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ชื่อโครงการ Efficiency of acoustic absorption board from banana pseudo-stem

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Efficiency of acoustic absorption board from banana pseudo-stem

Sutinee Kaewprakaidet

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Accepted by Department of Environmental Science, Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science.

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Abstract

Urbanization and transport development are the causes of noise pollution problem in present that adversely affects both human and animal health. The method to control these problems is using acoustic absorbing materials. Especially, local natural materials or agricultural wastes that green and sustainable. This study presented the efficiency of acoustic absorption board from banana pseudo-stem with different thickness; 0.5 cm, 1 cm, and 2 cm at constant density of 0.151 g/m^3 and different density; 0.151 g/m^3, and 0.357 g/m^3 at constant thickness of 0.5 cm. The measurement of sound absorption coefficient (α) was conducted using a standing wave tube method according to ASTM C384-04. The result shown, the thickness of 2 cm of acoustic absorption board achieved highest value 0.81 ± 0.02 of NRC and 0.83 ± 0.15 of sound absorption coefficient, which shown it obtained best acoustical performance. The thickness of 0.5 cm with different density obtained equally value of NRC, also sound absorption coefficient. Thus, different density not influence to sound absorption coefficient and NRC. When the thickness of acoustic absorption board increase, sound absorption coefficient and NRC will also increase.

Keywords: natural fibers, acoustic materials, acoustic absorber, banana pseudo stem, sound absorption coefficient, noise reduction coefficient

หัวเรื่อง ประสิทธิภาพของวัสดุดูดกลืนเสียงจากลำต้นกล้วย
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ปีการศึกษา 2562

บทคัดย่อ

การพัฒนาเมืองและคมนาคมเป็นสาเหตุที่ทำให้เกิดปัญหามลภาวะทางเสียงในปัจจุบัน ซึ่งส่งผลกระทบต่อสุขภาพทั้งมนุษย์และสัตว์ วิธีที่จะช่วยควบคุมปัญหาเหล่านี้ได้ก็คือการใช้วัสดุดูดซับเสียง โดยเฉพาะอย่างยิ่งวัสดุธรรมชาติที่มาจากท้องถิ่นหรือของเสียจากเกษตรกรรม ซึ่งเป็นมิตรต่อสิ่งแวดล้อมและมีความยั่งยืน การศึกษาในครั้งนี้ได้นำเสนอถึงประสิทธิภาพของวัสดุดูดกลืนเสียงจากลำต้นกล้วยที่มีความหนาแตกต่างกัน คือ 0.5 เซนติเมตร, 1 เซนติเมตร, และ 2 เซนติเมตร โดยมีความหนาแน่นคงที่เท่ากับ 0.151 กรัมต่อลูกบาศก์เซนติเมตร และที่ความหนาแน่นแตกต่างกัน คือ 0.151 กรัมต่อลูกบาศก์เซนติเมตร และ 0.357 กรัมต่อลูกบาศก์เซนติเมตร โดยมีความหนาคงที่ เท่ากับ 0.5 เซนติเมตร ค่าสัมประสิทธิ์การดูดกลืนเสียงสามารถวัดได้โดยใช้วิธีท่อคลื่นนิ่ง ตามมาตรฐาน ASTM C384-04 จากผลการศึกษา พบว่า วัสดุดูดซับเสียงจากต้นกล้วยที่ความหนา 2 เซนติเมตร มีค่าสัมประสิทธิ์การลดเสียงสูงสุด เท่ากับ 0.81±0.02 และค่าสัมประสิทธิ์การดูดกลืนเสียงสูงสุด เท่ากับ 0.83±0.15 ซึ่งแสดงถึงความสามารถในการดูดซับเสียงที่ดี วัสดุดูดซับเสียงจากต้นกล้วยที่ความหนา 0.5 เซนติเมตร โดยมีความหนาแน่นแตกต่างกัน พบว่า สัมประสิทธิ์การลดเสียงและสัมประสิทธิ์การดูดกลืนเสียงมีค่าเท่าๆกัน โดยสรุปได้ว่าความหนาแน่นที่แตกต่างกันไม่ส่งผลต่อสัมประสิทธิ์การลดเสียงและสัมประสิทธิ์การดูดกลืนเสียง เมื่อความหนาของวัสดุดูดซับเสียงเพิ่มขึ้น สัมประสิทธิ์การลดเสียงและสัมประสิทธิ์การดูดกลืน

คำสำคัญ: เส้นใยธรรมชาติ, วัสดุดูดซับเสียง, ตัวดูดซับเสียง, ลำต้นกล้วย, สัมประสิทธิ์การดูดกลืนเสียง, สัมประสิทธิ์การลดเสียง

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Sutinee Kaewprakaidet

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CHAPTER I

INTRODUCTION

1.1 Background and Rational

As the population grows and urban development , there will be more environmental problems such as climate change, air pollution, water pollution or noise pollution. Today, Noise pollution is one of the biggest problems in cities that affects human and animal live. Urbanization and transport development are the causes of noise pollution. This problem is caused by unwanted or loud noise from urbanization and transport development that can cause disturbance or irritation, which causes temporary or permanent hearing loss to humans and animals (Senate Public Works Committee, 1972, Hogan and Latshaw, 1973 ,Goines and Hagler, 2007). In addition, it also adversely affects health such as annoyance, sleep disturbance, or even ischemic heart disease (Cao et al., 2018).

The method to control these problems is using acoustic absorbing materials that could be classified into two basic categories: resonant sound absorbing materials ,and porous sound absorbing materials. The porous sound absorbing materials are using to control the quality of indoor noise on building. They are usually made from fibrous porous materials, such as rock wool, glass wool or foam. However, the production of synthetic materials is not environment friendly. From Life Cycle Assessment (LCA), it requires more energy and has high global warming potential (Asdrubali, 2006, Asdrubali et al., 2012). Nowadays, natural materials are interesting for green alternative and sustainable acoustic absorbers. In addition, they have good absorption performance and low environmental impact. Many local natural materials were obtained to produce sound absorbing materials, such as coir fibers (Fouladi et al., 2011), ,kenaf fibers (Lim et al., 2018), and pineapple leaf fibers (Putra et al., 2018). Similarly, waste deriving from agricultural work, such as oil palm empty fruit bunch fibers (Or et al.,2017), and olive pruning wastes (Martellotta et al., 2018).

Banana (Musa sapientum Linn.) is most well-known and useful plant in Thailand. Almost all the parts of this plant such as, fruit, flower bud, leaves and pseudo-stem, can be utilized. The pseudo-stem is one of the parts that is rarely used and becoming agricultural wastes. However, banana pseudo-stem can made fibers that have proper characteristics for acoustic absorbing materials. This fiber is very fibrous because it consists of thick-walled cell tissue, bonded together by natural gums and is mainly composed of cellulose, hemicelluloses and lignin (Hendriksz, 2017). From the characteristics of this material are appropriate using to make acoustic absorption board. In addition, banana pseudo-stem fibers have high disposability and renewability. Also, they are recyclable and biodegradable.

This study investigates the efficiency of the acoustic absorption board from banana pseudo-stem and comparison the efficiency of the acoustic absorption board from banana pseudo-stem with different thickness and density of acoustic absorption board.

1.2 Objectives

1. To investigate the efficiency of the acoustic absorption board from banana pseudo-stem.
2. To compare the efficiency of the acoustic absorption with different thickness and density of acoustic absorption board.

1.3 Benefits

1. To utilize the agricultural wastes.
2. To development the acoustic absorbing materials from banana pseudo-stem.
3. To study the efficiency of acoustic absorbing materials from banana pseudo-stem.

CHAPTER II

THEORETICAL BACKGROUNDS AND LITERATURE REVIEW

2.1 Theoretical Backgrounds

2.1.1 Sound and Noise

Sound is a form of energy that is caused by the vibration of the sound source or the source of the noise from the energy, which causing the vibration of the sound waves to change the density of the waves or the air and cause the travel of sound in the form of waves called "sound waves". Sound wave traveling through air will cause a sinusoidal pressure variation in the air and will be back and forth in the direction of the propagation of the sound, a characteristic of longitudinal waves.

Noise is unwanted sound, unpleasant, loud, disruptive to hearing or sound that has a disturbance with a sound level higher than the background sound level. From point of physics, noise is hard to distinguish from sound because of both are vibrations through a medium, such as air, water, or solid.

