บทความวิจัย

Insulated Sandwich Panels from Natural Rubber and Rubber Wood

Parntip Phohchuay and Sureurg Khongtong*

ABSTRACT

The focus of this research was to study the properties of insulated sandwich panels created from natural rubber as a core and rubber wood strands as surface layers in order to introduce more sustained components for construction materials. This panel was fabricated under the hot compression at the temperature of 150^{o}C to trickle a blowing agent mixed in rubber compounds to decompose and yield amounts of gas leading to a porous rubbery core. This brought the density of this product to reach 410-550 kg/m^3 which was about four times lighter than that of the brick and concrete walls. This density was even lower than that of the commercial light weight panels for three times while the strength of the panel from this research was about two times greater. It was also found that the panel from this research revealed the value of thermal conductivity at 0.07-0.08 w/mK which was drastically lower than that of the brick and concrete walls for sixteen times as well as lower than that of the commercial light weight panels for almost two times. Moreover, this panel displayed the value of sound transmission lost at 35-80 dB which was about two times better than that of the wall materials used currently.

Keywords: insulated panels, sustained construction, natural rubber

Polymer Engineering Programs, School of Engineering and Resources, Walailak University

*Corresponding author, email: ksureurg@wu.ac.th

Introduction

Wall materials have become one of the focuses on the development of green building. Light weight panels are currently used as materials of a wall in order to reduce energy consumption on the construction of the building in the aspect of material transportation and size reduction of the building structure compared with that of typical walls, particularly brick and concrete one [1]. In addition, using of materials developed from the renewable sources would provide more environmentally friendly and sustained construction. Presently, light weight panel is made from wood chips and wood fibers mixed with cement or gypsum [2]. The wood components would herein make this panel lighter and cement is added in order to enhance all compositions to be intact as well as provide water resistance and strength to the panel.

Rubber wood and natural rubber (NR) are likely sustained materials because they are renewable and, in fact, have become the major biopolymers for industry [3]. Rubber wood is mainly a source of timber in South East Asia as it is a by-product of cultivated tree and usually cut down after trees are aged and yield low volume of latex. Wood particles is subsequently the waste from rubber wood timber industry and is normally burned out or thrown away. NR is the product from rubber tree and, initially, in a form of colloidal latex, consisting of natural *cis*-1,4-polyisoprene particles in an aqueous phase collected from the bark of rubber trees [4], and is usually a raw material for latex gloves and condoms industries. In addition, dry rubber is a material for tire manufacturing.

The aim of this research is to introduce NR and rubber wood as raw materials for the fabrication of a wall panel. Wood strands, prepared from the under sized rubber wood, are shaped into rigid surfaces of the panel to provide the strength. A porous core made from NR compounds, providing thermal and sound insulation, is sandwiched by these rigid surfaces. Wood particle sieved from rubber wood sawdust is also included to the rubbery core layer to enhance its strength as well as raise this product to reach higher levels of carbon sink [5]. As a result, this panel likely becomes as a green material for the building construction. Density, water resistance, bending strength, thermal conductivity and sound barrier properties of this panel are also studied in order to ensure that it is appropriate for the wall panel application.

Materials and Methods

1. Materials for facing layers

The under size branches of rubber wood (25-30 years of age) with diameter and length at about 8 and 150 mm was used in this research in order to enhance waste reduction in rubber wood industry. The bark of these branches was peeled off and they were then sent to a disc flaking machine to transform to wood strands with the dimensions of 150 x 25 x 1 mm^3. Rubber wood strands were then dried in a rotary drum oven at the temperature of 60°C until the moisture content reached 3%. Additionally, methylene diphenyl isocyanate (MDI) with the amount of 5 wt% of wood strands was added into dry wood strand as an adhesive and mixed in a rotary mixing tank for 40 min.

2. Materials for a core layer

Raw rubber sheets from Phrom Kiri district, Nakhon Sri Thammarat province were used as NR in this research. NR was premixed with dry wood particles, 2 mm sieved from rubber wood sawdust, at the amounts of 0 and 75 wt% of NR and rubber compounds were then prepared following the recipe shown in Table 1. All ingredients were mixed on two roll mills within 20 min. Rubber compounds were then transformed into a sheet before taking out of two roll mills and left at room temperature for 16 hours before further uses.

Table 1 A recipe of rubber compounds for the core layers of insulated panels. The amount of ingredients showed herein was in the unit of part per hundred parts of rubber (phr). The functions of each ingredient were also included.

