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Thai Cultivated Banana Fibers as The Sustainable Sound and Heat Insulation Materials

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Abstract: This study was aimed to develop on the sound absorber and the heat insulator derived from natural fiber (cultivated banana fiber) to be an alternative way. Normally, the community consume this equipment derived from synthetic materials (asbestos and fiberglass) which cause of the negative human health. The process of specimen preparation was started by the banana stem cutting-off step to prepare banana fibers which had been determined to slit of 2-3 mm fiber diameter by cutter and then dehydrated on these banana fibers. Eventually, a high-speed of grinder was applied to mill these fibers and then the 30 US MESH size of filter was utilized to 0.6 mm reducing fiber length. Therefrom, this cultivated banana fiber was prepared to test on Noise Reduction Coefficient (NRC) and Thermal Conductivity (TC) according to various factors: (1) banana fiber-gypsum ratio on 2:8 and 3:7 by weight, (2) banana fiber length of 0.6 mm and (3) 25.0 mm thickness of each specimen. These experiments were determined on the NRC value based on ISO10534-2 standard at frequency range 250-4,000 Hertz and the TC value based on ASTM C518 standard. In addition, the structural and scattering images of banana fiber and surface were investigated by Scanning Electron Microscope (SEM). The NRC result showed as 0.52 of banana fiber specimen in the length of 0.6 mm and banana fiber-gypsum ratio on 3:7 by weight that appeared more porosity and space area. Likewise, the TC result was found at 0.063 W/m.K. Consequently, this local natural material prepared by cultivated banana fiber was proven effective in noise reducing and heat-insulating purposes for Thailand's community.

Keywords: Cultivated Banana Fiber; Noise Reduction Coefficient; Thermal Conductivity

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1. Introduction

In Thailand, the high quantity of agricultural wastes (for examples: 10.89 tons per year of rice straw, 15.17 tons per year of canes leave, 16.37 tons per year of palm fibers, etc.) were available on every regions [1]. These agricultural wastes would be the value-added materials and encouraged to reduce on the particulate matters (PM) 2.5 communities' nuisance [2] from the incineration including on the negative human health and temperature increment as the result of global greenhouse effect. Likewise, the sound level of 90 dBA or above is harmful to the whole human hearing [3]. In the present, many natural materials from waste are going to study widely on lifestyle purposes, particularly noise and heat control within the field of building and construction as the alternatives to the traditional materials (i.e., fiberglass, asbestos, etc.) that World Health Organization (WHO) mentioned the hazard of asbestosis on lung cancer, pleurisy lung cancer and ovarian cancer about 107,000 people per year [4]. Furthermore, the Europe, America and Asia regions also found global mesothelioma deaths that were reported by the World Health Organization [5]. In general, there are two main categories of natural materials: (1) natural materials (i.e. cotton, hemp, sheep wool, flax, clay, etc.) and (2) recycling materials (i.e. rubber, plastic, cellulose, etc.). Most of life cycle assessment (LCA) is also available and these natural fiber composites were found as positively environmental fiber, therewith cheaper and lighter than synthetic fiber [6]. Some research found the natural porous materials as the good sound absorber, in the range of medium and high frequencies [7]. In comparison to the traditional sound absorber and heat insulator, the natural porous materials preferably are benefit on environmental friendly. Also, the effective factors in sound absorption such as fibers size, air-flow resistance, porosity, curve, thickness and density of these nature absorbers were deeply investigated [8]. Many kinds of fibrous materials were studied on noise reduction and heat insulation, moreover, these natural fibers have been studied in terms of flame retardant, high-temperature resistance and moisture resistance, metallic fibers as well [9]. The thermal properties of natural fibers (hemp and kenaf) were equivalent to synthetic fibers [6]. To meet living environment requirements and increase social perception, the natural material might be greater chances. Thus, the continued development of technologies is forced to support on these needs. In previous studies, there were many ways in which natural materials can utilize in modern construction. However, the natural fiber was impacted with fungi, parasites and less fire-resistant, thus these natural fibers were technically prepared before using [10].

