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ชื่อโครงการ **Efficiency of acoustic absorption board from pomelo peels**

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Department Environmental Science

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Efficiency of acoustic absorption board from pomelo peels

Phapasorn Panudomluck

A Senior Project Submitted in Partial Fulfillment of the Requirements for
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Abstract

This study focused on the evaluated efficiency of the acoustic absorption board from pomelo peels and comparison sound absorption efficiency with different thicknesses and densities of the acoustic absorption board. The thickness of the sound absorber was varied in 3 sizes in 3 sizes i.e., 0.5 cm, 1 cm, and 2 cm, and 2 densities i.e., 784 kg/m^3 and 1569 kg/m^3 at constant thickness of 0.5 cm. The impedance tube testing according to ASTM C384-04 was used to measure the sound absorption coefficient. The results showed, at the difference thickness the 2 cm thickness with constant density of 784 kg/m^3 of pomelo peel fibers sound absorber provided the maximum absorption performance which achieved NRC at 0.67±0.06 while the 0.5 cm and 1 cm provided 0.66±0.06 and 0.57±0.03 respectively. With the difference density, the 784 kg/m^3 and 1569 kg/m^3 of pomelo peel fibers sound absorber provided no statistically significant difference with a significance level of 0.05 which achieved NRC at 0.66±0.06 and 0.71±0.01 respectively.

Keywords: natural fibers, pomelo peels, acoustic material, acoustic absorber, sound absorption coefficient

หัวเรื่อง	ประสิทธิภาพของวัสดุดูดกลืนเสียงจากเปลือกส้มโอ
โดย	นางสาวพกัสสรณ์ ปานอุดมลักษณ์ **รหัสนิสิต** 593 33286 23
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ภาควิชา	วิทยาศาสตร์สิ่งแวดล้อม
ปีการศึกษา	2562

บทคัดย่อ

การศึกษาในครั้งนี้มีวัตถุประสงค์เพื่อประเมินประสิทธิภาพของวัสดุดูดซับเสียงที่ทำมาจากเปลือกส้มโอ และเปรียบเทียบประสิทธิภาพการดูดซับเสียงของวัสดุดูดซับเสียงที่มีความหนาและความหนาแน่นแตกต่างกัน โดยแบ่งความหนาของตัวอย่างออกเป็น 3 ขนาด คือ 0.5 เซนติเมตร, 1 เซนติเมตร, และ 2 เซนติเมตร ที่ความหนาแน่น 784 กิโลกรัมต่อลูกบาศก์เมตร และแบ่งความหนาแน่นออกเป็น 2 ความหนาแน่น คือ 784 กิโลกรัมต่อลูกบาศก์เมตร และ 1569 กิโลกรัมต่อลูกบาศก์เมตร ผลการศึกษา พบว่า ความหนาที่แตกต่างกันส่งผลให้วัสดุดูดซับเสียงที่ทำมาจากเปลือกส้มโอความหนา 2 เซนติเมตร มีประสิทธิภาพการดูดซับสูงสุด โดยมีค่าสัมประสิทธิ์การลดเสียงเท่ากับ 0.67 ± 0.06 ในขณะที่ความหนา 0.5 เซนติเมตร และ 1 เซนติเมตร ให้ค่าสัมประสิทธิ์การลดเสียงเท่ากับ 0.66 ± 0.06 และ 0.57 ± 0.03 ตามลำดับ และความหนาแน่นที่แตกต่างกัน วัสดุดูดซับเสียงที่ทำมาจากเปลือกส้มโอความหนาแน่น 784 กิโลกรัมต่อลูกบาศก์เมตร และ 1,569 กิโลกรัมต่อลูกบาศก์เมตร ไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติที่ระดับนัยสำคัญ 0.05 โดยให้ค่าสัมประสิทธิ์การลดเสียงเท่ากับ 0.66 ± 0.06 และ 0.71 ± 0.01 ตามลำดับ

คำสำคัญ : เส้นใยธรรมชาติ, เปลือกส้มโอ, วัสดุดูดซับเสียง, ตัวดูดซับเสียง, ค่าสัมประสิทธิ์การดูดซับเสียง

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Phapasorn Panudomluck

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CHAPTER I
INTRODUCTION

1.1 Background

Noise or unwanted sound is a major problem affecting numerous people which can impact health directly (Stansfeld & Matheson, 2003). It can contribute to the chances of getting the risk of cardiovascular diseases increased, cause sleep disturbance, and other diseases. The factors driving environmental noise are urbanization, economic expansion, and transportation development (Organization, 2011).

To mitigate and control this problem, the sound absorber is one of the important materials that can decrease the sound energy and noise pollution. Each material of the absorber can absorb the sound at different levels. Such as, sound absorber which made from fibers of sugarcane show good acoustic performance at 1.2 - 4.5 kHz with an average absorption coefficient of 0.65 (Putra et al., 2013) while sound absorber which made from fibers of oil palm empty fruit bunch have high efficiency at a frequency above 1 kHz with an average absorption coefficient of 0.9 (Or, Putra, & Selamat, 2017).

Some raw materials which are a composition of the sound absorber have been found to have an impact on human health. For instance, the sound absorber which is made from asbestos can be harmful to the exposed person. The diseases associated with inhalation of asbestos dust are asbestosis, lung cancer, mesothelioma, and other forms of cancer (Curtis, 1991). Therefore, the natural material which provides a low impact on the environment and human health (Asdrubali, Schiavoni, & Horoshenkov, 2012) is another good option to make the sound absorber.

Pomelo (*Citrus maxima* or *Citrus grandis*) is the largest citrus fruit that is grown in Southeast Asia and its peel accounts for 30% of the total weight (Wandee, Uttapap, & Mischnick, 2019). In Thailand, pomelo is a fruit that can be produced throughout the year which amounts to more than 200,000 tons/year (Looyrach, Methacanon, Gamonpilas, Lekpittaya, & Lertworasirikul, 2015). The pomelo peel contains a foamy fibrous layer but and a large number of pectin (Guo et al., 2018). The structure of the pomelo peel has porous size varies according to the thickness of the peel (Ortiz, Zhang,

& McAdams, 2018) and arranged in a loose shape like foam and has a lot of surface area which is suitable for making sound-absorbing materials.

Thus, this study focuses on the evaluation efficiency of the acoustic absorption board from pomelo peels and comparison sound absorption efficiency with different thicknesses and densities of the acoustic absorption board.

1.2 Objectives

The objectives of this study are to

1.2.1 To compare the efficiency of acoustic absorption in different thicknesses and densities of the acoustic absorption board.