Ingredients	phr	Functions
NR*	100	natural rubber
stearic acid	1	activator
zinc oxide	5	activator
supercell-promotor	1.5	kicker
oxybis benzene sulfonyl hydrazide	5	blowing agent
zinc-N-diethyl dithiocarbamate	3	accelerator
sulfur	2.5	crosslinker

***Note:** Rubber sheets were premixed with the wood particles at the amounts of 0 and 75 wt% of natural rubber.

3. The fabrication of panels

Rubber compound sheets were cut and stacked into a slab with the dimensions of 25 x 50 x 3 cm^3 and then sandwiched by facing layers of 394 g of glued wood strands for each surface. These materials were then used as a blank for the compression moulding process under a force of 24 kg/cm^2 and the temperature of 150°C. During this process, heat would transfer through the surface layers to trickle MDI to adhere wood strands as well as transfer into a core layer to kick off a blowing agent to release gases; subsequently, the thickness of mould cavity was gradually raised in order to allow the expansion to a rubber core layer. This step enhanced bonding to wood strands inside the surface layers and expansion to the rubber core until the whole panels reached the thickness of 65 mm, within 22 and 30 min for the panels filled with 0 and 75 wt% of wood particles respectively. Additionally, using of these intervals was found to bring rubber core samples to reach the sufficient degree of curing which was reflected by toluene swelling test.

4. The measurement of panel properties

4.1 The cure characteristic of NR compounds was evaluated by following ASTM D 2084 testing methods [6] by using oscillating disc rheometer (ODR) (Gotech testing machine, model GT – 0707 – S2). Specimens were rested in an ambient for at least 16 hours and then the test was conducted at the temperature of 150°C for 15 min. The experimental result was calculated by the instrument software.

4.2 The density of panels was evaluated by following ASTM D 3574 – 95 testing methods [7] and calculated according to the following equation,

$$D = \frac{M_0}{V}$$

when D = density (g/cm^3) of specimens

M_0 = weight (g) of specimens

V = volume (cm^3) of specimens

4.3 Water absorption (WA) was conducted by following EN 317 testing methods on the specimens with the dimensions of 50 x 50 x 65 mm^3 [8]. The specimens were then immersed into water at room temperature for 24 hours. Values of WA was calculated according to the following equation,

$$\text{water absorption} = \frac{W_1 - W_0}{W_0} \times 100$$

when W_0 = weight (g) of dry specimens

W_1 = weight (g) after 24 hours of water immersion

4.4 Thickness swelling (TS) was evaluated by following EN 317 testing methods using the same specimens mentioned in 4.3 [8]. TS values of the specimens were calculated according to the following equation,

$$\text{Thickness swelling} = \frac{T_1 - T_0}{T_0} \times 100$$

when T_0 = thickness (mm) of dry specimens

T_1 = thickness (mm) after 24 hours of water immersion

4.5 Microstructure images of a rubber core layer were studied by using a field emission scanning electron microscope (FESEM) (Zeiss, Merlin compact model). Specimens (5 x 5 x 1 mm^3) were mounted on an aluminum stub and sputter-coated with gold by using a sputter coater. They were then examined using an accelerating voltage of 10 kV to obtain 3D images at the magnification of 40 times.

4.6 Internal bonding strength (IB) of the panels was determined on a universal testing machine (UTM) (Lloyd Instruments, model LR300K) with the 10 kN load cell in accordance with EN 319 testing methods [9]. Both surfaces of the test specimens (50 x 50 mm^2) were mounted to the sample holder of UTM by hot gluing and left for at least 24 hours prior to testing. The values of IB were evaluated by the instruments software using the following equation,

$$\text{IB} = \frac{F_{max}}{l \times W}$$

when IB = internal bonding (MPa)

F_{max} = maximum load (N)

l = specimen length (mm)

W = specimen width (mm)

4.7 Modulus of rupture (MOR) was determined on a UTM with the load cell of 150 kN. The test was conducted via four-point static bending on specimens (200 × 75 × 65 mm^3) cut from the whole panel in accordance with ASTM D7249/D7249M testing methods [10]. Values of MOR were evaluated by the instruments software using the following equation,

$$\text{MOR} = \frac{PL}{bt^2}$$

when MOR = modulus of rupture (MPa)

P = maximum force at the specimen fracture (N)

L = span length (mm)

b = specimen width (mm)

t = specimen thickness (mm)

4.8 Thermal conductivity of the whole panel and its components was determined by a hot disk thermal constant analyzer in accordance with ASTM C518-10 testing methods [11]. The values of heat flux were measured in order to evaluate thermal conductivity of the specimens.