Banana is one of the most widely cultivated crops in Thailand. There were 547,055 Rai of

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banana plantations and 782 million tons of product including total exports of 35,266 tons [11]. When using the general microscope to see longitudinal images of banana fibers from their stem, these banana fibers are comprised of bubbles, which are common throughout the stem of banana [12] and this fibrous configuration comprises many cavities (porosity of fibers) within parallel fibers bundle as shown on Fig.1(b).

Ordinarily, this banana fiber composes of a set of continuous filaments and air passageways, where sound energy strike on these fibers caused to lose its energy due to frictions [13]. Therefore, the research objectives were to develop on the sound absorber and the heat insulator that derived from the cultivated banana fiber to be an alternative way, these fibers were mixed with binder as gypsum and fused silica were studied relate to (1) banana fiber-gypsum ratio on 2:8 and 3:7 by weight, (2) banana fiber length of 0.6 mm and (3) 25.0 mm thickness of each specimen.

2. Raw Materials, Specimen Preparation and Analysis Methods

2.1 Raw Materials

2.1.1 The Cultivated Banana Fiber

The cultivated banana (Scientific name: Musa ABB CV.Kluai “Namwa”, this local banana can find in the Thailand region) were prepared for fibers with an average cut length of 0.6 mm after dehydration as shown in Fig. 1(a) and (c).

2.1.2 Gypsum Powder

The type of gypsum powder or calcium sulphate dehydrate (molecular formula: $CaSO_4.H_2O$) is 2B according to Thai Industrial Standard No.188 [14]. The physical properties is the expansion setting less than 2.0% and surface hardness, that diameter of indentation less than 5 mm. The chemical properties comprise on the main component 35.0% of SO_3, CaO > 23.3%, and MgO < 0.3%, respectively.

2.1.3 Fused Silica (SiO_2)

The general name is Fused silica that is the by- product of Quartz. The physical properties describe on its molecular weight: 60.1, specific gravity: 2.2-2.6, melting point: 1,710 °C, white color, and its size: 0.1-0.5 mm Fused silica has the characteristics of strengthening and adhesive agent which the chemical properties consist of SiO2 min: 98.5%, Al2O3 max: 0.1-0.5 %, and Fe2O3 max: 0.03%, respectively [15].

2.2 Specimen Preparation and Analysis Methods

To specimen preparation, the process of specimen preparation was indicated in Fig. 2 to determine on Noise Reduction Coefficient (NRC) as required on ISO10534-2 standard [16] and Thermal Conductivity (TC) as required on ASTM C518 standard [20].

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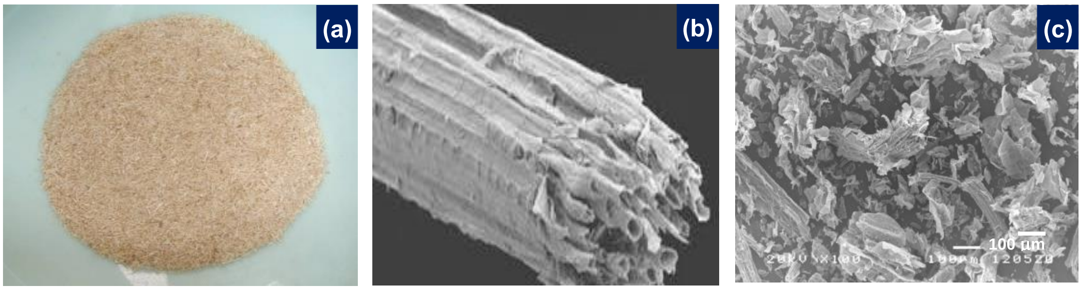

Fig. 1 (a) The 0.6 mm length of cultivated banana fiber, (b) Longitudinal section of banana fiber by SEM image at 100x and (c) The fine 0.6 mm cultivated banana fiber

