International Journal on Advanced Science Engineering Information Technology

Vol.8 (2018) No. 3
ISSN: 2088-5334

Development of Thermal Insulation Material Using Coconut Fiber to Reuse Agricultural Industrial Waste

Ryushi Kimura [#], Masato Ohsumi[#], Lusi Susanti[*1]

[#] *Department of Social Design Engineering, National Institute of Technology, Kochi college, Kochi, 783-8508, Japan*
E-mail: kimura@ce.kochi-ct.ac.jp

* *Department of Industrial Engineering, Andalas University, Padang, 25163, Indonesia*

[+]*Faculty of Information Technology, Andalas University, Padang, 25163, Indonesia*
[1]*E-mail: susantilusi@gmail.com*

***Abstract*— This paper aims to report a development of thermal insulation material using coconut fiber, which is one of agricultural industrial waste in Indonesia and a verification of an effect of thermal insulation. Seven test pieces were developed under various conditions (amount of fiber, two types of binder, amount of water, temperature setting and drying time) and thermal properties such as thermal conductivities were measured using microcomputer "Arduino UNO" equipped with radiation thermos-camera. As a result, the insulation material which mixed 30g of the coconut fiber, 30g of tapioca starch and 300ml of water, drying under the setting temperature of 120 ^{o}C for 24 hours showed the lowest conductivity of 0.104 Wm^{-1}K^{-1}.**

***Keywords*— thermal insulation material; coconut fiber; agricultural industrial waste; reuse and low energy building material**

I. INTRODUCTION

In recent years, economic growth in South East Asian countries is remarkable. According to World Economic Outlook Databases published by IMF, economic growth rate based on GDP in Indonesia shows averagely 5.4 % since 2000 [1]. Improvement for quality of life, especially indoor air quality causes increasing huge number of air-conditioner demands and affects energy consumption in household sector [2-3]. Sukarno et al. reported that 92 % of Padang electricity supply went for residential sector and 17 % of the household electricity consumption was used for cooling load [4]. It is important to effectively use of air-conditioner to reduce energy consumption. However, because typical residential building constructed by bricklaying is not attached thermal insulation material on walls, the construction brings an increase of cooling load.

Therefore, to reduce energy consumption with the effective use of air-conditioner for residential buildings, development of thermal insulation material is important. Our final goal in this study is to develop thermal insulation material using domestic materials and techniques in Indonesia to spread widely the insulation material to buildings and reduce energy consumption. Additionally, one of the social issues in Indonesia is to reuse agricultural industrial waste such as the huge amount of coconut fibers discharged from coconut shells after extraction of palm fruit. In this study, to propose reusing the industrial waste effectively, we developed thermal insulation material made from coconut fiber. In order to verify an effect of the insulation materials, we also developed simple and low-cost measuring system for recording temperature to calculate thermal conductivity using microcomputer board "Arduino UNO" as a sensor node with non-contact radiation thermos camera to measure multiple pointed temperature simultaneously and small PC board "Raspberry Pi3" as a data logging platform. To develop the measuring system, authors have ever experienced developing wireless electricity measuring system [5-9].

II. MATERIAL AND METHOD

The whole process for development of thermal insulation is explained as follows: 1) making test pieces, 2) developing measuring system (hardware and software), 3) calculating conductivity, 4) calibration for the developed system.

A. Preparation of test pieces

Fig.1 shows a process of making test pieces. There are main four processes to make test pieces as followings; 1) Shredding fiber in 3 mm to 5 mm by cutting machine after flaking coconut shell, straining off water, 2) Mixing fiber with 2 types of binders such as natural binder, tapioca starch or chemical binder, polyvinyl alcohol and water, 3) Molding test piece whose size of width 100 mm x depth 100 mm x height 30 mm using wooden form, 4) Drying by electric oven and demolding test piece.

TABLE I shows components of test pieces. To provide 7 types of test pieces, 5 items such as amount of fiber (30 g or 35 g), water content (200ml or 300ml), two types of binder (tapioca starch or polyvinyl alcohol gel), drying temperature (40, 80 or 120 ^{o}C), drying time (24h, 48h or 72h) were combined.