1.2.2 To evaluate the efficiency of the acoustic absorption board from pomelo peels.

1.3 Benefits

1.3.1 To reduce the amount of agricultural waste.

1.3.2 To utilize waste from the pomelo peels to be the natural acoustic material.

1.3.3 To study the efficiency of sound-absorbing materials produced from pomelo peel.

CHAPTER II
THEORETICAL BACKGROUNDS AND LITERATURE REVIEW

2.1 Sound

2.1.1 Definition

Sound is a mechanical wave that is caused by the vibrating of the object. When the object vibrates, it causes compression (the part of the sound waves where the molecules of air are pushed together) and rarefaction (the part of the waves where the molecules are far away from each other) of the sound waves and is passed through an intermediary such as the air to the ear. The sound cannot travel through a vacuum and require the media for propagation such as air, water, or metal (Woodford, 2020).

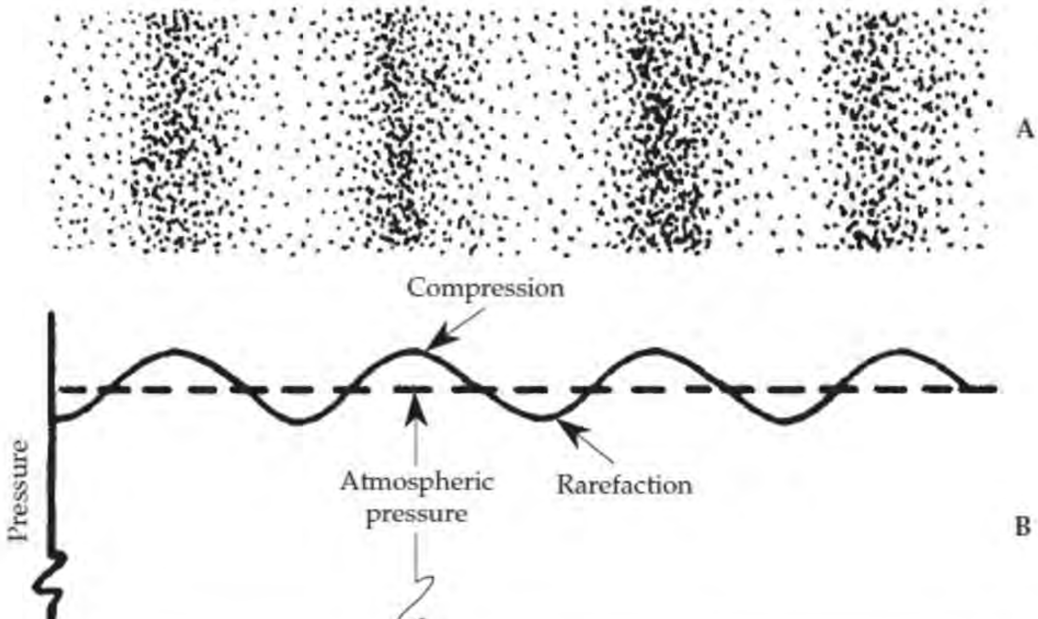

Figure 2.1 Pressure variations of sound waves (Everest & Pohlmann, 2009)

2.1.2 Sound absorption

Sound absorption is the absorption of sound energy by the material or media which the sound traveling through.

The sound wave was generated and traveling through the air and will be absorbed by the air absorption. When the sound wave traveled to hit the acoustic absorbing material or wall. Some sound energy is reflected. And another part causes the refraction of the sound because of the density of the media and travels through the sound absorbing material or wall. Loss of sound energy from air absorption will occur. Finally, the remaining sound waves after being absorbed have reduced energy from the original sound energy (Everest & Pohlmann, 2009)

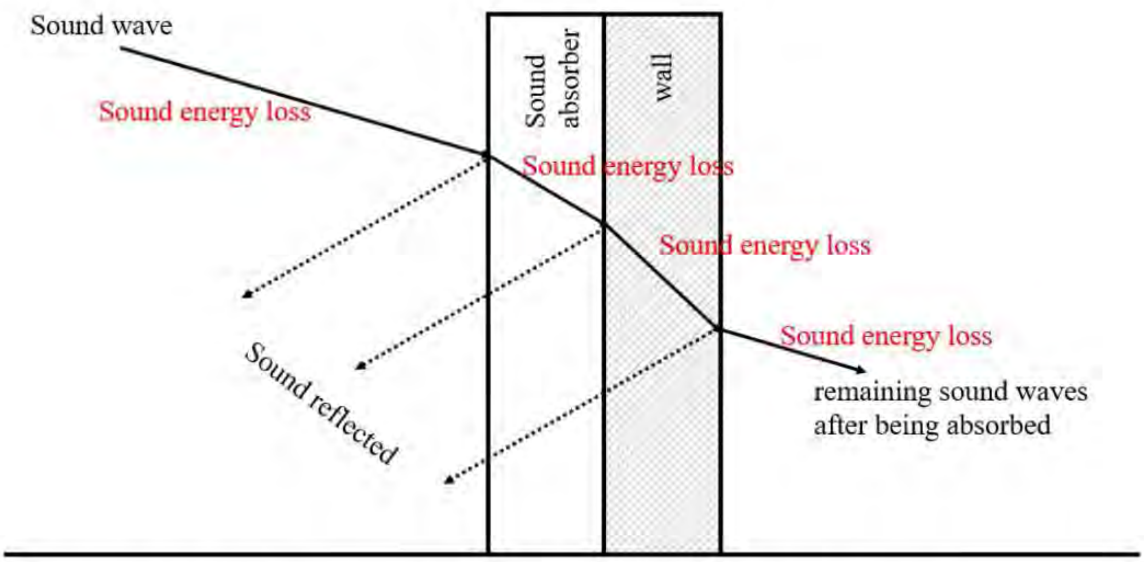

Figure 2.2 Route of a sound wave traveling and sound absorption

2.1.3 Sound absorber

The sound absorbers have divided into three types: porous absorbers, panel absorbers, and resonance absorbers (Everest & Pohlmann, 2009).

2.1.3.1 Porous absorbers

The porous absorber is the material that provided a large number of the surface area and pores, for instance, mineral wool, glass fiber, and rock wool. The sound waves travel into the porous absorber and were changed into heat energy. The heat transfer will happen and some sound energy is reflected. The porous absorber is most effective with the middle and high frequencies (SoundproofLivingTeam, 2020).

Figure 2.3 Example of porous absorber: Glass fiber (Energyconceptgroup, 2016).

2.1.3.2 Panel absorbers or membrane absorber

Panel absorber or membrane absorber is a common feature as the building components, for instance, windows, doors, and walls. It is most effective at lower frequencies (SoundproofLivingTeam, 2020).