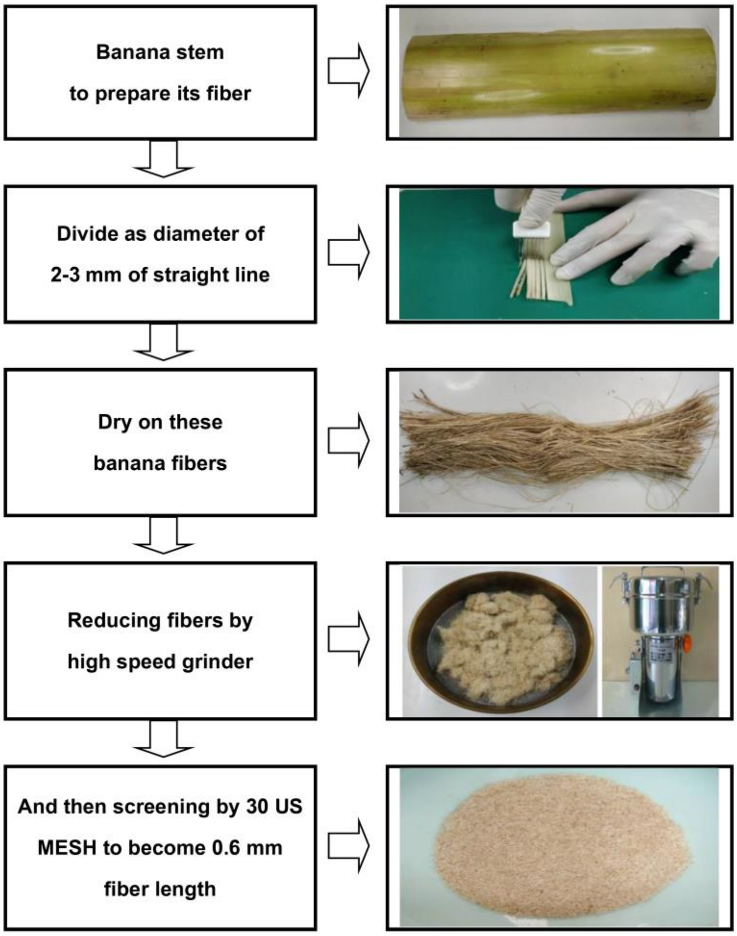

Fig. 2 The preparation process of specimen

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2.3 Analysis

2.3.1 Noise Reduction Coefficient Determination

Based on the relevant research of E. Tholkappiyan [19], the specimen was prepared by controlling on various factors: (1) fiber length of 0.6 mm, (2) banana fiber-gypsum ratio on 2:8 and 3:7 by mass, at 25.0 mm thickness of each specimen, were aimed to determine on Noise Reduction Coefficient (NRC) by impedance tube method based on ISO10534-2 standard [16] as following on Table 1 and Fig. 3

Table 1 The mixture proportions of each specimen

Specimen No.	Fiber length (mm)	Banana fiber-gypsum ratio (by mass)	Water-fused silica ratio (by mass)
K1/2	0.6	2:8	5:1
K1/3	0.6	3:7	5:1

(a)

(b)

Fig. 3 (a) Specimen # K1/2 and (b) Specimen # K1/3

Each mixture proportion was provided on 6 specimens which were molded into a pair of circulars at the diameter of 9.8 cm and 2.8 cm, at 25 mm thickness for testing in low-sensitivity zone (0-1,600 Hz) up to high-sensitivity zone (1,600-4,000 Hz), respectively until these specimens become to be dried at ambient temperature. The reaction between gypsum and water was able to linkage with banana fiber, especially fused silica with Si - H bonding reinforcement. Also, the total of 12 specimens were recorded on weight before and after drying to calculate on bulk density as the equation (1).