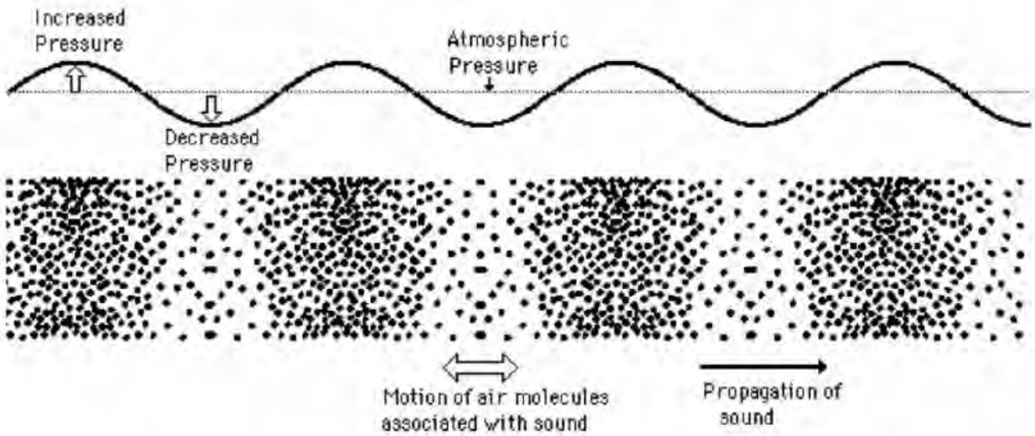


Figure 2.1 Transverse and longitudinal pressure wave represent changes in air pressure (Fehlmann, 2014)

2.1.2 Sound absorption

Sound absorption is sound energy, which is removed from the sound wave as the wave pass through an absorption material, such as flat wall, floor, partition, ceiling, corner loaded bass traps, curtains, foam, and soft furniture. When a sound wave encounters an object or sound absorber, which may be transmission, reflection, and absorption. From Figure 2.2, sound wave is reflection or absorption so losing energy when it passed through sound insulating wall. Sound absorption materials can be divided into 2 basic types: porous sound absorption materials and resonant sound absorption materials.

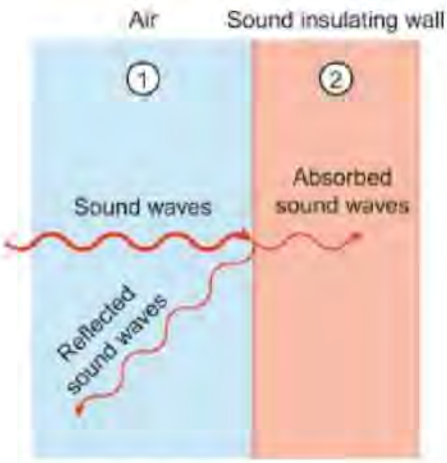


Figure 2.2 Sound absorption (Shrivastava, 2018)

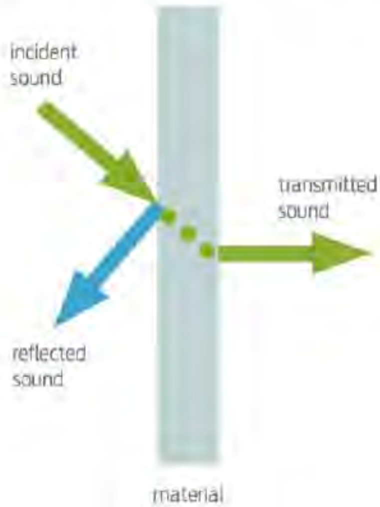


Figure 2.3 Sound wave interacts with materials (Oosterhoff, 2015)

2.1.3 Sound absorbing materials

Sound absorbing materials could be classified into two basic categories: porous sound absorbing materials ,and resonant sound absorbing materials.

2.1.3.1 Porous sound absorbing materials

Porous sound absorbing materials are composed of many macropores and micropores which allow the sound waves entering the materials. Sound energy is converted into heat and the viscous effect between the solid frame and numerous air cavities will attenuate part of the sound energy, when the sound wave comes into the sound absorption materials. Then, temperature distinction between different parts is caused heat transfer and dissipate sound energy. The vibration of air in the bulk materials will lead to the vibration of fibers. At high frequencies, the sound absorption property is better than low frequencies. Porous sound absorbing materials are made of natural fibers, synthetic fibers, Inorganic fibers, organic foams, inorganic foams, or hybrid foams (Peng, 2017 and Cao et al., 2018).

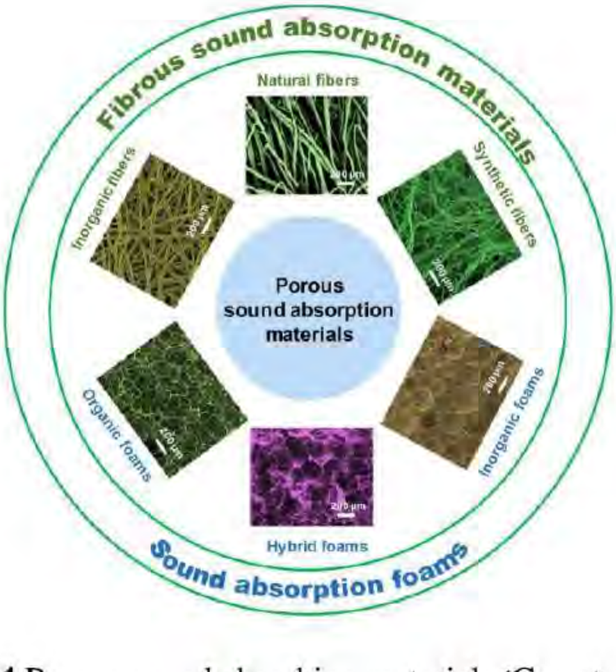


Figure 2.4 Porous sound absorbing materials (Cao et al., 2018).

2.1.3.1 Resonant sound absorbing materials

Resonant sound absorbing materials are based on the principle of internal resonance effect, which often receive from the disadvantage of narrow frequency band of sound absorption ,whereas they give these materials with good absorption properties in low frequency. They mainly involved single Helmholtz resonator perforated panels and membrane absorbers (Cao et al., 2018).

2.1.4 Sound absorption coefficient (α)

Sound absorption coefficient is uses to evaluate the performance of sound absorption materials. The ratio of absorbed energy to incident energy is sound absorption coefficient and represented by α. If the acoustic energy can be absorbed entirely, then $\alpha = 1$

The sound absorption coefficient of materials is correlate with frequency, and it varies with different frequencies. The sound absorption properties of different frequencies were illustrated by the sound absorption coefficient frequency characteristic curves. It is not convenient to compare and state. The average sound absorption coefficient at a specified set of frequencies, can be used for simplification.

2.1.5 Noise reduction coefficient (NRC)

Noise reduction coefficient (NRC) is a scalar representation of the amount of sound energy absorbed upon striking a surface. To calculating noise reduction coefficient is using average absorption coefficient varies with frequency; 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz (125 Hz and 4000 Hz are not used). It can be calculated by equation 1.

$$NRC = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4} \qquad \text{equation 1}$$

2.1.6 Factors influencing sound absorption

2.1.6.1 Fiber size

The sound absorption coefficient was increase with a decrease in fiber diameter. Moreover, the fine fibers provide a dramatic increase in acoustical performance than coarse fibers.

2.1.6.2 Porosity

From the sound dissipation by friction, the sound wave must enter through the porous material and the surface of the material has enough pores for the sound wave pass through and get dampened. Number, size, and type of pores are important factors of porosity. When the porosity is increase, the sound absorption coefficient is increased.

2.1.6.3 Tortuosity

Tortuosity can describe the influence of the internal structure of a material on its acoustical properties. The value of tortuosity measures the high frequency behavior of sound absorbing porous materials.

2.1.6.4 Thickness

The low frequency sound absorption has direct relationship with thickness. The sound absorption coefficient is increased only at low frequencies, as the materials get thicker. This means, at high frequencies has not significant effect on sound absorption.

2.1.6.5 Density

Density is one of the important factors that influences the sound absorption behavior of the material. At middle and higher frequency, the sound absorption coefficient is increased as the density of the sample increased.

(Seddeq, 2009)

2.1.7 Impedance tube method

Measurements of the absorption coefficients and acoustic impedance of acoustic absorbing materials are the standing wave tube (also known as an impedance tube) method. The impedance tube is conveniently and accurately method to measure the acoustic absorption parameters. Moreover, this method requires only small size samples of the absorbing material to measurement.

Figure 2.5 shows Standing wave apparatus. A loudspeaker produces an acoustic wave which travels through the pipe and reflects from the sample. The phase interference between the waves are incident in the pipe and reflected from the sample will result in the formation of a standing wave pattern. If the incident wave is all reflected, then the incident and reflected waves have the same amplitude. In contrast, if some of the incident wave is absorbed by the sample, then both waves will have different amplitudes.

