the requirement of environmentally safe and energy saving in building, considering for substitution the commercial insulating materials, there is an interest in other renewable materials. Several researches have succeeded in developing renewable materials and environment-friendly using lignocellulosic fibers in many countries. These lignocellulosic materials, not only provide a renewable material source, but also generate a non food source of economical development for rural areas. In the previous works, there are the use of lignocellulosic fibers as raw materials for production particle board from many different regions of the world, such as coffee husk and hulls

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(Bekalo and Reinhardt, 2010), wood (Kawasaki and Kawai, 2006; Loh *et al*., 2010; Azizi and Faezipour, 2006; Akgul *et al*., 2007), waste tea leaves (Shi *et al*., 2006; Yalinkilic *et al*., 1998), coconut husk (Viswanathan *et al*., 2000; Van Dam *et al*., 2004), bagasse (Widyorini *et al*., 2005), cotton (Alma *et al*., 2005), oil palm (Khalil *et al*., 2007; Feng *et al*., 2011; Suradi *et al*., 2010). Furthermore, many researchers have studied thermal insulation materials from lignocellulosic fibers. It is found that the fiberboard made from cotton stalk fibers with no chemical additives using high frequency hot pressing showed a lower thermal conductivity values ranging from 0.0585 to 0.0815 W m^{-1} K^{-1} with a density of 150-450 kg m^{-3} (Zhou *et al*., 2010). Low-density binderless particleboards from kenaf core were successfully developed using steam injection pressing and the thermal conductivity of boards showed values similar to those of insulation material (i.e., rock wool), which was viable options to apply in building insulation (wall and ceiling) (Xu *et al*., 2004). Flax and hemp fibers were also evaluated as raw materials for making a good thermal insulation (Kymalainen and Sjoberg, 2008).

From above studies, it is revealed that natural fibrous materials have numerous advantages for production thermal insulation and thus are the most promising for building. Therefore, this study concentrates in finding an a lternative measure from locally available lignocellulosic materials papyrus to produce thermal insulation construction materials. The papyrus ((*Typha angustifolia* L.) is one of the fibrous plants available in abundance (It is normally a weed), it is found widely in Thailand. The production of particleboards made from papyrus fiber is the idea to develop as a value-added product like thermal insulation for building construction material with low thermal conductivity, in order to decrease the energy consumption of building facilities. This will not only reduce the operation cost but also help to preserve environment.

The study covers methods for producing particleboards and investigates physical properties of products made from papyrus fiber. In addition, the binder adhesive as natural rubber latex (free formaldehyde) which is of great interest from an environmental perspective is chosen to produce particle boards and the products are free from formaldehyde emission, which is especially suitable for interior construction use.

MATERIALS AND METHODS

Materials: Raw materials were papyrus leaves (*Typha angustifolia* L.) which were collected from Uttaradit province in the Northern region of Thailand. The papyrus leaves were cut to a length of approximately 20 cm by hand and soaked into 10 wt% NaOH solution for 30 min to obtain soften fibers, and then dried in oven at 80°C for 12 h. The dried samples were cut into particle pieces of 2-5 mm length by commercial grinders. All particles were again oven-dried at 80°C for 12 h to use for particleboards preparation.

Methods: Three types of boards were prepared with particle: binder ratios of 1 : 2, 1: 3 and 1: 4. The boards were made by spray a binder (as the pretreated natural rubber latex) on the papyrus leave particles to form a squared thermal insulation with the size of 20 cm and 1.5 cm thickness in a forming box. After forming, the board was cut into various test samples. Each measurement was the average of three samples cut from each three different boards. The tests applied on the samples were density, water absorption, thickness swelling, fire-resistance and thermal conductivity. The density, water absorption and thickness swelling of samples were carried out according to the Japanese Industrial Standard (JIS A 5905). The fire-resistance test was based on the American Society for Testing Materials (ASTM D 635-98). In order to determine the thermal conductivity of the samples, the measuring equipment was constructed in accordance with ASTM C177-97. Microstructures analysis was also performed on surface of boards by Scanning Electron Microscopy (SEM).

RESULTS AND DISCUSSION

Physical properties: Figure 1 shows SEM images of papyrus fiber and particle boards prepared with particle: Binder ratios of 1 : 2, 1: 3 and 1: 4. From SEM micrograph, it revealed that the papyrus consisted of fiber having widths between 50 - 100 μm (Fig. 1a) and the surface of boards (Fig. 1b-d) showed fibrous network structures which were covered and bonded by binder. It is seen that the fibrils were bonded strongly with each other and it should result in good density of boards. However, all boards were found to have a big space which distributed on the surface. As a result, the boards prepared in this work gave a low density. This is the effect of the preparation process which performed by hand and without pressing by machine. On observation of the board surface, it showed that the board prepared with 1:4 ratio had a greater binder on the surface and dispersed into spaces between fibers in mat than other boards, which the voids between fibers were closed, leading to the increase of the board density.