B. Outline of measuring system

1) Hardware of measuring system:

Components of measuring system are shown in Fig.6. The measuring system for thermal conductivity was based on the determination of steady-state thermal transmission properties and Hotbox method [10]. The system is composed two parts, hot box part and automatic measuring part. Hot box (width

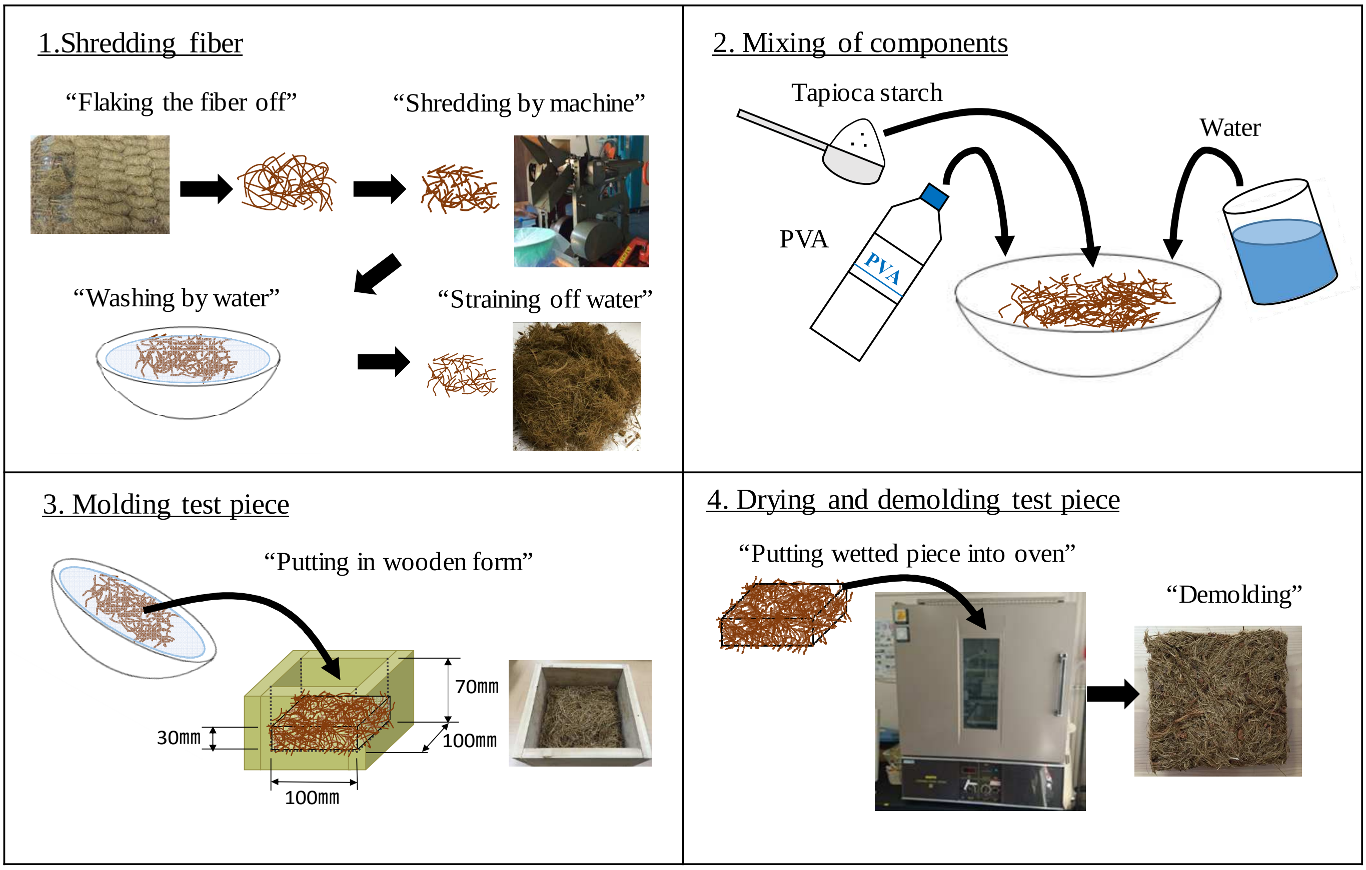

Fig 1. Process of making test pieces

TABLE I
COMPONENTS OF TEST PIECES

Case No.	Item						
	Coconut fiber	Water	Binder		Drying temperature	Drying time	Weight after drying
			Tapioca starch	Polyvinyl alcohol			
	[g]	[ml]	[g]	[ml]	[degree C]	[hour]	[g]
Case1	35		-	200	80	48	38.1
Case2	30	200	30	-	80	48	50.7
Case3	30	200	20	-	80	48	38.6
Case4	30	200	40	-	80	48	60.3
Case5	30	300	30	-	80	72	48.8
Case6	30	300	30	-	40	72	52.5
Case7	30	300	30	-	120	24	42.7