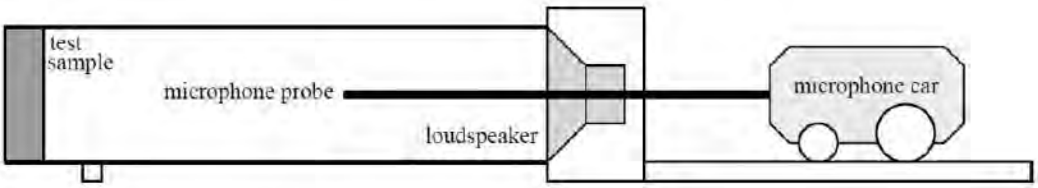


Figure 2.5 The Impedance tube method (Russell, 2004)

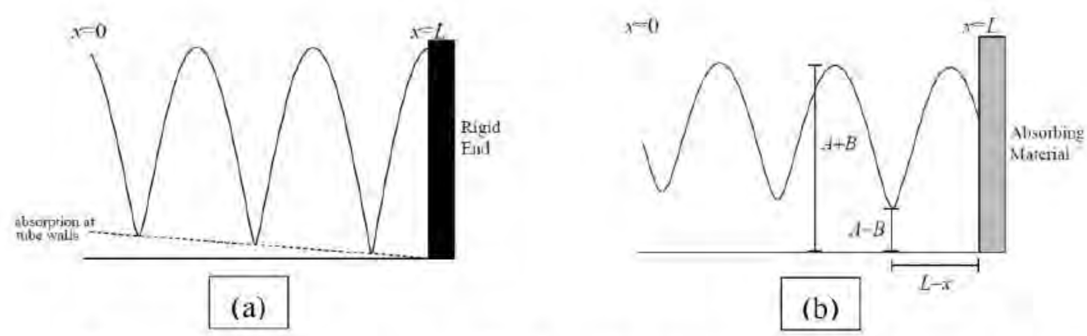


Figure 2.6 The pressure amplitude in the pipe is terminated at x = L with (a) a rigid end and (b) an acoustic absorbing material (Russell, 2004)

The amplitude at the maximum pressure (antinode) is (A+B), and the amplitude at the minimum pressure (node) is (A-B). Antinode and node can be measured by using the standing wave tube. Follow equation 1 below. The standing wave ratio (SWR) can be calculated by the ratio of antinode to node.

$$SWR = \frac{A+B}{A-B} = \frac{P_{rms,max}}{P_{rms,min}} \qquad \text{equation 1}$$

From equation 1, It may be arranged to provide the sound reflection coefficient (R_π)

$$R_\pi = \frac{B}{A} = \frac{SWR - 1}{SWR + 1} \qquad \text{equation 2}$$

The sound absorption coefficient (α) is given by equation 3 below

$$\alpha = 1 - R^2 = 1 - \frac{(SWR - 1)^2}{(SWR + 1)^2} = \frac{4}{SWR + \frac{1}{SWR} + 2} \qquad \text{equation 3}$$

2.1.8 Banana pseudo-stem

A main part of the banana plant that look like a trunk, which include middle core and wrapped with the tightly packed overlapping, and spirally arranged leaf sheaths is pseudo-stem part. This part consists mostly of water and can support a bunch that weight over 50 kg. The banana sheaths from pseudo-stem part consists of cellulose about 50%, which is the highest constituents in the dried sheaths. In addition, it has high amount of lignocellulose and consists of lignocellulosic about 60%–85% of its dry weight (Jayaprabha et al., 2011). The banana pseudo-stem fiber is like the pineapple leaf, sisal, and other hard fibers, though the banana pseudo-steam fiber is a little more elastic (Subagyo et al., 2018). Physical characteristics of banana pseudo-stem fiber, it has good modulus of elasticity, tensile strength, and hardness, which makes it a promising fiber material (Li et al., 2010).

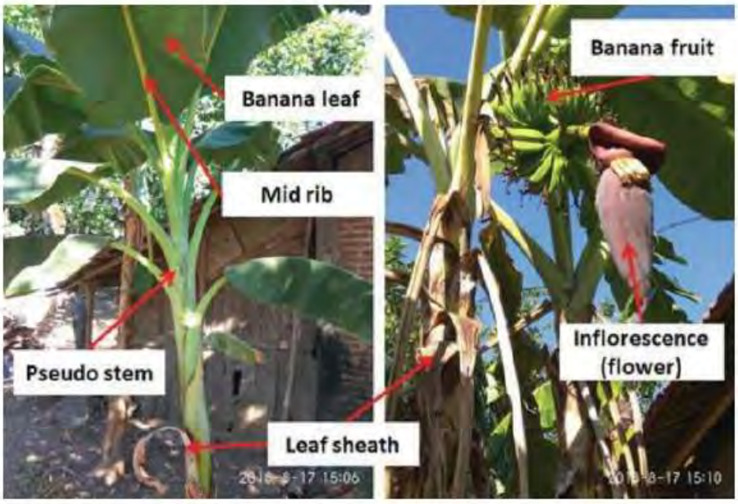


Figure 2.7 Parts of banana tree (Subagyo et al., 2018)

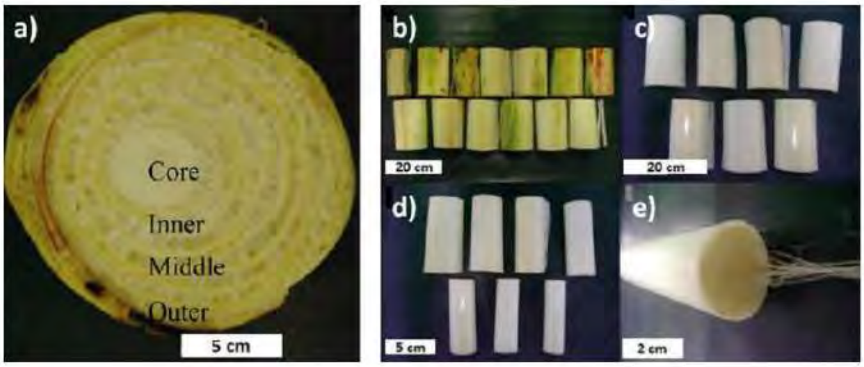


Figure 2.8 (a) Banana pseudo-stem trunk cross section and its parts: (b) outer parts; (c) middle parts; (d) inner parts; and (e) core parts (Pereira et al., 2014)

2.2 Literature Review

Fouladi et al., (2011) evaluated acoustical characteristics of coir fiber from coconut husk. The coir fibers are investigated, fresh from wet market and industrial prepared mixed with binder. The experimental measurements of absorption coefficient in an impedance tube based on standard ISO 10534-2. The results shown that fresh coir fiber has an average absorption coefficient of 0.8 at for $f > 1360$ Hz, $f > 940$ Hz and $f > 578$ Hz at thicknesses of 20 mm, 30 mm and 45 mm, respectively. The sound absorption is improved in lower frequencies when the thickness is increased, having the same average at $f > 578$ Hz and 45 mm thickness. The coir fibers can be mixed with additives in commercial use to enhance its characteristics such as stiffness, unti-fungus and flammability. To summary, other approaches such as adding air gap or perforated plate are necessary to improve the acoustical properties of industrial treated coir fiber.

Putra et al., (2013) reported utilizing sugarcane wasted fibers as a sustainable acoustic absorber that fabricated sugarcane mixed with different composition of binder. The binders used are polyurethane and polyester. The measurement of the sound absorption coefficient in an impedance tube based on ISO 10534-2-2001. The results shown that average absorption coefficient of 0.65 at the frequency of 1.2 - 4.5 kHz and achieved good acoustic performance

Mati-Baouche et al., (2016) investigated the mechanical, thermal and acoustical properties of a bio-based composite made from crushed particles of sunflower stalks binded together by chitosan, a bio-based binder. The results shown that the materials were highly compacted and low porosity. The higher porosity composites of materials with lower density obtained higher absorption coefficient.

Othmani et al., (2016) studied experimental and theoretical investigation of the acoustic performance of sugarcane wastes-based material. The test sample were made from bagasse in the fiber size varies from 0.7 m to 1 mm. The results of the evaluation of the acoustic performance of the sugarcane wastes-based material, the decrease of the fiber size generates the increase of the flow resistivity and the acoustic absorption coefficient. While the resin content decrease causes the flow resistivity increase and the acoustic absorption coefficient decrease.

Or et al., (2017) reported sound absorption performance of oil palm empty fruit bunch fibers. The samples were fabricated from raw oil palm empty fruit bunch fibers with different densities and thicknesses; 10 mm, 20 mm, 40 mm and 50 mm. The measurement of the normal incidence absorption coefficient in an impedance tube based on ISO 10534-2. The results shown that the sample from oil palm empty fruit bunch fibers have absorption coefficient of 0.9 on average above 1 kHz. The sound absorption performance of this fibers is comparable to that of the commercial synthetic rock wools.

Mederuelo-sanz et al., (2018) evaluated potential use of cigarette filters as sound porous absorber. The sound porous absorber fabricated from cellulose acetate material that made from cigarette filters. The results shown that acoustical performance of used and non-used cigarette filters similar, that present a slightly better performance for low frequencies, due to a higher porosity and a lower flow resistivity than used cigarette filters. Thus, increasing of the bulk density, porosity, and flow resistivity, the sound absorption also increased. The comparison shows that the acoustical performance is similar or better as a commercial products in building construction.