4.9 Sound transmission loss was determined by using the impedance tube in accordance with ASTM E90-70t testing methods [12]. Sound waves with the frequency in the range of 100-6300 Hz, which is the frequency range of sound occurred in daily life, were used in this experiment.

Results

1. From NR and rubber wood to Insulated Sandwich Panels

Since the core layer of insulated sandwich panels reported herein was mainly constituted of porous NR filled with rubber wood particles, vulcanization property of this rubber compound was evaluated by ODR and it suggested that wood particles caused compound not only to cure faster, but also to gain better properties. Obviously, optimum cure time of the compound containing 75 wt% of wood particle was shorter than that of the unfilled one (Table 2). This might be due to higher value of thermal conductivity of wood particle over NR; therefore, greater heat transfer through rubber compound loaded with wood particle was achieved [13]. In addition, values of scorch time showed the same tendency and supported the influent of wood particle on vulcanization. It was also observed from this experiment that wood particle loaded compound exhibited higher level of maximum torque, referring to mechanical properties of the vulcanizate, than that of the unloaded one. This result suggested that rubber wood particle, which was designated as the industrial waste, might enhance productivity as well as strength to the samples of sandwich panels.

Table 2 Vulcanization properties of rubber compounds for the panel core layer.

Vulcanization properties	0 wt% Wood particles	75 wt% Wood particles
optimum cure time, T_{C90} (min.sec)	7.12 – 7.65	5.26-5.53
scorch time, T_{s5} (min.sec)	2.57-2.78	2.21-2.49
maximum torque, M_H (dN-m)	12.30-12.90	14.98-16.47

As mentioned that this panel composed of a NR compound core and glued wood strand surfaces, these two components were therefore formed in a 25 x 50 cm^2 mould. During this fabrication, we observed an expansion of the core layer to yield porous rubbery foam due to gases created from the decomposition of a blowing agent added into the compound (Figure 1). This led to changes in the density of a core layer from 0.97 to 0.41 g/cm^3 and raised the panels to reach the thickness of 6.5 cm within 22 and 30 min of moulding time for the panels filled with 0 and 75 wt% of wood particles respectively.

(a) (b)

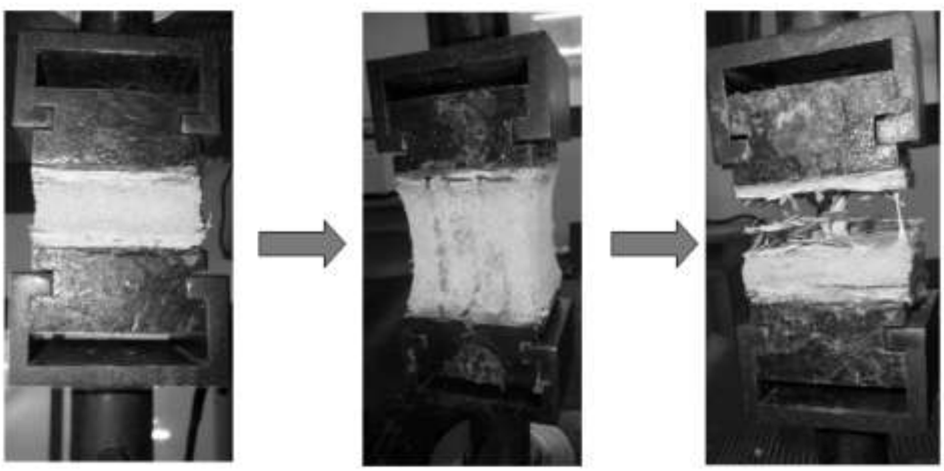
Figure 1 The image of compositions for core and surface layers (a) and the image of cured panels composed of intact wood strand surfaces and a rubbery foam core (b).

It was found that the density of the whole panel, including the surfaces and the core layer with 0 and 75 wt% of wood particles, was at 0.41 and 0.51 g/cm^3 which were in the same range as that of insulated panels used in the green building [14]. Moreover, the density of this panel was much lower than that of the materials presently used on the wall of the building in Thailand, i.e., commercial light weight panels, brick and light weight concrete [15] (Table 3). The comparison of density just mentioned inferred that using of panels made from NR and rubber wood might reduce the energy consumption on the transportation of materials as well as even on the construction of the building itself.