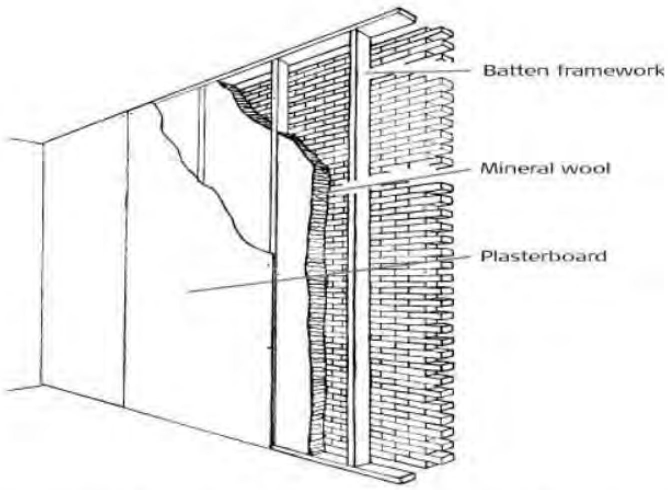

Figure 2.4 Example of panel absorber: Plasterboard wall (Troldtekt, 2020).

2.1.3.3 Resonance absorbers

Resonance absorber consists an oscillating system and can only absorb one frequency to decrease the resonance sound which is an energy transformation from the sound energy to the oscillatory energy (Troldtekt, 2020). Resonance absorber is most effective at lower frequencies (Everest & Pohlmann, 2009).

Figure 2.5 Example of Resonance absorber: Helmoholtz Resonator (Foley, 2014).

2.1.4 Sound Absorption Coefficients

The sound absorption coefficient (α) is the best parameter that can describe the efficiency of the sound absorber to reduce the sound energy and sound level. The sound absorption coefficient value is a range in 0 to 1. If the coefficient value of the sound absorber is 1, there means that sound absorber can absorb 100% of the incident sound (António, 2011).

Each material of the absorber can absorb the sound at different levels. The sound absorption coefficients of common materials were showed in Table 2.

Table 2.1 Sound Absorption Coefficients of Common Materials in Construction (Zhang, 2011)

Class and name	Thickness (cm)	Apparent Density (kg/m^3)	Sound Absorption Coefficient						Installation
			125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
1.Inorganic materials									
- Plasterboard (with decorative pattern)	-	350	0.03	0.05	0.06	0.09	0.04	0.06	Plaster firmly
- Cement vermiculite plate	4.0		-	0.14	0.46	0.78	0.50	0.60	Paint walls
- Gypsum mortar (blended with cement glass fiber)	2.2		0.24	0.12	0.09	0.30	0.32	0.83	
- Cement expanded perlite plate	5		0.16	0.46	0.64	0.48	0.56	0.56	
- Cement mortar			0.21	0.16	0.25	0.40	0.42	0.48	
- Brick (Plain brick wall)	1.7		0.02	0.03	0.04	0.04	0.05	0.05	
2. Organic materials									
- Cork board	2.5	260	0.05	0.11	0.25	0.63	0.70	0.70	Plaster firmly to the wood
- Shuisi board	3.0		0.10	0.36	0.62	0.53	0.71	0.90	
- Veneer board (three layers)	0.3		0.21	0.73	0.21	0.19	0.08	0.12	Keel with an air layer of 10cm or 5cm in between
- perforated plywood (five layers)	0.5		0.01	0.25	0.55	0.30	0.16	0.19	
- Zylonite	0.8		0.03	0.02	0.03	0.03	0.04	-	
- wood of fiberboard	1.1		0.06	0.15	0.28	0.30	0.33	0.31	

Table 2.1 Sound Absorption Coefficients of Common Materials in Construction (Zhang, 2011) (continue)

Class and name	Thickness (cm)	Apparent Density (kg/m^3)	Sound Absorption Coefficient						Installation
			125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
3. Porous material									
- Foamed glass	4.4	1260	0.11	0.32	0.52	0.44	0.52	0.33	Plaster firmly
- urea formaldehyde foamed plastics	5.0	20	0.22	0.29	0.40	0.68	0.95	0.94	Plaster firmly
- Foamed cement (exterior plaster)	2.0		0.18	0.05	0.22	0.48	0.22	0.32	Closely against walls
- Sound absorbing perforated plate									
- Foamed plastics			0.27	0.12	0.42	0.86	0.48	0.30	
	1.0		0.03	0.06	0.12	0.41	0.85	0.67	
4. fibrous material									
- Slag wool	3.13	210	0.10	0.21	0.60	0.95	0.85	0.72	Plaster firmly
- Glass wool	5.0	80	0.06	0.08	0.18	0.44	0.72	0.82	Plaster firmly
- Phenolic aldehyde glass fiber board	8.0	100	0.25	0.55	0.80	0.92	0.98	0.95	Plaster firmly
- Industrial felt	3.0		0.10	0.28	0.55	0.60	0.60	0.56	Plaster to the wall

2.1.4.1 Noise reduction coefficient (NRC)

Noise reduction coefficient (NRC) is the average value of the sound absorption coefficient for the frequency of 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz. Therefore, the two materials which achieve the same value of NRC might not perform in the same performance. And if the NRC of the sound absorber has a value of 0.00, it means that the material has completely reflective (Patricia, 2013).

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

Table 2.2 Example of materials with NRC (Noll, 2019)

Material	Noise reduction coefficient (NRC) Rating
Brick	0.00-0.05
Carpet over concrete	0.20-0.30
Carpet with foam pad	0.30-0.50
Concrete (smooth)	0.00-0.20
Glass	0.05
Gypsum Wall Board	0.05
Plywood	0.10-0.15
Polyurethane foam (1 inch. thick)	0.30

2.1.4.2 Measurement of sound absorption coefficients

The sound absorption of fibrous materials can be measured by using the impedance tube method for normal-incidence sound absorption coefficient and reverberation chamber method for random-incidence sound absorption coefficient.