Lim et al., (2018) studied sound absorption performance of natural kenaf fibers both under normal and random sound incidence. The normal-incidence sound absorption coefficient measurement was conducted using the impedance tube method based on the transfer-function method according to ISO 10534-2. For the random-incidence sound absorption coefficient, the test was conducted in a reverberation chamber. From both methods, the results shown that the bulk density of 140–150 kg/m^3 and thickness of 25–30 mm, the absorption coefficient is above 0.5 starting from 500 Hz and can reach 0.85 on average above 1.5 kHz. The frequency bandwidth and absorption coefficient increase significantly when bulk density and thickness are increased. The absorption performance of natural kenaf fibers is comparable to the synthetic rock wool.

Putra et al., (2018) investigated sound absorption performance of extracted pineapple leaf fibers with different densities and thicknesses, which fabricated samples from raw pineapple leaf. The sample was measured by the impedance tube based on ISO 10534-2. The results shown that the pineapple leaf fibers can achieve sound absorption coefficient of 0.9 on average above 1 kHz by controlling the densities of the fibers or introducing the air gap behind the samples. It can be concluded that the sound absorption performance is like the commercial rock wool fibers and synthetic polyurethane foam.

Martellotta, Cannavale et al., (2018) produced sound absorbers from olive pruning wastes, which used chitosan as a binder. The samples were formed in 5 cm thickness PVC mold with 2 different diameters; 4 cm and 10 cm. The olive tree leaves were crushed to obtain 3 different granulometries; 5 mm, 15 mm and 40 mm. The samples were measured by the standing wave tube based on ISO 10534-2:1998, using the transfer function method. The experimental results shown that absorption coefficients as high as 0.9 can be obtained above 1 kHz using a 50 mm sample.

CHAPTER III

MATERIALS AND METHODS

3.1 Equipment and Materials

3.1.1 Standing wave tube

- Impedance tube
- Function generator (JUPITER 2000)
- Loudspeaker
- Microphone probe
- Sound level meter (RION model NL-18)

3.1.2 Knives

3.1.3 Balance

3.1.4 PVC mold 10.5 cm diameter (thickness: 0.5 cm, 1 cm and 2 cm)

3.1.5 Banana pseudo-stem

3.1.6 Sodium hydroxide (NaOH)

3.1.7 TOA Latex Adhesive No. LA-22S

3.1.8 Water

This project chose thickness; 0.5 cm, 1 cm, 2cm as commercial sound absorber to compare sound absorption efficiency.

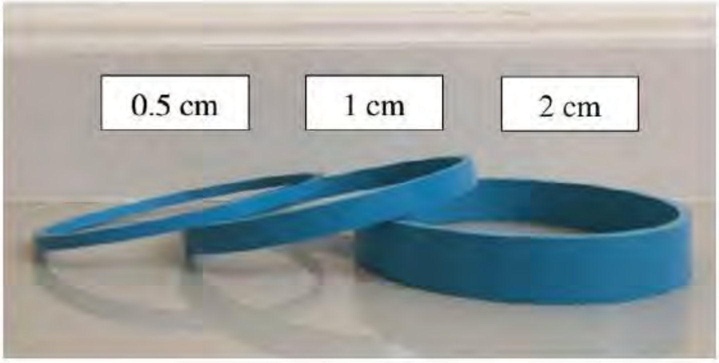


Figure 3.1 PVC mold with diameter 10.5 cm (thickness: 0.5 cm, 1 cm and 2 cm)

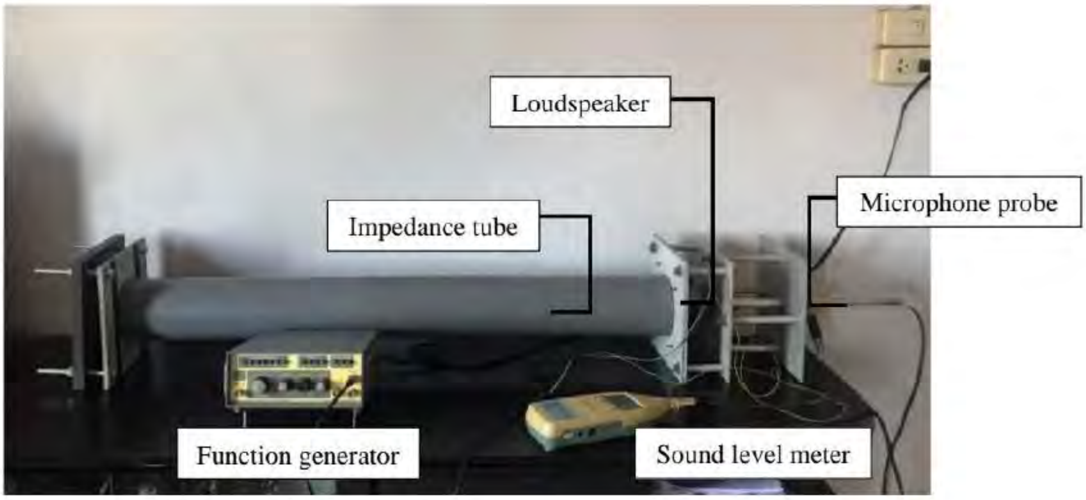


Figure 3.2 Standing wave tube

3.2 Methods

3.2.1 Extraction of banana pseudo-stem fibers

The first step, separating the fiber bundles from the cortex of banana plant and then the leaves are stripped from the pseudo-stems. The second step is removed the gum or non-fibrous and any residual components contained in the fibers after the first process by knives. Then, they were stripped and ripped by knives again to produce the fibers. The next step is dried the fibers with sun.

The fibers were treated with 5% w/w NaOH for 3 hours to increase the wet ability. Then, they are washed thoroughly with water. Finally, the fibers are dried with sun for 1 day to remove the moisture present in it and cut the fibers with length about 1.5-2.0 cm.

Figure 3.3 Extraction of banana pseudo-stem fibers:

(a) banana pseudo-stem fibers (b) the fibers treated with 5% w/w NaOH (c) dried treated fibers and (d) the cut treated fibers for using sample fabrication

3.2.2 Sample fabrication

The sound absorbers were tested in 3 different thickness; 0.5 cm, 1 cm, and 2 cm, and 2 different density; 0.151±0.04 g/cm^3 and 0.357±0.00 g/cm^3 at constant thickness of 0.5 cm. For each thickness, there are same weight composition ratios of fibers to TOA Latex Adhesive for 2:1. In the preparing stage, the extracted fibers were mixed with TOA Latex Adhesive that was used as a binder. Then, the mixture was pressed in a PVC mold with diameter 10.5 cm to obtain a cylindrical shape. In the next step, the test samples were dried with sun until they were constant. Then, remove the test samples from the PVC mold and dried again with sun for 1 day to remove moisture content. Finally, the test samples were weighted for density calculating from equation 5 and repeated 3 samples for each thickness.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \qquad \text{equation 5}$$