The test results of the physical properties such as moisture contents, density, Thickness Swelling (TS) and Water Absorption (WA) are given in Table 1. From Table 1, it is shown that the moisture content was

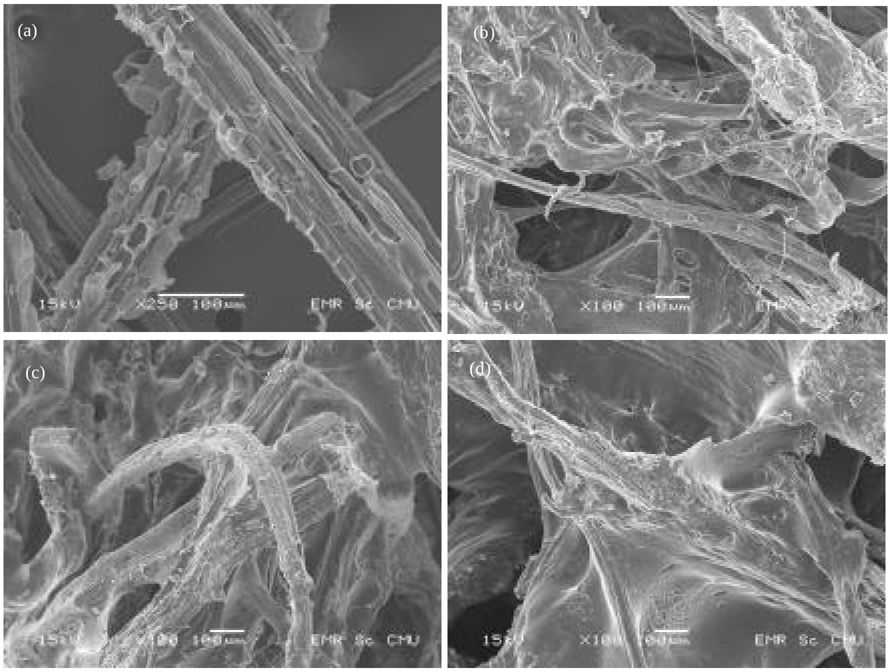

Fig. 1: SEM micrographs: (a) papyrus fiber, (b) 1:2 board, (c) 1:3 board and (d) 1:4 board

Table 1: The physical properties values of particle boards

Particle:binder	Moisture contents (%)	Density (kg m^{-3})	WA (%)		TS (%)	
			2 h	24 h	2 h	24 h
1:2	6.03	232	154	156	12	15
2:3	5.75	258	133	145	20	31
1:4	5.09	266	101	120	24	33

inversely proportional to the density of boards. The average moisture contents of boards were 6.03, 5.75 and 5.09% for 1:2, 1:3 and 1:4 ratio, respectively. This is because the lower density board has higher voids and space in the mat. As a result, the lower density board can absorb more moisture. The density of board is found that it increased with increasing content of binder. Average densities of boards were 232, 258 and 266 kg m^{-3} for boards bonded with particle: Binder ratio of 1:2, 1:3 and 1:4, respectively. This observed from SEM, where board of higher binder had lower voids in board. This is due to the binder is cured more effectively in the void spaces. Since, the high porosity is relate to the low density board and the board made from higher binder has higher density. The results of the TS and WA tests shown in Table 1 were measured after 2 and 24 h immersion in distilled water at 20°C, following the JISA 5905 standard. The WA values in this study were relatively high owing to the porous character of the low-density board. This is due to porosity of the low-density board which provides absorption more water than the high-density board. The WA values decreased with increasing board density. The WA after 2 h immersion was 154, 133 and 101% and after 24 h immersion was 156, 145 and 120% for the board density of 232, 258 and 266 kg m^{-3}, respectively. For TS values of the boards shown in Table 1, the percent TS was greater in higher density board than the lower density board. This is because the more fibrous material in the higher density board absorbs much water and the thickness and linear expansion increase after the absorption of the moisture. However, for the board used high binder between the particles in the mat, the binder is cured more effectively in the void spaces of the board and there is less water absorption. Thus, even the fibers absorb much water resulting in higher TS of high-density board, whereas WA decreases because of limited void spaces. The minimum TS of 12% along thickness was for the board density of 232 kg m^{-3} for 2 h soaking and the maximum of 33% for the board density of 266 kg m^{-3} for 24 h soaking. However, the TS and WA values of boards obtained from this work are higher those values which are required in the Japanese Industrial Standard (JIS A 5905). This is the effect of the low density of the board which was manufactured without using a compression molding machine. Therefore, an increase of particleboard density could improve the physical properties to meet the standard value, as found in the boards produced from waste tea leaves (Yalinkilic *et al*., 1998), rubberwood (Loh *et al*., 2010) and wheat straw (Tabarsa *et al*., 2011).