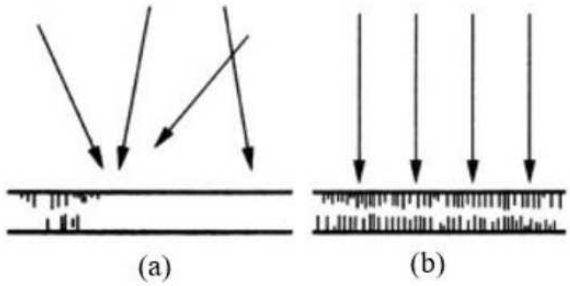

Figure 2.6 (a) random incidence and (b) normal incidence (Liu & Chen, 2014)

2.1.4.2.1 The impedance tube method

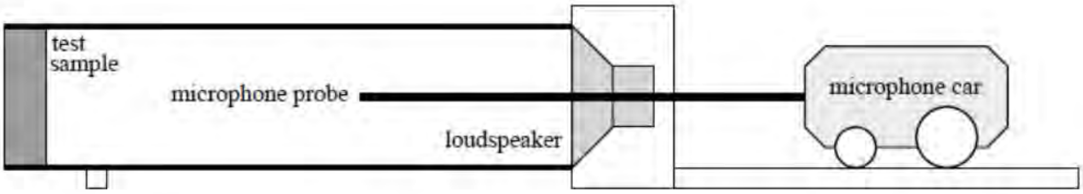

Figure 2.7 The measurement setup of impedance tube method (Russell, 1999)

When the standing waves generate in the impedance tube and travel to hit the rigid end at x = L (a), the waves will be reflected with the same amplitude. And the sound energy decreased by the absorption of the tube walls. On the other hand, the standing waves travel to hit the absorbing material at x = L (b), the standing wave will be absorbed some energy by the absorbing material. The other part will be reflected but in different amplitude from the incident waves.

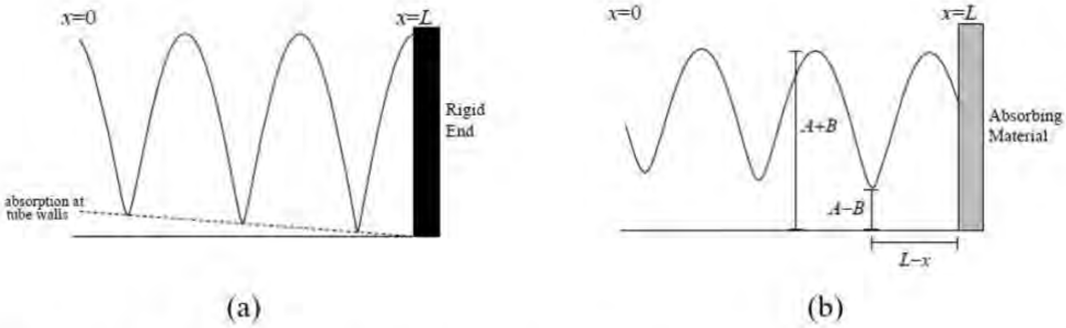

Figure 2.8 The pressure amplitude in the pipe with : (a) rigid termination at x = L, (b) absorbing material (Russell, 1999)

The ratio of pressure maximum (A+B) to pressure minimum (A−B) or the standing wave ratio (SWR) can be calculated by using equation 2

$$\mathrm{SWR} = \frac{A+B}{A-B} \qquad \text{equation 2}$$

The standing wave ratio (SWR) also provide the reflection coefficient (B/A) and the sound power reflection coefficient (R_π) which calculate by using equation 3 and equation 4

$$B/A = \frac{SWR-1}{SWR+1} \qquad \text{equation 3}$$

$$R_\pi = \left|\frac{B}{A}\right|^2 = \left(\frac{SWR-1}{SWR+1}\right)^2 \qquad \text{equation 4}$$

Thus, the standing wave ratio (SWR), the reflection coefficient (B/A), and the sound power reflection coefficient (R_π) were known. The sound absorption coefficients (α) can be calculated by using equation 5.

$$\alpha = 1 - R_\pi^2 = 1 - \frac{(SWR-1)^2}{(SWR+1)^2} = \frac{4}{SWR+\frac{1}{SWR}+2} \qquad \text{equation 5}$$

2.1.4.2.2 The reverberation chamber method

The reverberation chamber method is the method for test the sound absorption coefficients ($\bar{\alpha}$) of the sound absorber by using the acoustic testing room. The standing waves generated with different frequencies and directions but in the same probability. The sound absorption coefficients ($\bar{\alpha}$) will be measured by varied reverberation time (RT) (Liu & Chen, 2014).

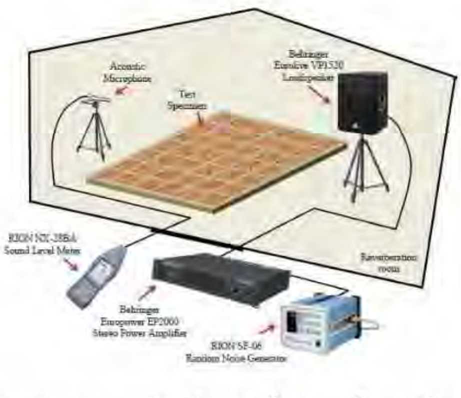

Figure 2.9 The measurement setup of reverberation chamber method (Lim, Putra, Nor, & Yaakob, 2018)

2.1.5 The impact of sound on human health

World Health Organization (WHO) had estimated the environmental burden of disease owing to environmental noise by using the quantitative risk assessment. The noise caused cardiovascular disease, cognitive impairment in children, sleep disturbance, tinnitus, and annoyance. Cardiovascular disease is caused by increasing the road traffic and aircraft noise and can provide the risk of ischaemic heart disease and high blood pressure increased. Moreover, the noise also decreased the cognitive ability of children by the noise exposure for a long time and remained for a while even after stopped exposure. (Organization, 2011).

Xie et al. (2009) presented the impact of noise on patients' sleep in ICUs. Sleep disturbance is caused due to the noise in ICU which are staff conversation and alarms that can increase the risk of delirium which accounts for 70-80% of the ICU patients and cause the probability of post-traumatic stress disorder. Furthermore, disrupt immune function by sleep deprivation.