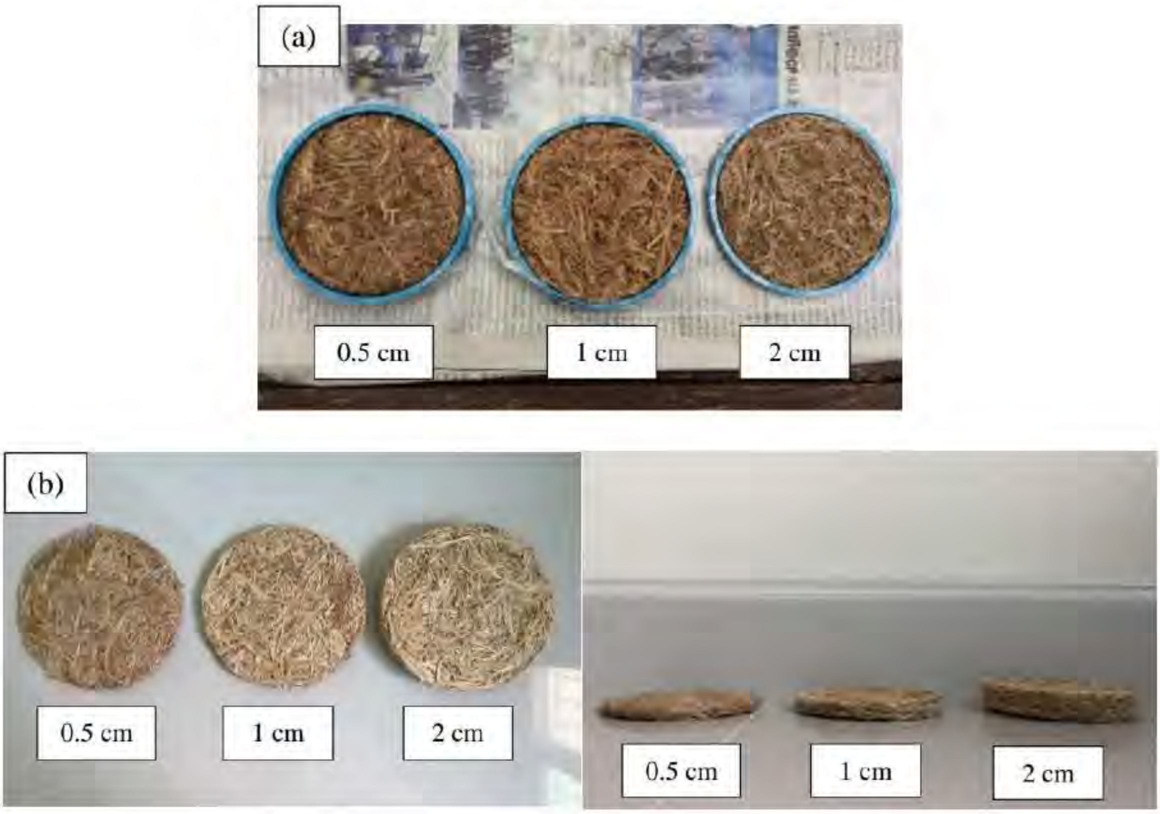


Figure 3.4 Sample fabrication: (a) samples forming and

(b) the test samples for each thickness

The flow chart of processes was shown in Figure 3.5 and Figure 3.6.

Figure 3.5 Extraction of banana pseudo-stem fiber

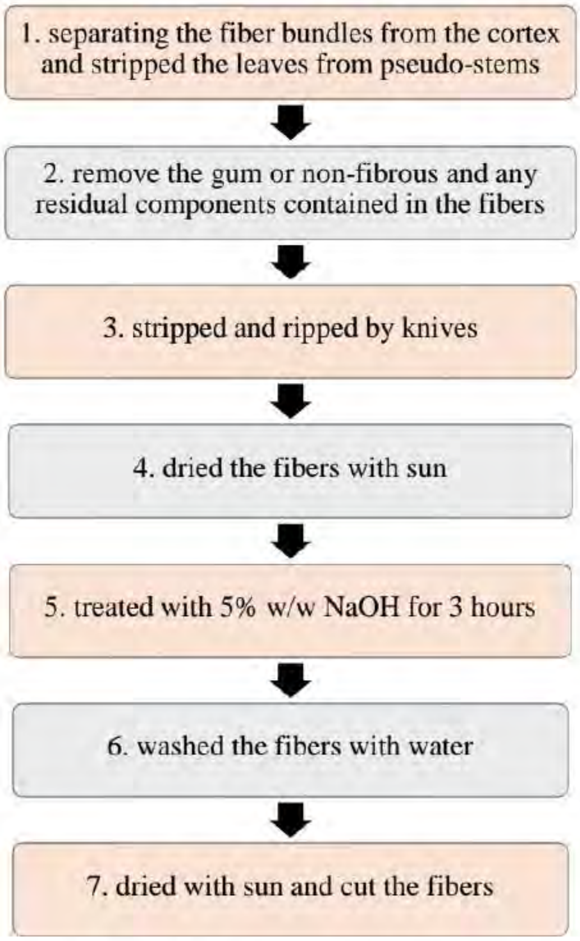
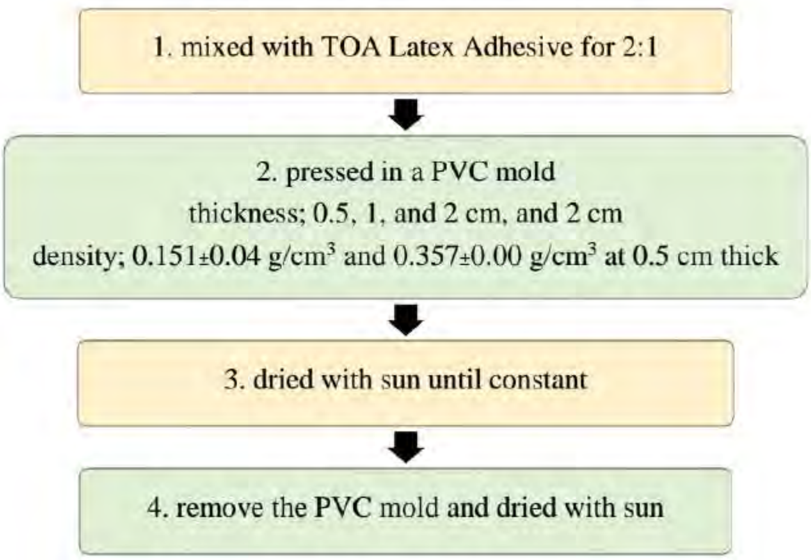


Figure 3.6 Sample fabrication



3.2.3 Measurement of sound absorption coefficient

The measurement of sound absorption coefficient was conducted using a standing wave tube method according to ASTM C384-04. Figure 3.3 represents the diagram of the experimental setups. The test sample was placed in the cap at end of the impedance tube and clamp the cap down tight without gap. The microphone probe was placed close to the test sample and gradually move the microphone probe away from the test sample while a loudspeaker released white noise into the tube. The decibel levels were measured by the sound level meter and can be using to calculated sound absorption coefficient.

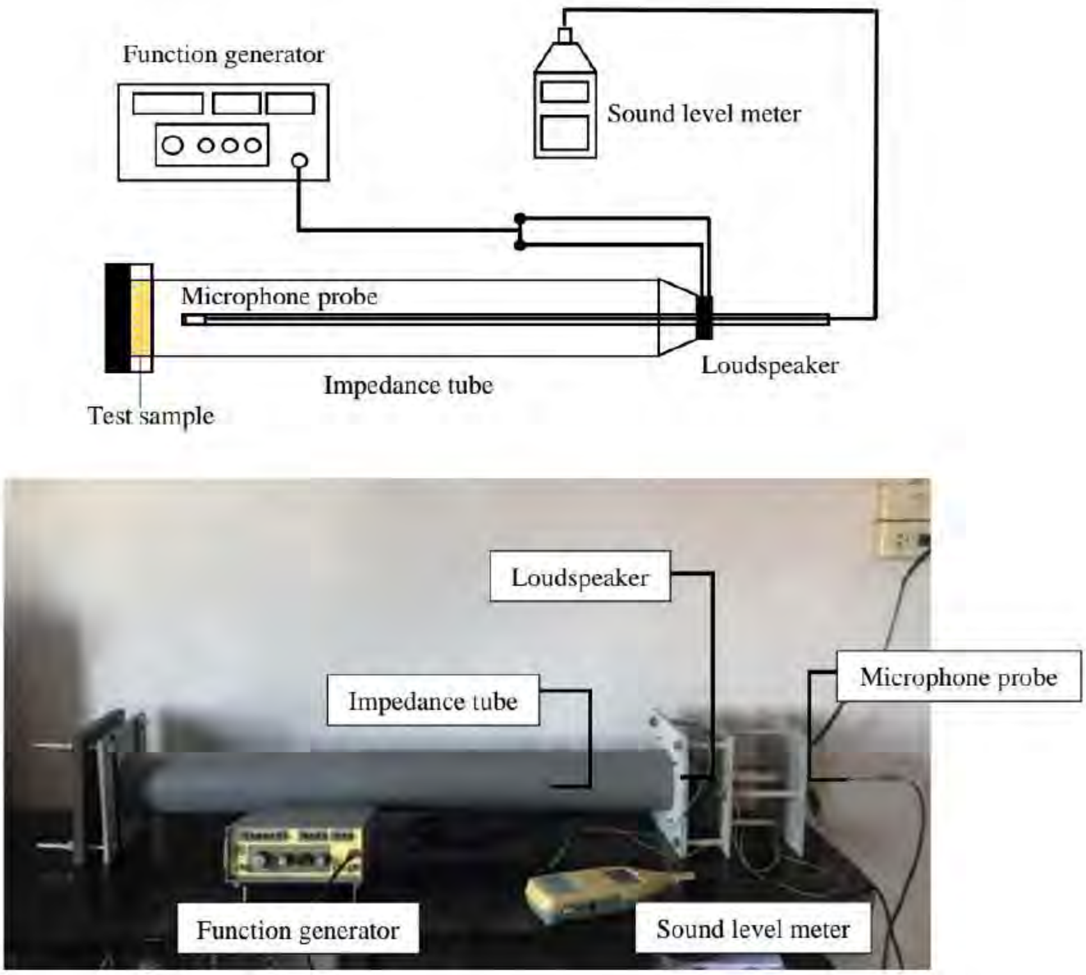


Figure 3.7 The experimental setup to measure sound absorption coefficient

Procedure and calculation of sound absorption coefficient are following the steps below (Russell, 2004).