300 mm x depth 300 mm x thickness 30 mm) which made

from extrusion-expanded styrene board set silicon panel heater can generate heat load constantly to make steady state thermal condition. The upper part of the board has a square (100 mm x 100 mm) hole for setting test pieces. To generate heat quantity of 10 Wcm^{-2} from the heat panel, 10 V was output by a volt regulator. Automatic measuring part is composed Micro-Computer board “Arduino UNO” (Fig.3) for sensor controlling PC board “Raspberry Pi3” (Fig.4) for data logging from Micro-Computer board, two IC precision centigrade temperature sensors LM35 of Texas Instruments Inc. (Fig.5), and non-contact radiation thermos camera D6T-44 of OMRON Co.Ltd (Fig.6) which can measure thermal array of 16 points (4 x 4) (Fig.7).

2) Software of measuring system:

Fig.8 shows data flow from sensor. One of the features of Arduino is equipped with communication ports to read several types of data interactively and simultaneously. For instance, in the system, analog data from LM35 as temperature data is an input to Arduino

Fig.3 MC board
Arduino UNO

Fig.4 PC board
Raspberry Pi3

Fig.5 Temperature sensor LM35

Fig.6 Thermos camera
OMRON D6T-44

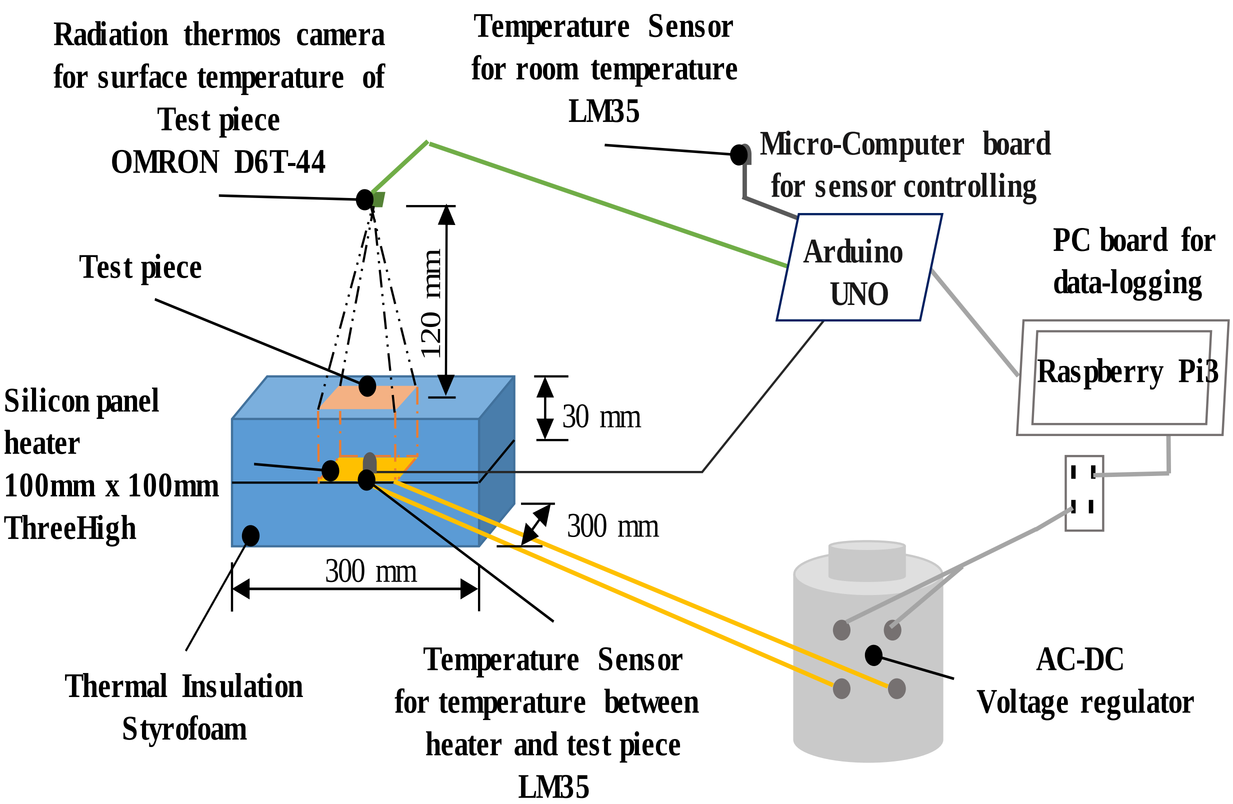

Fig .2 Components of thermal conductivity measurement system using Arduino and Raspberry Pi3 through analog port directly. Analog data with I2C communication protocol from D6T-44 as radiation temperature data is input through I2C ports (SDA and SCL). To change these analog data from each sensor to temperature value, Arduino is written equations coding by Arduino IDE using Arduino language similar to C++ language. Data reading by Arduino is sent to Data platform in Raspberry Pi3 and converted to .TXT or .CSV format as output file using JAVA based programming language Processing 3. Each sampling code was referred author's website [11].