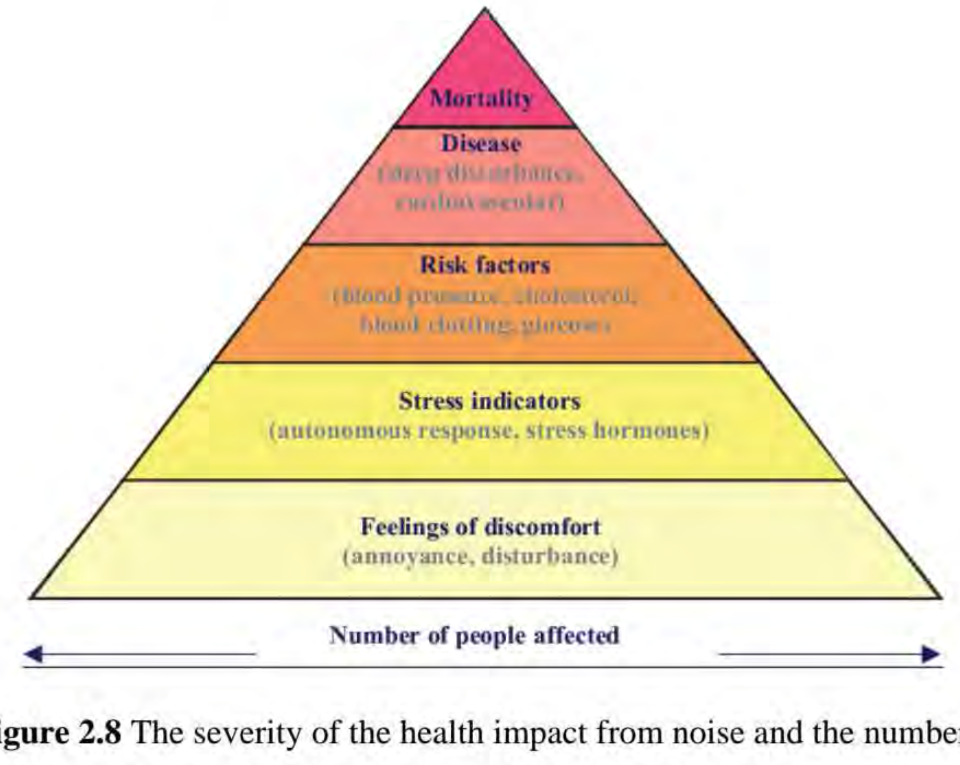

Figure 2.8 The severity of the health impact from noise and the number of people affected (Organization, 2011).

2.2 Pomelo peel

Pomelo (*Citrus maxima* or *Citrus grandis*) is the largest citrus fruit which native to South-East Asia. Its peel is the largest and thickest peel of all the citrus fruits which accounts for 30% of the total weight (Tocmo, Pena-Fronteras, Calumba, Mendoza, & Johnson, 2020). The peel consists two layers: flavedo which contains oils and pigments and albedo which contains cellulose, pectin, and hemicellulose (Aruoma et al., 2012).

In 2019, Thailand produced the pomelo accounts for 122,000 tons approximately (Extension, 2020). Due to the high production and consumption, it causes a large number of agricultural wastes.

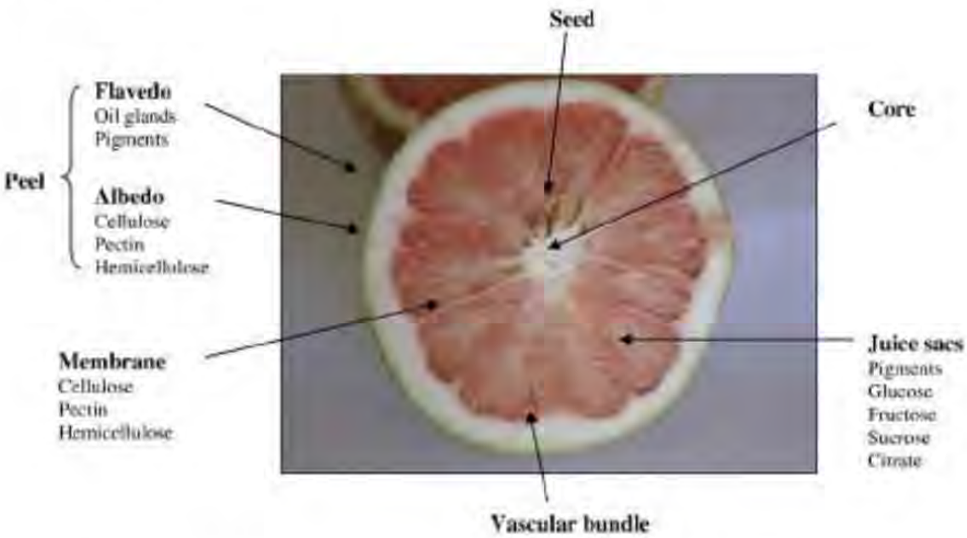

Figure 2.9 Cross-section of citrus fruit (Aruoma et al., 2012)

2.3 Literature review

Nordin et al. (2006) presented how materials change the absorption behavior. The results focused on the effects of the fibers on density, thickness, and air gap. Increasing tortuosity and density provided more airflow resistance. The increasing airflow resistance can improve sound absorption property. If the material achieved too high airflow resistance, sound absorption has fewer values due to the difficulty sound movement.

Putra et al. (2013) studied sugarcane fibers (*Saccharum officinarum*) which are a natural fiber to be an alternative acoustic material by using the impedance tube method. The result showed the thickness ½ inch of the sugarcane fibers sample which achieved an average absorption coefficient of 0.65 at frequency 1.2 - 4.5 kHz is the same efficiency as commercial sound absorber and can be used as an alternative acoustic material.

ALRahman et al. (2013) exhibited the potential for using date palm fiber and coconut coir fiber as sound absorbers. The result showed date palm fiber and coconut coir fiber have good performance at low and high frequencies. However, the date palm fiber showed better acoustic absorption performance than coconut coir fiber. It provided acoustic absorption coefficient 0.84 (thickness:20 mm) and 0.98 (thickness:40 mm) at the frequencies 2600-3000 Hz and 1300-1500 Hz respectively. While coconut coir fiber provided acoustic absorption coefficient 0.71 (thickness:20 mm) and 0.77 (thickness:40 mm) at the frequencies 4100-4500 Hz and 2400-2500 Hz respectively.

Fouladi et al. (2013) studied the acoustic behavior of coir, corn, sugar cane, and grass by impedance tube method and implemented them as absorbers. The results showed, increasing the thickness of coir, corn, and grass to 2.0 cm can be reduced their porosity and improved the absorption coefficient which absorbed more than 70% of the incident sound at the frequency more than 1300 Hz. Whereas the sugar cane showed a similar efficiency at the narrow frequency.

Berardi et al. (2015) presented the acoustic characterization of the natural fibers: kenaf, wood, hemp, coconut, cork, cane, cardboard, and sheep wool. The absorption coefficient and the flow resistance of the different thickness samples were measured by theoretical models. The result showed sheep wool and the coconut achieved a high value of NRC. The less dense kenaf and some types of canes showed NRC values higher than the predicted. This can be observed that natural fibers are another good option for reduced sound energy.