1. Calibrate sound level meter
2. Connect the function generator through the amplifier to the loudspeaker and set the sound level meter for octave band measurement.
3. Place a test sample in the cap at end of the impedance tube and clamp the cap down tight without gap.
4. Turn on the function generator and set the frequency of the sine wave at 250 Hz.
5. At first, move the microphone probe close to the test sample and gradually move the microphone probe away from the test sample until the sound level meter indicates a first minimum level (L_{min} in dB) and recorded it.
6. Gradually move the microphone probe away from the test sample until the sound level meter indicates a maximum level (L_{max} in dB) and records it.
7. Calculate the minimum rms pressures ($P_{min,rms}$) and maximum rms pressures ($P_{max,rms}$) using equation 6

   $$P_{rms} = 10^{\frac{Level_{dB}}{20}}$$ equation 6

8. Calculate the standing wave ratio (SWR) using equation 2

   $$SWR = \frac{P_{rms,max}}{P_{rms,min}}$$ equation 2

9. Calculate the sound reflection coefficient (R_π) using equation 3

   $$R_\pi = \frac{B}{A} = \frac{SWR - 1}{SWR + 1}$$ equation 3

10. Calculate the sound absorption coefficient (α) using equation 4

    $$\alpha = 1 - R^2 = 1 - \frac{(SWR - 1)^2}{(SWR + 1)^2} = \frac{4}{SWR + \frac{1}{SWR} + 2}$$ equation 4

11. Calculate the noise reduction coefficient (NRC) using equation 1

    $$NRC = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4}$$ equation 1

12. Return to step 3 and repeat for the 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz octave band.

3.4 Data analysis

The data analysis was conducted using IBM SPSS Statistics version 22.

1. The relationship between the average sound absorption coefficient (α) and the thickness of the test samples was analyzed by correlation.
2. The relationship between the average sound absorption coefficient (α) and the density of the test samples was analyzed by correlation.
3. Testing the differentiation of variable thickness that influence to noise reduction coefficient (NRC) by one-way ANOVA with 95% confidence interval
4. Testing the differentiation of variable density that influence to noise reduction coefficient (NRC) by independent sample t-test with 95% confidence interval

CHAPTER IV

RESULTS AND DISCUSSION

This study investigated the efficiency of the acoustic absorption board from banana pseudo-stem and comparison the efficiency of the acoustic absorption board from banana pseudo-stem with different thickness and density of acoustic absorption board. The sound absorbers were tested in 3 different thickness; 0.5 cm, 1 cm, and 2 cm, and 2 different density; 0.151 g/cm3 and 0.357 g/cm3 at constant thickness of 0.5 cm. For each thickness, there are same weight composition ratios of fibers to TOA Latex Adhesive for 2:1, which TOA Latex Adhesive was used as a binder. The samples were formed with PVC mold with diameter 10.5 cm. The measurement of sound absorption coefficient was conducted using a standing wave tube method according to ASTM C384-04. The results were presented and discussed in this chapter.

4.1 Characteristic of acoustic absorption board

From the physical properties of acoustic absorption board from banana pseudo-stem, there were pale yellowish-brown color, rough skin, smell like straw mixed with latex glue and light weight. The porous structure of acoustic absorption board composed with many pores which the sound wave enters through and get dampened, that improve acoustical performance of acoustic absorption board.

Figure 4.1 The acoustic absorption board from banana pseudo-stem

4.2 Efficiency of acoustic absorption board

The acoustic absorption board were tested in 3 different thickness; 0.5 cm, 1 cm, and 2 cm, and 2 different density; 0.151±0.04 g/cm^3 and 0.357±0.00 g/cm^3 at constant thickness of 0.5 cm. The results of sound absorption coefficient (α) and noise reduction coefficient (NRC) were shown in Table 4.1-4.2 and Figure 4.1-4.4.

Table 4.1 Sound absorption coefficient (α) and Noise reduction coefficient (NRC) of the acoustic absorption board from banana pseudo-stem in density of 0.151±0.04 g/cm^3 with different thickness; 0.5 cm, 1 cm, and 2 cm

Thickness (cm)	Sound absorption coefficient (α)					α avg	Noise reduction coefficient (NRC)
	Frequency (Hz)						
	250	500	1000	2000	4000		
0.5 cm	0.85±0.11	0.84±0.10	0.58±0.27	0.42±0.05	0.83±0.09	0.70±0.20	0.67±0.07
1 cm	0.78±0.17	0.84±0.06	0.58±0.05	0.40±0.30	0.86±0.07	0.69±0.20	0.65±0.07
2 cm	0.93±0.02	0.93±0.04	0.58±0.10	0.82±0.04	0.90±0.04	0.83±0.15	0.81±0.02

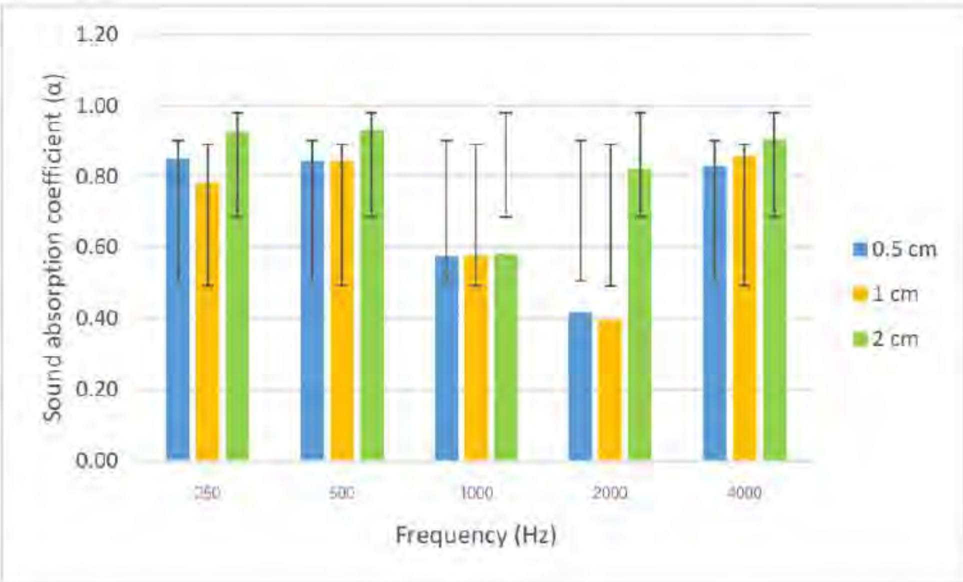


Figure 4.2 Sound absorption coefficient (α) of the acoustic absorption board from banana pseudo-stem in density of 0.151±0.04 g/cm3 with different thickness

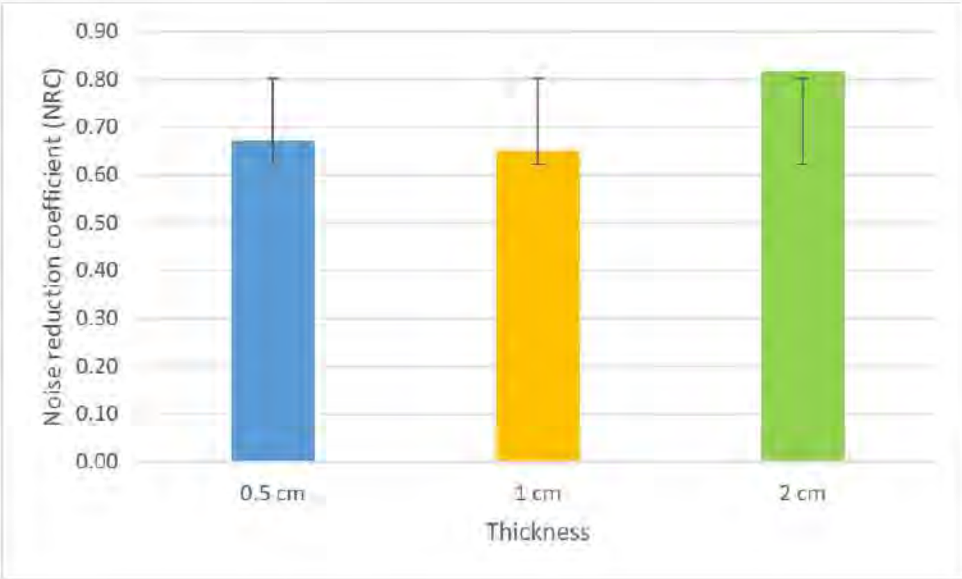


Figure 4.3 Noise reduction coefficient (NRC) of the acoustic absorption board from banana pseudo-stem in density of 0.151±0.04 g/cm^3 with different thickness

Table 4.2 Sound absorption coefficient (α) and Noise reduction coefficient (NRC) of the acoustic absorption board from banana pseudo-stem in thickness of 0.5 cm with different density; 0.151±0.04 g/cm^3, and 0.357±0.00 g/cm^3