C. Measurement condition

The measurement was conducted in a laboratory (floor area 60 m^2) at National Institute of Technology, Kochi College in Kochi, Japan (Longitude 133.38 °E, Latitude 33.3 °N), measuring period was from November 11, 2016 to December 30, 2016. Room temperature was set 22 °C and controlled by air conditioner during measuring period (TABLE Ⅱ).

TABLE II
MEASURING CONDITIONS

Period	November 11, 2016 to December 30, 2016
Location	3rd floor, building of department of environmental civil engineering and architecture, National Institute of Technology, Kochi college, Kochi, Japan Longitude 133.38 °E Latitude 33.3 °N
Indoor set temperature	22 °C (control by air-conditioning)

D. Calculation of thermal conductivity

Equation 1 shows general equation for the heat load Q. The coefficient of heat-transfer was ignored because the air around the hot box set test piece was circulated by DC fan constantly to prevent retention of the air.

$$Q = \lambda \frac{T_{high} - T_{low}}{d} A \qquad (1)$$

Equation1 transformed into Equation2. Then, item $\sum_{i=1}^{16} T_{low,i}$ is an average 16 (4 x 4) points of surface temperature on test piece measured by radiation thermos camera (D6T-44).

$$\lambda = \frac{Qd}{\left(T_{high} - \frac{\sum_{i=1}^{16} T_{low,i}}{i} \right) A} \qquad (2)$$

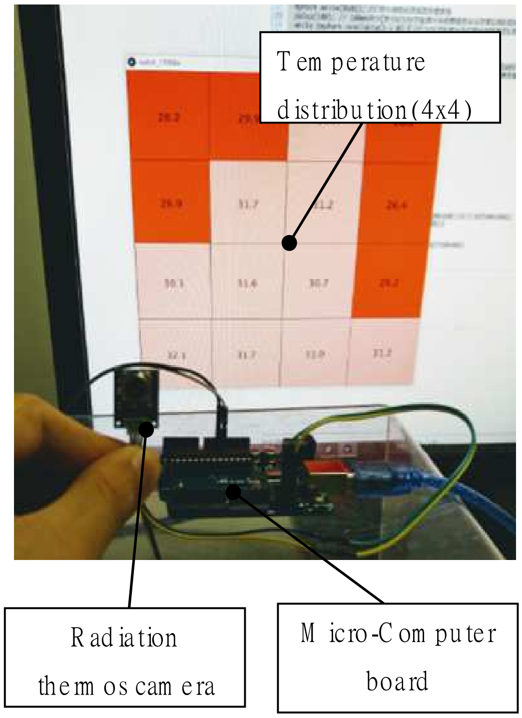

Fig.7 Temperature distribution using radiation thermos camera (OMRON D6T-44)