$$\text{Bulk density (g/cm}^3\text{)} = W / V \qquad (1)$$

Note: W = The Weight of Each Dried Specimen
V = The Volume of Each Specimen

In comparing sound-absorbing materials for the noise control, the impedance tube method using the Kundt's tube on Fig. 4 [17] can be determined on NRC is the arithmetic mean of Sound Absorption Coefficient (α) at frequencies 250, 500, 1,000 2,000 and 4,000 Hz on the ability of sound absorption on the surface of the material as the equation (2) [18].

$$NRC = (\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000} + \alpha_{4000}) / 5 \qquad (2)$$

When: NRC = Noise Reduction Coefficient
α = Sound Absorption Coefficient

In this study, porosity of each specimen was calculated from the equation (3) [19].

$$\text{Porosity} = 1 - \frac{\text{Fiber Density}}{\text{Bulk Density}} \qquad (3)$$

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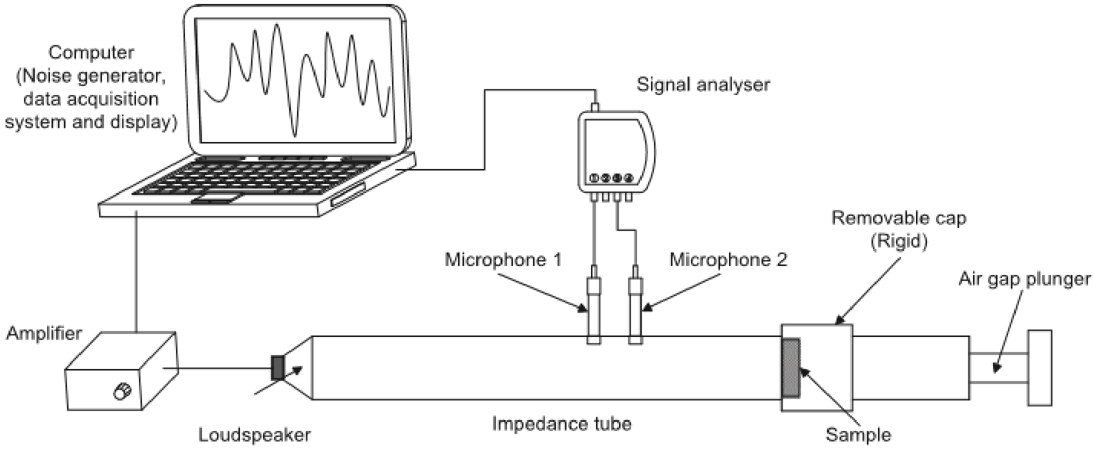

Fig. 4 The Kundt's tube to determine on NRC

2.3.2 Thermal Conductivity Determination

Based on an experimental, the specimen was prepared by controlling on various factors: (1) fiber length of 0.6 mm, (2) banana fiber-gypsum ratio on 2:8 and 3:7 by mass, at 25.0 mm thickness of each specimen, were aimed to determine on Thermal Conductivity (TC) by the comparative method based on ASTM C518 standard [20] as follow in Table 1 and Fig. 5

Each mixture proportion was provided on 3 specimens which were molded into 20 x 20 x 2.54 cm. By the comparative method, the heat flow meter was provided to measure the temperature of heat transferring from hot plate toward cold plate at steady state according to ASTM C518 standard [20] as shown in Fig. 6.

(a)

(b)

Fig. 5 (a) Specimen # K1/2 and (b) Specimen # K1/3

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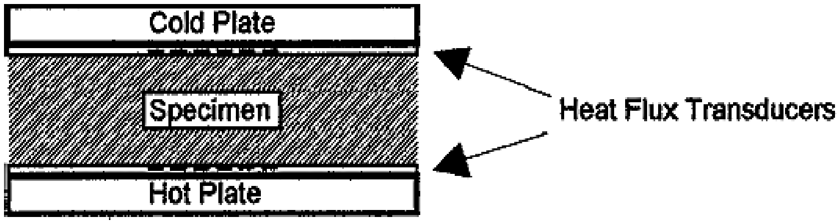