Density (g/cm^3)	**Sound absorption coefficient (α)**					**α_{avg}**	**Noise reduction coefficient (NRC)**
	Frequency (Hz)						
	250	**500**	**1000**	**2000**	**4000**		
0.151	0.85±0.11	0.84±0.10	0.58±0.27	0.42±0.05	0.83±0.09	0.70±0.20	0.67±0.07
0.357	0.97±0.03	0.78±0.05	0.57±0.26	0.30±0.06	0.92±0.08	0.71±0.28	0.66±0.06

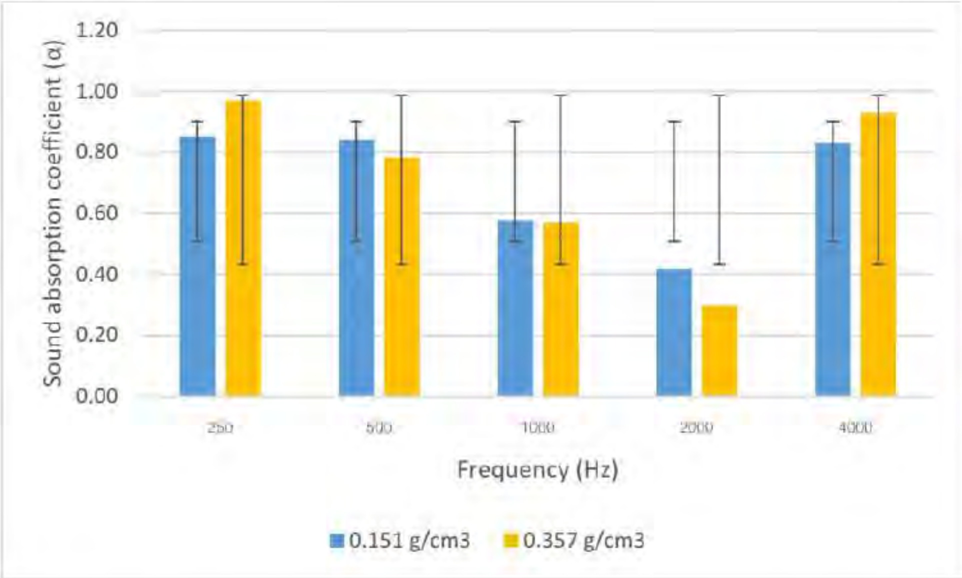


Figure 4.4 Sound absorption coefficient (α) of the acoustic absorption board from banana pseudo-stem in thickness of 0.5 cm with different density

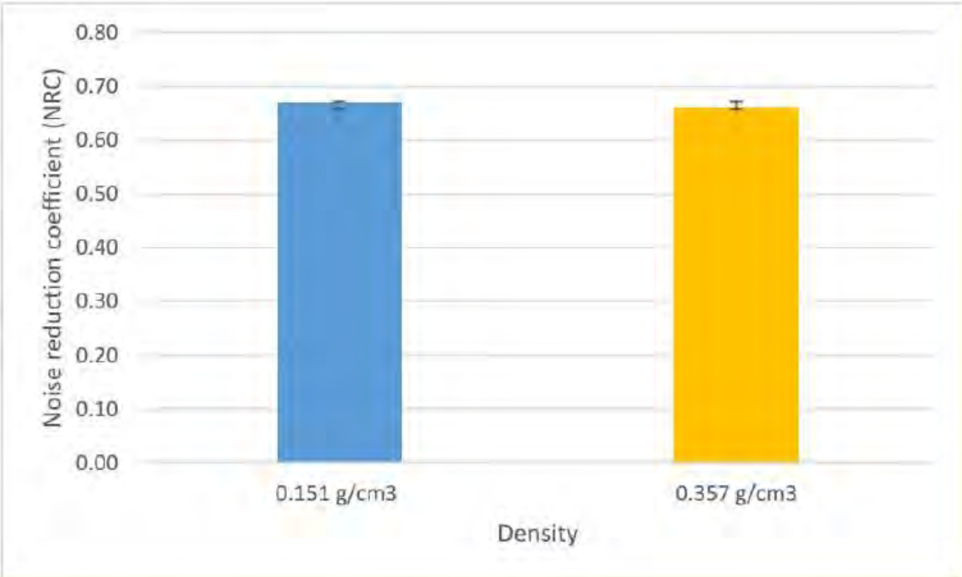


Figure 4.5 Noise reduction coefficient (NRC) of the acoustic absorption board from banana pseudo-stem in thickness of 0.5 cm with different density

4.2.1 Sound absorption coefficient (α)

Table 4.1 shown sound absorption coefficient (α) of the acoustic absorption board from banana pseudo-stem in density of 0.151±0.04 g/cm^3 with different thickness; 0.5 cm, 1 cm, and 2 cm. The average sound absorption coefficient lied between 0.69±0.20 and 0.83±0.15. The maximum value of sound absorption coefficient is 0.93±0.04 at the frequency of 250-500 Hz in thickness of 2 cm. Same as, the thickness of 2 cm achieved highest value 0.83±0.15 of sound absorption coefficient, that mean it obtained best acoustical performance. Figure 4.2 shown the results, the sound absorption coefficient is lowest at the frequency of 1000 Hz of all the thickness. While, the sound absorption coefficient is highest for the thickness of 2 cm at the frequency of 2000 Hz more than other thickness. The relationship between sound absorption coefficient and thickness of the acoustic absorption board, the results found there had correlation very few with a significance level of 0.05 (Pearson correlation = 0.258, p-value > 0.05).

For the different density at constant thickness of 0.5 cm, Table 4.2 shown sound absorption coefficient (α) of the acoustic absorption board from banana pseudo-stem in thickness of 0.5 cm with different density; 0.151±0.04 g/cm^3, and 0.357±0.00 g/cm^3. The maximum value of sound absorption coefficient is 0.97±0.03 at the frequency of 250 Hz in density of 0.357±0.00 g/cm^3. The density of 0.151±0.04 g/cm^3 and 0.357±0.00 g/cm^3 obtained equal to sound absorption coefficient but the density of 0.357±0.00 g/cm^3 obtained higher value than the density of 0.151±0.04 g/cm^3 very few. The results were shown in Figure 4.4, the sound absorption coefficient is lowest at the frequency of 2000 Hz of all the density. While, the sound absorption coefficient is highest at the frequency of 250 Hz of all the density. The relationship between average sound absorption coefficient and thickness of the acoustic absorption board, the results found there had correlation very few with a significance level of 0.05 (Pearson correlation = 0.013, p-value > 0.05).

At the frequency of 250-500 Hz, the thickness of 2 cm of acoustic absorption board achieved highest value of sound absorption coefficient same as the both densities of 0.151±0.04 g/cm^3 and 0.357±0.04 g/cm^3. Like, the sound absorber from olive leaves at a lower frequency that provided maximum value (Martellotta, Cannavale et al., 2018). At frequency of 1000 Hz, all samples obtained lowest sound absorption coefficient same as this project (Park and Lee, 2005)

Or et al., (2017) tested sound absorption of oil palm empty fruit bunch fibers with different density. The results shown that the low density of 117 g/cm^3 and 234 g/cm^3 obtained not different sound absorption coefficient same as the acoustic absorption board from banana pseudo-stem. While, the sound absorption coefficient increased from low to high frequency range for all of density. These shown the density should be more different for more obvious results of sound absorption coefficient.

4.2.2 Noise reduction coefficient (NRC)

Noise reduction coefficient (NRC) of the acoustic absorption board from banana pseudo-stem in density of 0.151±0.04 g/cm3 with different thickness; 0.5 cm, 1 cm, and 2 cm were shown in Table 4.1, there lied between 0.65±0.07 and 0.81±0.02. Figure 4.3 were shown the results, the thickness of 2 cm achieved highest value 0.81±0.02 of NRC, that mean it obtained best acoustical performance. The statistical analysis by one-way ANOVA shown the different thickness that influence to NRC statistical significance with a significance level of 0.05 (p-value < 0.05). ANOVA (Post Hoc Tests) found the thickness of 0.5 cm and 2 cm were influence to NRC with significance level of 0.05 (p-value < 0.05). Same as the thickness of 1 cm and 2 cm were influence to NRC with significance level of 0.05 (p-value < 0.05).

Table 4.2 and Figure 4.45 shown noise reduction coefficient (NRC) of the acoustic absorption board from banana pseudo-stem in thickness of 0.5 cm with different density; 0.151±0.04 g/cm^3, and 0.357±0.04 g/cm^3. The density of 0.151±0.04 g/cm^3 and 0.357±0.00 g/cm^3 obtained equal to NRC but the density of 0.151±0.04 g/cm^3 obtained higher value of NRC than the density of 0.357±0.00 g/cm^3 very few. The statistical analysis by independent sample t-test shown the different density that not influence to NRC statistical significance with a significance level of 0.05 (p-value > 0.05).