Thermal properties: There are many parameters for selecting thermal insulation such as, durability, cost, thermal conductivity, ease of application and fire resistance (Al-Homoud, 2005). However, the fire resistance of the board is the most important property which presents the capability of flame spread retardation and can be considered for interior applications such as ceiling and wall. The results of the fire resistance are shown in Fig. 2. The fire resistances were measured according to the ASTM D 635-98 standard. The board prepared with 1:3 ratios of particle : Binder showed the best fire resistance of 2.12 min, as 1.42 and 1.44 min. for boards of 1:2 and 1:4 ratios, respectively.

The thermal conductivity, k, of the particleboards was tested in accordance with the American Society for Testing Materials (ASTM C177-97). For comparison, the thermal conductivity of fiber glass was tested by the same method (The k value was 0.036 W m^{-1} K^{-1} which corresponded to the result reported in a previous paper (Dai *et al*., 2005). Thermal conductivity is an indicator of the value of a material as a heat insulator. It is directly related to the density of the board, the highest density boards having the least insulating effect. This is due to the fact that the low-density board contains a large number of voids filled with air, which is one of the poorest conductors (Suleiman *et al*., 1999; Zhou *et al*., 2010). Voids filled by air serve as scattering centers for phonons. The heat flow transfers through solid substance and void, while the thermal conductivity of air within the voids is much lower than that of solid substance, which leading to a lower thermal conductivity of the whole material. Thus the lower density boards conduct less heat than the higher density boards. Figure 2 obviously, the higher the density of papyrus fiber board, the higher is the thermal conductivity of boards. As shown in Fig. 2, at a density of 232, 258 and 266 kg m^{-3}, the k values of the board were 0.0296, 0.0298 and 0.0304 W m^{-1} K^{-1}, respectively. However, due to a close of their densities, the k values were slightly different. Comparisons of thermal properties of various materials are given in Table 2. It can be seen that the k of the papyrus fiber particleboard was lower than that for commercial particleboards and other

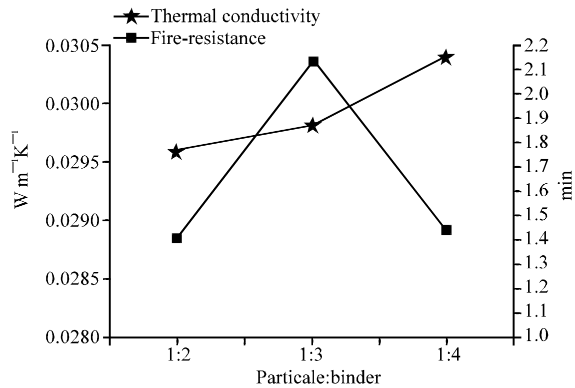

Fig. 2: The results of the fire-resistance and the thermal conductivity versus particle:binder

Table 2: Comparison of thermal conductivity (k) of various boards

Board types	Density (kg m^{-3})	K value (W m^{-1} K^{-1})	Reference
Papyrus fibers	258	0.029	Present study
Coffee husk and hulls	738	0.110	Bekalo and Reinhardt
Polystyrene foams	29	0.041	(2010)
Fiber glass wool	21	0.039	Dai *et al*. (2005)
Plywood-faced	340	0.089	"
Sandwich			"
Polyurethane	28	0.024	Al-Ajlan (2006)
Lightweight concrete	551	0.155	"
Cotton stalk fibers	150-450	0.059-0.082	Zhou *et al*. (2010)

particleboards, except polyurethane (Bekalo and Reinhardt, 2010; Dai *et al*., 2005; Al-Ajlan, 2006). Therefore, It can be concluded that low-density papyrus fiber particleboards are excellent materials for thermal insulators and this is also consistent with the previous work for Low-density straw panels (Sampathrajan *et al*., 1992).

CONCLUSIONS

This study indicates potential for using papyrus to produce a value-added product such as board or building insulation. The study clearly suggests that the application of papyrus fibers as thermal insulation in building construction is practicable. The particleboard can be manufactured using a binder (as the pretreated natural rubber latex) spray on pineapple leave particles with board densities ranging from 232-266 kg m^{-3}. The thermal conductivity of the boards was quite good relative to their low board density and almost the same as the insulation material. For overall consideration of the thermal conductivity and physical properties of the papyrus fibers particleboard, the boards with particle: Binder ratios of 1:3 with density of 258 kg m^{-3} are promising building materials for thermal insulation applications for energy saving.

Moreover, the binder adhesive without formaldehyde is used for making the boards and the products are free from formaldehyde emission, making them especially suitable for interior use. The low-density papyrus fibers particleboards can be used for many purposes in building component such as insulation strips for foundation walls, ceiling tiles and the core material for composite panels.

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