Fig. 6 Apparatus with two heat flux transducers and one specimen

To calculate the thermal conductivity of the specimen as follows:

$$\lambda = S \cdot E \cdot (L / \Delta T) \quad (4)$$

When:

λ = Thermal conductivity, W/(m·K).
S = Calibration factor of the heat flux transducer, $(W/m^2)/V$.
E = Heat flux transducer output, *V*.
L = Separation between the hot and cold plate assemblies during testing, m.
ΔT = Temperature difference across the specimen, *K*.

3. Results and Discussions

3.1 Noise Reduction Coefficient (NRC)

This NRC value demonstrates the material characteristic will absorb on the incident sound. Remarkably, the value of NCR: 0.4 – 1.0 indicated high level of noise absorption [21]. The average of Noise Reduction Coefficient showed on Fig. 7 that the result of specimen K1/3 (fiber size 0.6 mm and the ratio of banana fiber-gypsum equivalent to 3: 7 by mass) was indicated the sound absorption ability to be 0.5218, the specimen K1/2 (fiber size 0.6 mm and the ratio of banana fiber-gypsum equivalent to 2: 8 by mass) was determined to be 0.4733, consecutively. Thus, the specimen K1/3 was higher than the specimen K1/2 in term of NRC.

3.2 Density and Porosity

The average of density was presented on Fig. 8 that the result of the specimen K1/3 indicated to 0.71 g/cm^3 and the density of the specimen K1/2 was equivalent to 0.91 g/cm^3, consecutively. Thus, the specimen K1/2 was higher than the specimen K1/3 in density. Also, the average of porosity value was calculated as equivalent to 0.87.

3.3 Thermal conductivity (TC)

The average of thermal conductivity was showed on Fig. 9 that the result of specimen K1/3 indicated to 0.0629 W/m.K and the specimen K1/2 was equivalent to 0.0829 W/m.K, consecutively. Thus, the specimen K1/3 was better than the specimen K1/2 in term of heat insulator. Also, this specimen K1/3 has nearly TC with polystyrene which is the good quality of heat insulator.

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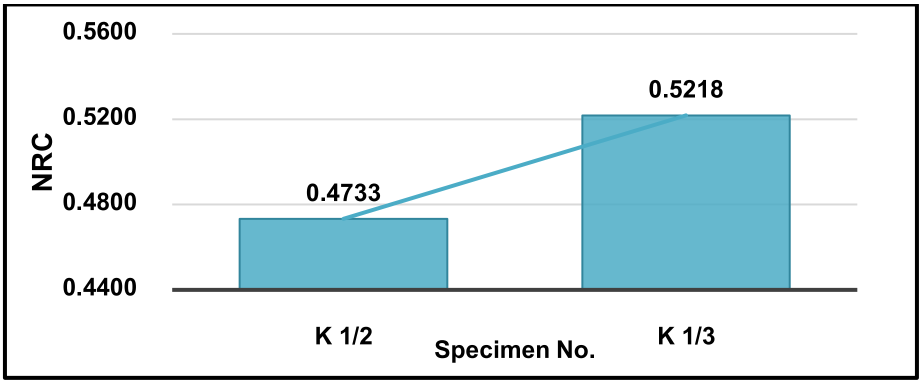

Fig. 7 Noise Reduction Coefficient (NRC)