Peng et al. (2015) studied the physical and mechanical properties, effects of the airflow resistivity, and air gap behind the sample of sound-absorbing composite material which made from wood fiber and polyester fiber produced by using polyester foam technology and wood-based composite technology. The measurement found that the composite materials provided excellent physical and mechanical properties in the conditions of hot-pressing at 150∘C with the 10min of composite time, 3:1 wood fiber to polyester ratio, 12% resin content, 8% foaming agent content, and the density was 0.2 g/cm3. The composite material showed excellent sound absorption property with the airflow resistivity of 1.98×10^5 Pa·s/m^2. And increasing air gap behind the sample improves acoustic absorption at a lower frequency.

Mamtaz et al. (2016) studied the acoustic absorption behavior of natural fiber composites. This study showed the fiber treated by alkaline treatment process will be reduced of the fiber diameter. The reduction in fiber diameter causes an increase in the fiber content and provided more area. This can help to absorb the sound at the low frequency due to the loss of more energy by the viscous friction. Absorber with high density and thickness showed increased absorption performance, due to the porosity and flow resistivity of the composite.

Or et al. (2017) presented the potential of fibers from the oil palm empty fruit bunch to be the natural acoustic material and made with the variation of densities and thicknesses. Measurement found that the oil palm empty fruit bunch achieves an absorption coefficient of 0.9 on average above 1 kHz.

Lim et al. (2018) studied the sound absorption characteristic of the kenaf plant (*Hibiscus cannabinus* L.) fibers by using the impedance tube method and reverberation chamber method. Kenaf fibers showed good sound absorption performance in both methods. Kenaf fibers provided the value of a sound absorption coefficient above 0.8 from 1.5 kHz onwards for the thickness of 40 mm and bulk density of 93.5 kg/m^3 in the impedance tube method while in the reverberation chamber method shown absorption coefficient above 0.5 starting from 400 Hz with the average value of 0.8. Thus, the sound absorber of kenaf fibers can be comparable with synthetic rock wool.

Ortiz et al. (2018) presented 3D model of the pomelo peel bioinspired foams with nonuniform pore distribution and validated through a case study under quasi-static compression and free-fall impact circumstances. The results showed that the bioinspired foam with nonuniform porosity demonstrated impact resistance and damping behavior and can produce a smaller reaction force compared to the foam with uniform porosity.

Silva et al. (2019) evaluated the sound absorption coefficient of three natural fibers: sisal, coconut husk, and sugarcane with variation of thickness (20, 30, and 40 mm). The result showed the sugarcane bagasse fiber which achieves an average absorption coefficient of more than 0.8 at frequency 800-1200 Hz for the thickness of 40 mm has a better sound absorption performance than sisal and coconut husk fibers. Moreover, the values of the coefficient sugarcane were higher than others for all the thicknesses evaluated.

CHAPTER III
MATERIALS AND METHODS

3.1 Research 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 Blender

3.1.3 Sieve

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

3.1.5 Balance

3.1.6 Knives

3.1.7 Scissors

3.1.8 Water

3.1.9 Sodium hydroxide (NaOH)

3.1.10 TOA Latex Adhesive Glue LA-22S

3.1.11 Pomelo peel

3.2 Research methods

3.2.1 Preparation of pomelo peel fibers

The pomelo peels were collected from Air Force Welfare Market, Don Mueang, Bangkok, Thailand, and removed the green layer of the peels (keep the white layer). Next, cut the white layer of pomelo peel into small pieces. Get rid of the dirt and any other particles which are attached to the pomelo peel fibers by soak pomelo peels for 1 day with 2% w/w of sodium hydroxide (NaOH) solution for the alkaline treatment process. Then, the pomelo peel fibers were obtained by washed the fiber with water and dried the fibers under the sun exposure to remove the moisture content. Finally, for easy forming in the mold, the fibers were crushed by a blender and filter by sieve.

3.2.2 Sample forming (molding)

The samples of pomelo peel fibers sound absorber were designed with variation in thickness. The thickness of the sound absorber was varied in 3 sizes: 0.5 cm, 1 cm, and 2 cm, and 2 densities: 784 kg/m^3 and 1569 kg/m^3 at constant thickness of 0.5 cm. The TOA Latex Adhesive Glue was used as a binder. So, the sample was manually mixed with a binder for 1:1. Then, the mixture was pressed in a PVC mold to obtain shape and left to dry. Finally, Take the sample out from the mold, mark, and weigh samples to calculate the density by using equation 6. Make 3 replicates samples for each thickness and density. The flow chart of the process is shown in Figure 3.1.

$$\text{density} = \frac{mass}{volume} \qquad \text{equation 6}$$

Table 3.1 Sample sizes of the sound absorber

Thickness	**Density**	
	784 kg/m^3	**1569 kg/m^3**
0.5 cm	3	3
1.0 cm	3	
2.0 cm	3	
total	9	3