Table 3 The density of panels from NR and rubber wood compared with that of wall materials for the building used in Thailand.

Types of materials	Density (g/cm^3)
panels from NR and rubber wood:	
0 wt% wood particles	0.41-0.43
75 wt% wood particles	0.51-0.55
commercial light weight panels	1.20-1.40
brick wall	1.62-1.70
light weight concrete	0.55-0.64

To ensure that all compositions in this panel were well adhered, internal bonding strength (IB) was then examined. It was found that this panel displayed the failure within the surface layer when the specimen was pulled away as showed in Figure 2 and the value of IB was in the range of 0.26 to 0.40 MPa for the panels with 0 and 75 wt% of wood particles. This indicated that both of rubbery core layer and the interface between rubbery core and wood strand surface were still intact and survived this test. Additionally, values of IB from this experiment were greater than that of the commercial products (oriented strand panels) which yielded the value of IB at 0.25 MPa [16, 17].



(a) (b) (c)

Figure 2 The evaluation of internal bonding strength: (a) the specimen before testing, (b) both surfaces of the specimen were pulled away, and (c) the failure occurred within the region of wood strand surface layer.

2. Panels from NR and rubber wood as a Wall of the Building

Since the panel from NR and rubber wood was light weight as discussed previously, we then studied its properties compared with that of the commercial light weight panels, particularly wood cement boards, fiber cement boards and gypsum boards, presently used in Thailand to ensure that this panel was appropriate for wall applications as the commercial one does. We first examined water resistance properties, including water absorption and thickness swelling, and these results were shown in Table 4. It was found that the panels from this research obviously revealed lower degree of water absorption and thickness swelling than that of the commercial one. This reflected that water resistance of the panels from this research was above the level of that for the wall application. Please also note that the panel without wood particles displayed greater water resistance property compared with that of the other one due to higher hydrophilicity of the filled wood particles core relatively to the one with bare NR. We then investigated the microstructure of air cells in a rubber foam layer containing 0 and 75 wt% wood particles and found that they were mainly the closed cells (Figure 3). This supported the performance of this panel on water resistant property just mentioned because water could not penetrate through the porosity of the core layer.

Table 4 Water resistant properties of panels from NR and rubber wood compared with the commercial light weight panels used in Thailand [16, 18]. A value of thickness swelling assigned by Thai Industrial Standard (TIS) was also included for comparison.

Types of materials	Thickness swelling (%)	Water absorption (%)
panels from NR and rubber wood:		
0 wt% wood particles	0.6	13-16
75 wt% wood particles	0.9	23-26
wood cement, fiber cement and gypsum panels	1	12-35
Thai Industrial Standard (TIS)	below 2	-

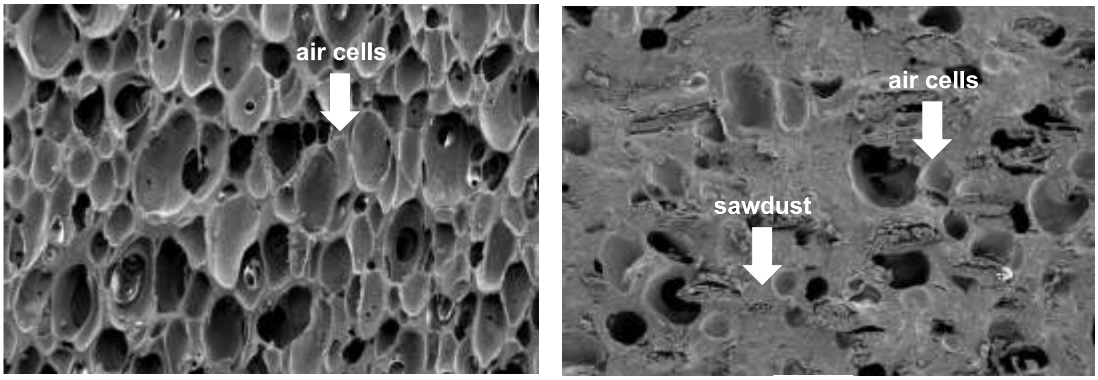


Figure 3 Microscopic images from SEM revealing the structure of air cells in rubbery foam core with: (a) 0 wt% wood particles and (b) 75 wt% wood particles.