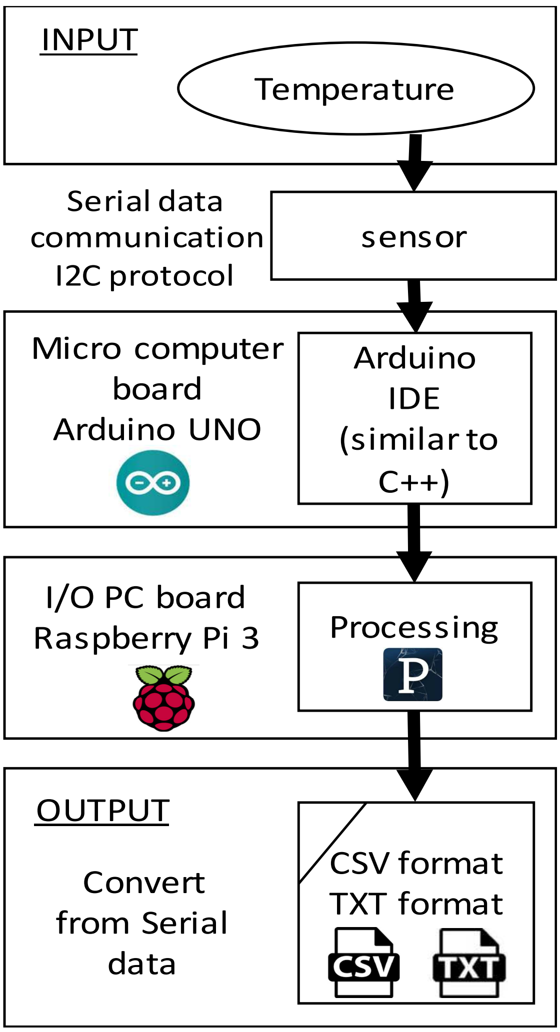

Fig.8 Data flow from sensor

E. *Calibration of measuring system*

To calibrate of the measuring system, Japanese cypress was measured because Japanese cypress is common building material and measured with reliable conductivity value of the cypress published by Timber Industry handbook [7]. The size of the test piece for calibration is width 100 mm x depth 100 mm x height 30 mm (Fig.9) as same as other test pieces for thermal insulation. The test piece was heated until becoming heat balanced steady-state. The steady-state is presumed a state which average difference of temperature for 10 minutes is less than 0.1 ^{o}C based on the limit of resolution of the sensor.

The result is shown in Fig.10 and TABLE Ⅲ. The conductivity was 0.140 $Wm^{-1}K^{-1}$ in almost 1 hour later when the heat balance become steady-state. According to the Timber Industry handbook[12], mean conductivity of Japanese cypress is 0.120 $Wm^{-1}K^{-1}$. An error ratio of conductivity between the measured value and referred value was 14.2%.

TABLE III
CALIBRATION RESULT (JAPANESE CYPRESS)

Thermal conductivity λ [$Wm^{-1}K^{-1}$]	0.140
Time reached steady-state [min]	64
Average surface temperature on test piece T_{low}[^{o}C]	25.03
Temperature between panel heater and test piece T_{high} [^{o}C]	43.52
Room temperature [^{o}C]	22.03

Fig.9 Test piece of Japanese cypress

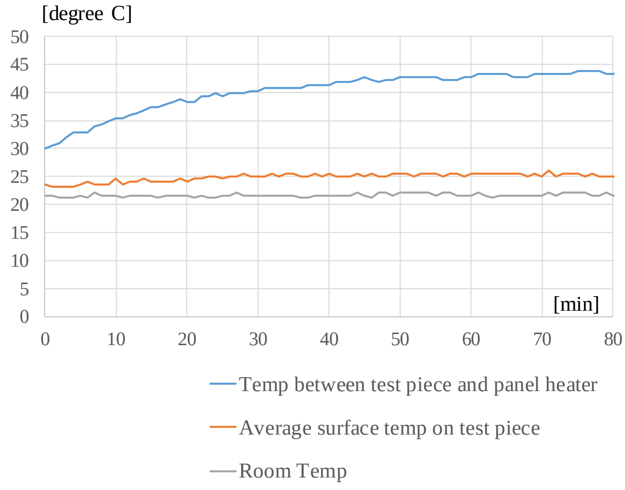

Fig.10 Change of temperature (Japanese cypress)

III. RESULT AND DISCUSSION

TABLE IV Shows results of the conductivity of all cases. The value of conductivities is distributed from 0.104 $Wm^{-1}K^{-1}$ to 0.160 $Wm^{-1}K^{-1}$. Figure.11 shows surface membrane made from tapioca starch on test pieces. An area of the membrane is marked a black line on Figure.11. All test pieces covered membrane hardened tapioca starch partly or the whole surface.