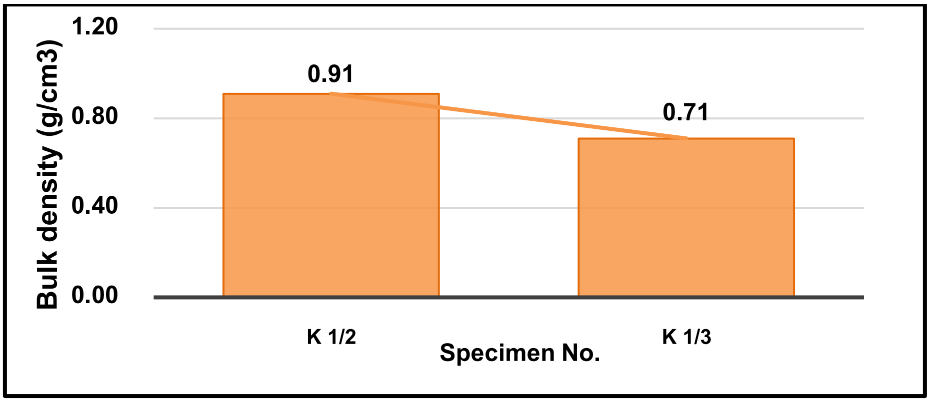

Fig. 8 Density of specimen # K1/2 and specimen # K 1/3

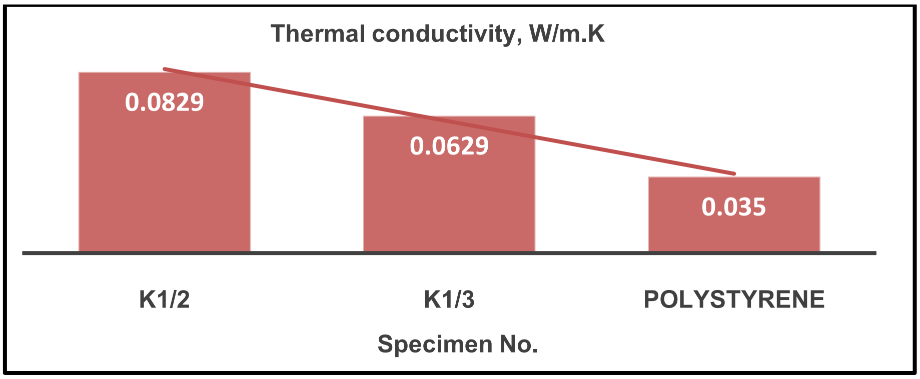

Fig. 9 Thermal Conductivity of specimen # K1/2, # K1/3 and Polystyrene

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3.4 The Structural Image of the Banana Fiber and Binders (Gypsum and Fused Silica)

This study demonstrated on Fig.10 that the fine banana fiber displayed as the short fibrous, more porosity and space. The specimen K1/3 indicated on the short fibrous interfered between binders (gypsum and fused silica) and porous and space within this specimen. Thus, size of the fibers implied on the less diameter and the more surface area as result in the higher sound absorption coefficient. Hence, porous material is excellent in sound absorption and thermal insulation.

3.5 Discussions

Banana is a native fruit of Thailand. Banana fiber was examined as long lining of fiber that this fibrous configuration comprised of many cavities (porous) within parallel fiber bundle and coated with cellulose and lignin [12]. The testing for determine on the Noise Reduction Coefficient (NRC) by using the acoustic material testing according to the ISO10534-2 international standard, was implied on the natural fibers in a straight line of banana fibers was good absorber.

In this research, the specimen K1/3 (the composition of fiber size 0.6 mm and the proportion of banana fiber/gypsum equivalent to 3: 7 by mass) was indicated as the good sound absorption ability to be 0.52 against the specimen K1/2 (fiber size 0.6 mm and the ratio of banana fiber-gypsum equivalent to 2: 8 by mass) was determined to be 0.4733 (the value of NCR between 0.4 – 1.0 were indicated on the high ability of noise absorption [21]). The characteristic of porous and dissipative media is a great sound absorber at high frequency level.