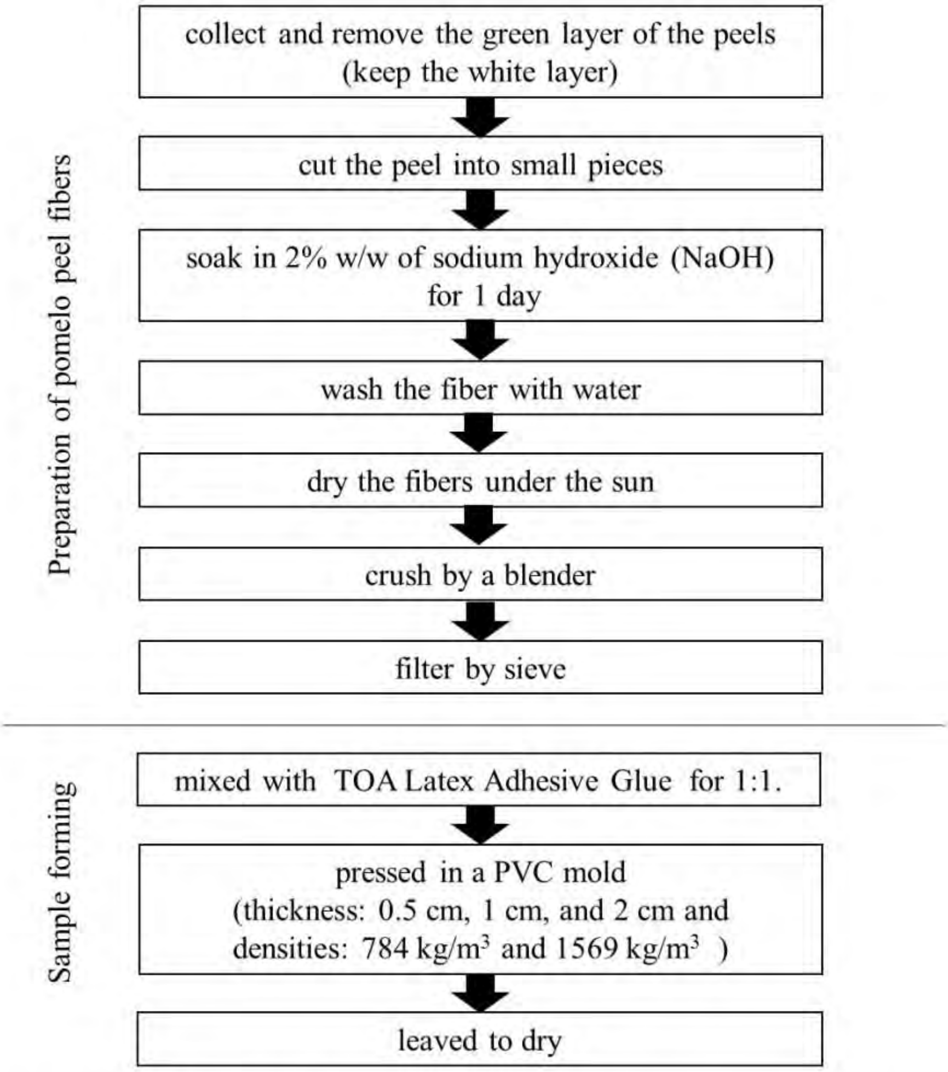

Figure 3.1 Flow chart of preparation and forming the sample

Figure 3.2 PVC mold 10.5cm diameter (thickness: 0.5cm, 1cm, and 2cm).

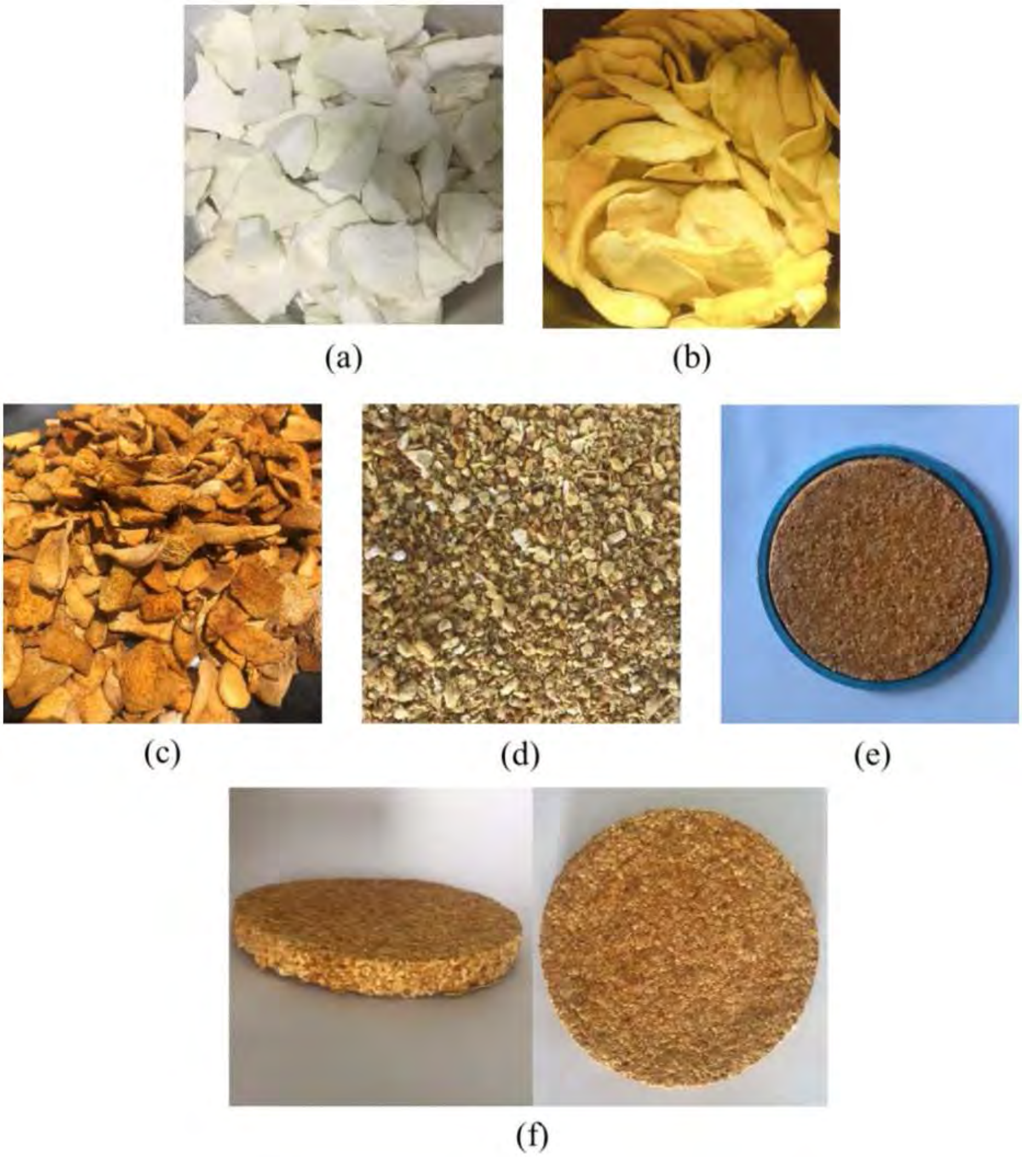

Figure 3.3 Preparation of fibers and sample forming: (a) pomelo peels (albedo layer), (b) the pomelo peels treated with 2% of sodium hydroxide (NaOH) solution, (c) dried peels, (d) the crushed sample, (e) sample forming, and (f) the test sample.

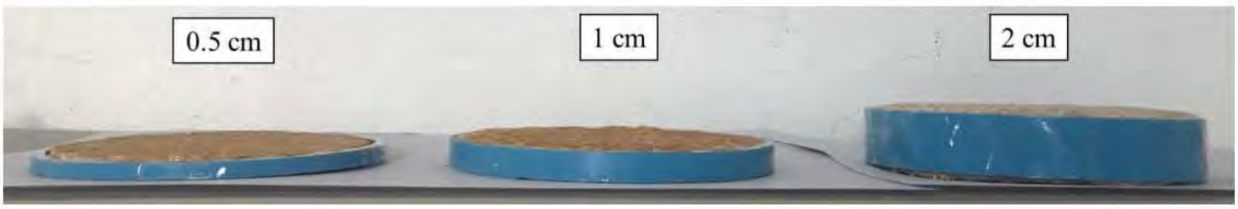

Figure 3.4 Examples of pomelo peel fibers sound absorber samples: 0.5 cm, 1 cm, and 2 cm thickness.