To reveal what factor affects change of conductivity, the best-performed result of 0.104 $Wm^{-1}K^{-1}$ in Case 7 and the worst-performed result of 0.160 $Wm^{-1}K^{-1}$ in Case 6 were compared. The components of coconut fiber, water, and tapioca starch used the same amount, however, drying time and temperature were different. Drying temperature and time of Case 6 were 40 ^{o}C and 72 hours in the oven respectively, on the other hand, the condition of Case 7 was 120 ^{o}C as 3 times higher than Case 6 and 24 hours or one-third of Case 6. The both cases were covered the membrane whole surface with visual observation. The surface of the test piece in Case 6 drawn by a broken line is uneven more than the surface of test piece in Case 7 because some parts of fiber have gravitated in hardening fiber process. On the other hand, the surface of the test piece in Case 7 was formed comparatively flat and smooth because gravitating the fiber could be prevented when the test piece become hardening under high temperature and brief time. As a matter of course, the form without unevenness can reduce heat loss by heat transfer through convective flow around the surface.

Additionally, the conductivity of test piece using PVA binder in Case1 was valued 0.105 $Wm^{-1}K^{-1}$ as one of the best results in other cases. The membrane was generated on the surface of the piece as similar to Case 6. Therefore, effective use of PVA as chemical binder should be considered to improve conductivity.

TABLE IV
RESULTS OF THERMAL CONDUCTIVITY

Case No.	Thermal conductivity [$Wm^{-1}K^{-1}$]
Case 1	0.105
Case 2	0.144
Case 3	0.130
Case 4	0.155
Case 5	0.122
Case 6	0.160
Case 7	0.104

IV. CONCLUSIONS

In this study, we developed thermal insulation material using coconut fiber to reuse industrial waste and to reduce energy consumption and simple thermal conductivity measuring system using microcomputer board Arduino UNO and reasonable PC board Raspberry Pi 3. As a result, the developed insulation material which mixed 30 g of the coconut fiber, 30 g of tapioca starch, 300 ml of water, under the dry condition with 120 ^{o}C and 24 hours was best-performed 0.104 $Wm^{-1}K^{-1}$ of thermal conductivity. Moreover, as drying condition for insulation material was brief and high temperature, surface membrane from tapioca starch was formed effectively and functioned to increase conductivity. The developed measuring system could measure thermal conductivity with an error less than 15 % using noncontact thermos camera.

As prospects for the future, to improve the insulating performance of coconut fiber insulation, we will examine 1) to combine antiseptic to prevent mold because tapioca starch would cause generating mold in some moisty cases, 2) to develop lower-environmental load insulation material using eco-friendly PVA binder.