The thickness of 0.5 cm of acoustic absorption board may be denser packed than the thickness of 1 cm, which increased the flow resistivity. There may be influence to noise reduction coefficient (NRC). The sample with higher flow resistance provided highest acoustical performance (Martellotta et al., 2018 and da Silva et al., 2019)

4.3 Production cost of acoustic absorption board

The acoustic absorption board from banana pseudo-stem price was about 280 baht/m^2 that included sodium hydroxide 2 kg cost about 100 baht, 3 bottles of TOA Latex Adhesive (No. LA-22S) 32 oz cost about 180 baht, and banana pseudo-stem from agricultural wastes cost about 0 baht. To compare with the commercial sound absorber, the rockwool acoustic panel cost was about 600 baht/m^2 that more expensive than the acoustic absorption board from banana pseudo-stem. Moreover, the acoustical performance of the acoustic absorption board from banana pseudo-stem was better than the rockwool acoustic panel.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study investigates the efficiency of the acoustic absorption board from banana pseudo-stem and comparison the efficiency of the acoustic absorption board from banana pseudo-stem with different thickness and density of acoustic absorption board. The measurement of sound absorption coefficient was conducted using a standing wave tube method according to ASTM C384-04. The results of thickness and density of absorber were summarized as below.

5.1.1. The thickness of 2 cm of acoustic absorption board at density of 1.51±0.04 g/cm^3 achieved highest value 0.81±0.02 of NRC and 0.83±0.15 of sound absorption coefficient, which shown it obtained best acoustical performance.

5.1.2. The density of 0.151±0.04 g/cm^3 and 0.357±0.00 g/cm^3 of acoustic absorption board at thickness of 0.5 cm obtained equally value of NRC, also sound absorption coefficient.

5.1.3. The thickness of acoustic absorption board increased, sound absorption coefficient and NRC also increased.

5.1.4. The different density of acoustic absorption board was not influence to sound absorption coefficient and NRC.

5.2 Recommendations

5.2.1 The density of acoustical absorption board should be increased for more obvious results.

5.2.2 Increase the number of test samples for more precise results.

5.2.3 The length of fiber should be short to reduce pore for improve sound absorption efficiency.

5.2.4 The fiber can be used as spray for acoustic absorbing material.

5.2.5 Sample fabrication should be found the way to control the density to be stable more.

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APPENDIX A

Table A.1 Sound absorption coefficient (α) of the acoustic absorption board from banana pseudo-stem in density of 0.151±0.04 g/cm^3 with different thickness; 0.5 cm, 1 cm, and 2 cm at the frequency of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz.

Sample		Sound absorption coefficient (α)					Density	Density$_{avg}$	α_{avg}	α_{avg}±SD
		Frequency (Hz)								
Thickness	No.	250	500	1000	2000	4000				
0.5 cm	1	0.76	0.73	0.50	0.47	0.92	0.22	0.15±0.04	0.68	0.70±0.20
	2	0.83	0.89	0.88	0.39	0.73	0.19		0.74	
	3	0.97	0.91	0.35	0.39	0.84	0.19		0.69	
1 cm	1	0.70	0.85	0.54	0.19	0.90	0.15		0.64	0.69±0.20
	2	0.98	0.90	0.63	0.25	0.78	0.14		0.71	
	3	0.66	0.78	0.56	0.74	0.89	0.11		0.73	
2 cm	1	0.92	0.96	0.61	0.78	0.93	0.12		0.84	0.83±0.15
	2	0.92	0.94	0.66	0.83	0.92	0.14		0.85	
	3	0.95	0.89	0.47	0.85	0.86	0.11		0.81	

Table A.2 Sound absorption coefficient (α) of the acoustic absorption board from banana pseudo-stem in thickness of 0.5 cm with different density; 0.151±0.04 g/cm^3, and 0.358±0.00 g/cm^3 at the frequency of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz.

Sample		Sound absorption coefficient (α) Frequency (Hz)					Density	Density$_{avg}$	α_{avg}	α_{avg}±SD
Density	No.	250	500	1000	2000	4000				
0.151±0.04	1	0.756	0.730	0.505	0.472	0.919	0.22	0.15±0.04	0.68	0.67±0.07
	2	0.827	0.886	0.879	0.394	0.734	0.19		0.74	
	3	0.971	0.912	0.346	0.387	0.838	0.19		0.69	
0.357±0.00	1	0.938	0.765	0.876	0.327	0.978	0.36	0.36±0.00	0.78	0.66±0.06
	2	0.995	0.838	0.415	0.228	0.838	0.36		0.66	
	3	0.978	0.739	0.423	0.340	0.971	0.36		0.69	

Table A.3 Noise reduction coefficient (NRC) of the acoustic absorption board from banana pseudo-stem in density of 0.151±0.04 g/cm^3 with different thickness; 0.5 cm, 1 cm, and 2 cm at the frequency of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz.

Sample		Sound absorption coefficient (α)				NRC	NRC±SD
		Frequency (Hz)					
Thickness	No.	250	500	1000	2000		
0.5 cm	1	0.76	0.73	0.50	0.47	0.62	0.67±0.07
	2	0.83	0.89	0.88	0.39	0.75	
	3	0.97	0.91	0.35	0.39	0.65	
1 cm	1	0.70	0.85	0.54	0.19	0.57	0.65±0.07
	2	0.98	0.90	0.63	0.25	0.69	
	3	0.66	0.78	0.56	0.74	0.69	
2 cm	1	0.92	0.96	0.61	0.78	0.82	0.81±0.02
	2	0.92	0.94	0.66	0.83	0.84	
	3	0.95	0.89	0.47	0.85	0.79	

Table A.4 Noise reduction coefficient (NRC) of the acoustic absorption board from banana pseudo-stem in thickness of 0.5 cm with different density; 0.151±0.04 g/cm^3, and 0.358±0.00 g/cm^3 at the frequency of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz.

Sample		Sound absorption coefficient (α)				NRC	NRC±SD
		Frequency (Hz)					
Density	**No.**	**250**	**500**	**1000**	**2000**		
0.151±0.04	1	0.756	0.730	0.505	0.472	0.62	0.67±0.07
	2	0.827	0.886	0.879	0.394	0.75	
	3	0.971	0.912	0.346	0.387	0.65	
0.357±0.00	1	0.938	0.765	0.876	0.327	0.73	0.66±0.06
	2	0.995	0.838	0.415	0.228	0.62	
	3	0.978	0.739	0.423	0.340	0.62	

APPENDIX B

Table B.1 The relationship between the average sound absorption coefficient (α) and the thickness of the acoustic absorption board from banana pseudo-stem was analyzed by correlation.

Correlations		**Thickness**	**Sound absorption coefficient (α)**
Thickness	Pearson Correlation	1	.258
	Sig. (2-tailed)		.088
	N	45	45
Sound absorption coefficient (α)	Pearson Correlation	.258	1
	Sig. (2-tailed)	.088	
	N	45	45

*The significance level is 0.05 (2-tailed)

Table B.2 The relationship between the average sound absorption coefficient (α) and the density of the acoustic absorption board from banana pseudo-stem was analyzed by correlation.

Correlations		**Density**	**Sound absorption coefficient (α)**
Density	Pearson Correlation	1	.013
	Sig. (2-tailed)		.947
	N	30	30
Sound absorption coefficient (α)	Pearson Correlation	.013	1
	Sig. (2-tailed)	.947	
	N	30	30

*The significance level is 0.05 (2-tailed)

Table B.3 The differentiation of variable thickness that influence to noise reduction coefficient (NRC) was analyzed by one-way ANOVA with 95% confidence.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.048	2	.024	7.633	.022
Within Groups	.019	6	.003		
Total	.068	8			

*The significance level is 0.05

Table B.4 The differentiation of variable thickness that influence to noise reduction coefficient (NRC) was analyzed by one-way ANOVA (Post Hoc Test) with 95% confidence.

Tukey HSD		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
(I) Thickness	(J) Thickness				Lower Bound	Upper Bound
0.5	1	.022333	.046016	.881	-.11886	.16352
	2	-.143333*	.046016	.047	-.28452	-.00214
1	0.5	-.022333	.046016	.881	-.16352	.11886
	2	-.165667*	.046016	.026	-.30686	-.02448
2	0.5	.143333*	.046016	.047	.00214	.28452
	1	.165667*	.046016	.026	.02448	.30686

*. The mean difference is significant at the 0.05 level.

Table B.5 The differentiation of variable density that influence to noise reduction coefficient (NRC) by independent sample t-test with 95% confidence interval.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
NRC	Equal variances assumed	.006	.943	.316	4	.767	.016667	.052664	-.129551	.162884
	Equal variances not assumed			.316	3.978	.768	.016667	.052664	-.129867	.163200

*The significance level is 0.05

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