We also studied the strength of this panel by examining the value of modulus of rupture (MOR) via static bending test which was one of the requirements for the wall panel materials. It was found that panels from this research yielded MOR at 14 and 57 MPa for 0 and 75 wt% wood particles-filled samples while that of the commercial one was in the range of 7-12 MPa (Table 5). Obviously, MOR of the panel from this research was about 2-5 times greater and, in addition, the panels filled with wood particles showed greater strength than that of the unfilled one which also supported the result of maximum torque values (M_H) from ODR mentioned earlier. This might be due to low deformation when this panel was bended since its surfaces consisted of oriented strands and the filled wood particles also enhance rigidity to bending to the panels [17, 19]. Microscopic images previously shown in Figure 3 (b) also provided the evidence supporting superb MOR property on wood particles filled samples. It was found that no phase separation at the interface between wood particles and continuous rubbery phase was observed. This indicated a high degree of interaction at the interface of these two components.

Table 5 Modulus of rupture (MOR) of panels from NR and rubber wood compared with that of the commercial light weight panels used in Thailand [16, 19].

Types of materials	MOR (MPa)
panels from NR and rubber wood:	
0 wt% wood particles	13-14
75 wt% wood particles	55-57
wood cement, fiber cement and gypsum panels	7-12

3. Thermal and Sound Insulated Properties of Panels from NR and rubber wood

Beside the performance mentioned previously, we also found that this panel behaved as a good thermal as well as sound barrier. Thermal conductivity of this panel was evaluated by using the method of heat flow from one surface to the other [11, 12] and this value was at 0.070 and 0.086 W/mK for the panel with 0 and 75 wt% of wood particles (Table 6). As expected, heat flow through the wood strand surface was greater than that through the rubbery foam core due to the difference in density of these two portions. This yielded the values of thermal conductivity at 0.140 W/mK for surface layers and about 0.040 W/mK for the core with 0 and 75 wt% of wood particles respectively. Please also note that values of thermal conductivity of the rubbery foam core was at about the same level of synthetic foam used in insulated panels of the green building [15]. As also shown in Table 6, the insulated panel from this research presented more than sixteen times of thermal conductivity lower than that of the brick wall which was a typical wall for the building. Moreover, the information in this table indicated that the panel from this research exhibited better thermal insulated property than that of any other wall materials used in Thailand [15, 16, 19].

Sound transmission loss of this insulated panel was also evaluated by using nineteen different sound frequencies in the range of 100-6300 Hz which is the frequency occurred in daily life. It was found that the panels with 75 wt% of wood particles displayed the values of sound transmission loss, the ability of materials to reduce sound intensity, in the range of 35-80 dB (Table 6). The values of that for the typical walls and the commercial light weight panels were also included in this table for comparison. Obviously, insulated panels from this research provided higher sound barrier property than that of the wall materials currently used [15, 16, 19].

Table 6 Thermal and sound insulated properties of the insulated panel compared with wall materials used in Thailand.

Wall materials	Thermal conductivity (W/mK)	Sound transmission loss (dB)
panels from NR and rubber wood:		
0 wt% wood particles	0.070	n/a
75 wt% wood particles	0.086	35-80
brick	1.15	36-40
light weight concrete	0.24	38-43
wood cement board	0.1-0.15	28-32
fiber cement board	0.08-0.15	38-64
Gypsum board	0.14-0.19	35-65

Conclusions and Discussions

This research studied the properties of green panels composed of a core and surfaces layers made from NR and rubber wood strands respectively. The panel was light weight due to the expansion of a NR core during hot-pressed fabrication. The density of the cured panels, in the range of 0.41-0.55 g/cm^3, is lower than any materials presently used on the wall of the building.

We also found evidences supporting the possibility of using this panel as the wall of the building since its strength, displaying by the value of MOR, is two to six times greater than that of the commercial products currently used for the light weight wall. In addition, values of thickness swelling and water absorption are at 0.6-0.9% and 13-26% respectively; as a result, this is about two times better than that of the commercial one. More importantly, this panel reveals only little value of thermal conductivity (0.070-0.086 W/mK) which is about two to sixteen times below the value of that for wall materials found in Thailand. This insulated panel displays not only supreme results on thermal insulation but also on sound barrier. It is found that the value of sound transmission loss for this panel is at 35-80 dB which is about two times better than that of the wall materials presently used.

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ได้รับบทความวันที่ 26 พฤศจิกายน 2560
ยอมรับตีพิมพ์วันที่ 29 มีนาคม 2561