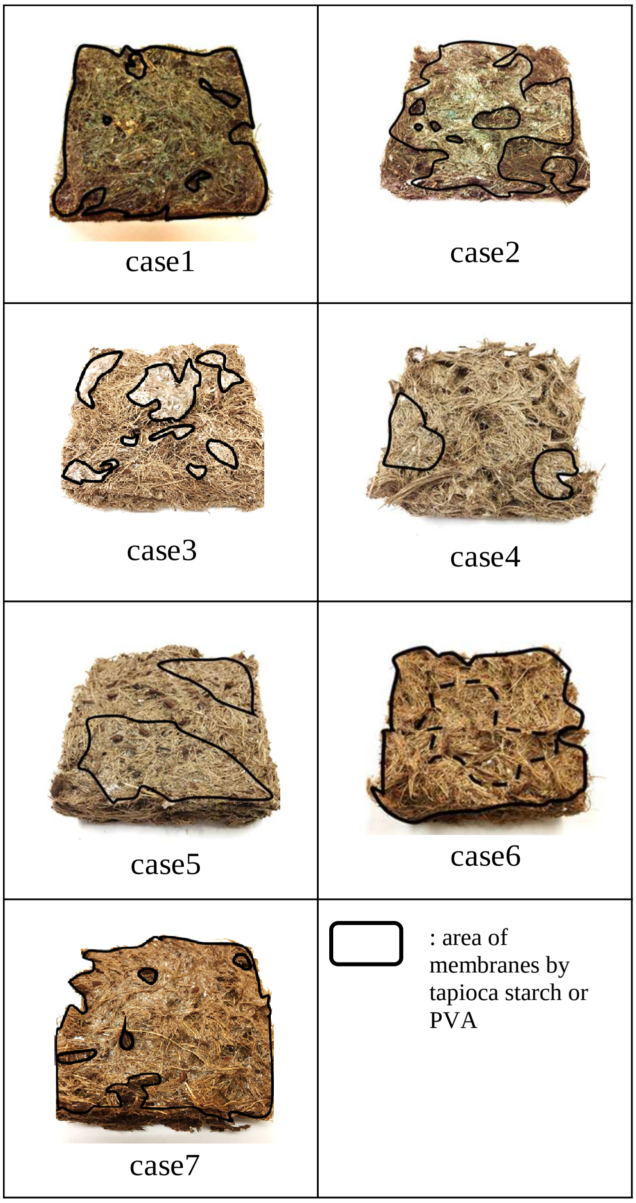

Fig.11 Membrane on test pieces

NOMENCLATURE

Q	heat load	W
d	thickness of test piece	m
T	temperature	℃

Greek letters

λ	thermal conductivity	$Wm^{-1}K^{-1}$

Subscripts

i	radiation thermos-camera measuring point

ACKNOWLEDGMENT

My deepest appreciation goes to staffs of recycle center at Andalas University managed by Dr. Lusi Susanti to supply experiment materials for this research. Research work performed by Dr. Lusi Susanti was partly supported by Research Grant of International Research Collaboration and Publication No. 06/UN.16.17/PP.KLN/LPPM/2017. Dr. Lusi Susanti also contributed to analyse the results.

REFERENCES

[1] World Economic Outlook Database April 2017, International Monetary Fund, http://www.imf.org/external/ns/cs.aspx?id=28

[2] M. Yamaguchi, H. Shibusawa and R. Kimura, Long Term Simulation for Number of households using geometric data, Research bulletin “Hibarino”of Toyohashi University of Technology, No.32, pp.17-29, 2010

[3] R. Kimura, H. Matsumoto, Fundamental study on development of energy mapping model and estimating simulation for number of households to calculate energy consumption in household sector in urban area, Transactions of AIJ. Journal of architecture, environmental engineering, 73(626), pp.495-502, 2008

[4] I. Sukarno, H. Matsumoto, L. Susanti and R. Kimura, Urban Energy Consumption in a City of Indonesia: General Overview, International Journal of Energy Economics and Policy, Vol. 5, No. 1, pp.360-373, 2015

[5] R. Kimura, S. Mito, K. Yamada and K. Nakamura, Study on mentoring for occupant’s daily action using energy harvesting electricity sensor, outline of development of electricity sensor and test operation, proceeding of Architectural Institute of Japan, Environmental Engineering section 2, pp.1105-1106, 2016

[6] D. Okazaki, S. Mito, R. Kimura and H. Kobayashi, Development of localization techniques of sensor node by anchor node method. 22th symposium of National Institute of Technology, session F-28, 2017

[7] K. Yamada, S. Mito, Development of devices to visualize indoor air environment considered to human relationship, FIT2017 proceeding 4th, pp.227-228 , 2017

[8] K. Yamada, R. Tsubakidani, R. Kimura, H. Kodayashi and S. Mito, Estimation for human activities at office using electricity sensors and vibration sensors, Technical report of IEICE HPB NO16, pp.10-14 , 2017

[9] K. Imai, S. Ueda, M. Ueda, T. Takamura, T. Nonaka, K. Hamaguchi, M. Saeki, K. Imanishi and R. Kimura, Measurement of thermal environment in house using IPv6 microcomputer board, IJCIEE,1st, proceeding, pp.19-21, 2014

[10] Japanese Industrial Standard A1420, Determination of steady-state thermal transmission properties, Hot box method, 1999

[11] How to use sensors using Arduino and Raspberry Pi, National Institute of Technology (2017), Department of Environmental Civil Engineering and Architecture web cite, http://www.kochi-ct.ac.jp/~kimura/lecture.html

[12] Forest Research and Management Organization, Timber Industry Handbook, section 2, properties of timber, 2004