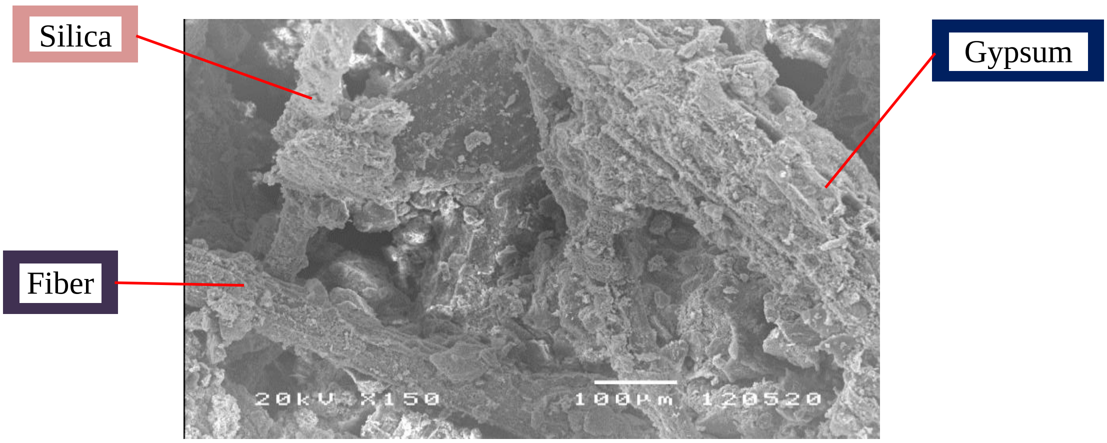

Fig. 10 Structural images of K1/3 were magnified 150x by SEM

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The explanation of sound phenomena is, when passing into the porous wall, the result of the sound energy reduction due to its friction loss [13]. Additionally, the value of TC of these specimen based on ASTM C518 testing method respectively was 0.0629 W/m.K for specimen K 1/3 and the specimen K1/2 was equivalent to 0.0829 W/m.K. wherewith polystyrene was equivalent to 0.0350 W/m.K, which is good heat insulator for presently commercial purpose. Apart from these results, this research also discovered the importance factors affecting on sound absorbing and heat insulating ability that (1) size of the fibers showed the less diameter and more surface area as result in the higher sound absorption coefficient and thermal conductivity, (2) porosity of materials consists frictional drag; thereby the sound energy propagated was converted to heat. Porous materials are excellent in sound absorption and good heat insulator. Theirs open pores allow restricted airflow through the material thus absorbing sound and also preventing efficient heat exchange. Wherewith, the higher bulk density varied on the lower ratio of banana fiber-gypsum. On the other view, the ratio of banana fiber/gypsum equivalent to 3: 7 by mass influenced positively on noise absorption and heat insulation. In regard to banana fiber, their characteristics are appropriate for an alternative engineering material, focus on Thai local materials and resources, recycling of wastes, maximum use of local skills, and environmental prevention and energy conservation. Thereby, the continued development of technologies is forced to encourage on these perceptions.

4. Conclusion and Suggestions

For the results of NRC from this study were observed on the development of banana fiber reinforced gypsum at frequency ranges between 250 Hz and 4,000 Hz with the average value of the good sound absorption ability. In addition, the higher bulk density varied on the lower ratio of banana fiber-gypsum. By using, the banana fiber was found as the short fibrous, was interfered between binders (gypsum and fused silica) with porous, likewise appeared on space area into this specimen. Furthermore, the thermal conductivity of these specimen was shown as the good kind of heat insulator. In this paper, the alternative sound absorber and heat insulator which were derived from the type of cultivated banana fibers for way of living and is involved to prevent on natural depletion, environmental pollution and sustainable material in nearly future. Likewise, the natural fibers are often commercialized in cement panels and blocks by using some binder. These considerations suggest to the environmental impacts of all the products used

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during the entire process of transformation of the natural fibers into building materials. Consequently, the role of natural material such as room acoustics and thermal insulation, building, enclosure, etc. is the interesting expected study in advance, especially the special characteristics of moisture resistance, extended weather ability and increased durability. Therefore, banana fiber could be the potential opportunity for Thailand communities to increase compatibility with the main direct materials.

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