3.2.3 Measurement of absorption coefficient

3.2.3.1 Measurement setup

The measurement of the sound absorption coefficient was conducted by using the impedance tube testing according to ASTM C384-04. The measurement setup for the test is shown in Figure 3.5. The sample is placed at the end of the impedance tube and fixes it tightly without gaps. The other end of the impedance tube is the location of a loudspeaker. The standing wave was generated from the function generator into the impedance tube through the loudspeaker. The microphone probe is located in the impedance tube and close to the sample at the beginning of the measurement. The sound level meter is used to measure the decibel levels.

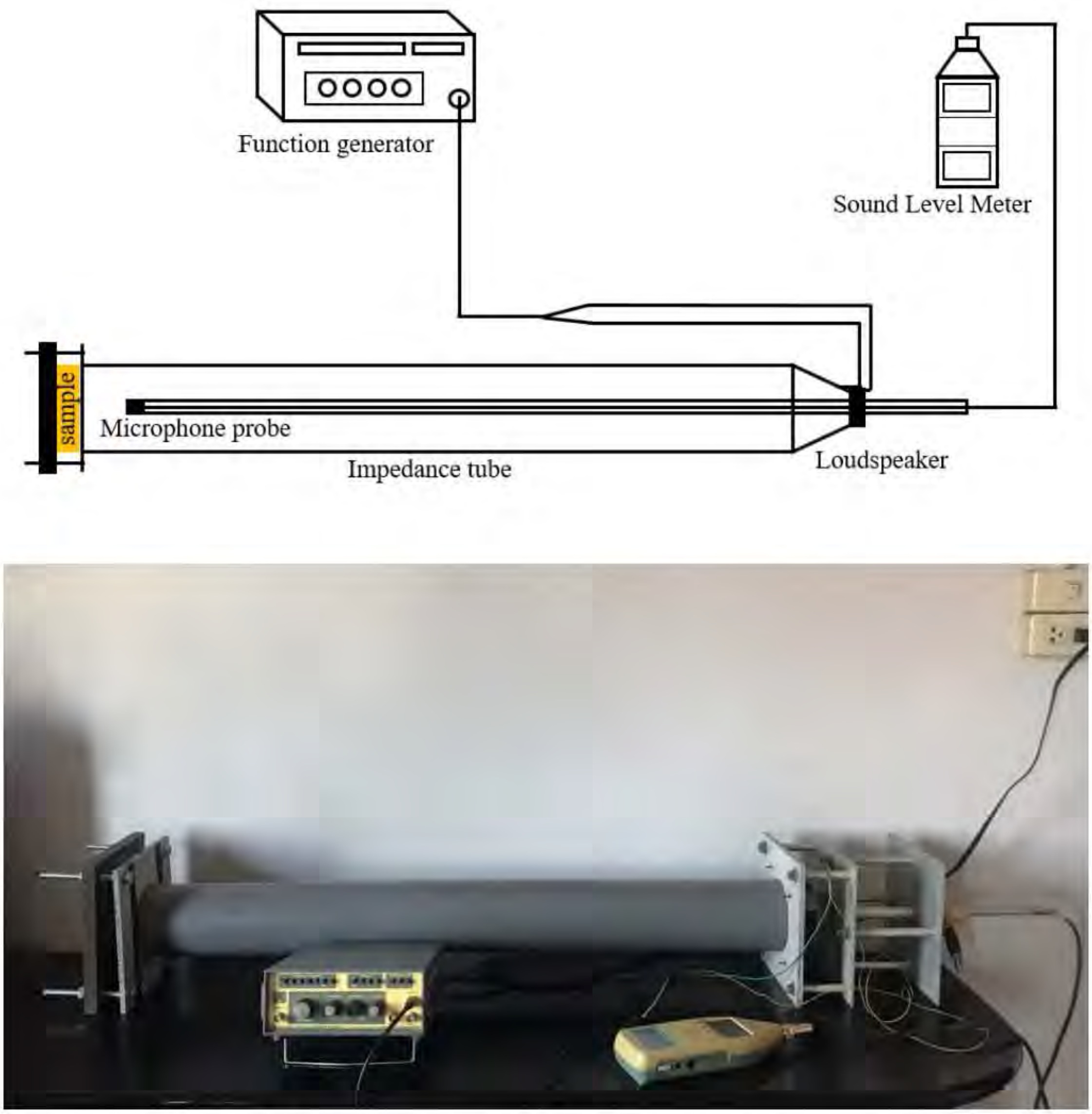

Figure 3.5 Measurement setup for the sound absorption test.

3.2.3.2 Procedure and calculation

Procedure and calculation of sound absorption coefficient are as follows (Russell, 1999) :

1) Calibrated the sound level meter.
2) Placed the test sample at the end of the impedance tube and fixes it tightly without gaps.
3) Turned on the function generator and adjust the frequency of the sine wave as 250 Hz.
4) Generated the sine wave from the function generator through the loudspeaker. At the beginning of the measurement, the microphone probe is placed close to the sample.
5) Moved the microphone probe out of the sample until found the first minimum levels($L_{(min)}$ in dB). Recorded and calculated the minimum rms pressure ($P_{min,rms}$) by using equation 7

$$P_{min,rms} = 10^{L(min)/20} \qquad \text{equation 7}$$

6) Moved the microphone probe out of the sample until found the next maximum levels($L_{(max)}$ in dB). Recorded and calculated the maximum rms pressure ($P_{max,rms}$) by using equation 8

$$P_{max,rms} = 10^{L(min)/20} \qquad \text{equation 8}$$

7) Calculated the standing wave ratio (SWR) by using equation 2

$$SWR = \frac{Pmax,rms}{Pmin,rms} \qquad \text{equation 2}$$

8) Calculated the sound absorption coefficient (α) by using equation 5

$$\alpha = \frac{4}{SWR+\frac{1}{SWR}+2} \qquad \text{equation 5}$$

9) Repeated the step 2-8 by changing the frequency from function generator as 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz and varied sample thickness and density.

10) Calculated the noise reduction coefficient (NRC) by using equation 1

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

3.2.4 Data analysis

Statistical analysis was conducted by using IBM SPSS Statistics version 22.

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

CHAPTER IV
RESULTS AND DISCUSSION

This study focused on the evaluated efficiency of the acoustic absorption board from pomelo peels and comparison sound absorption efficiency with different thicknesses and densities of the acoustic absorption board. The pomelo peels were collected from Air Force Welfare Market, Don Mueang, Bangkok, Thailand. The test samples were made in 3 sizes in 3 sizes i.e., 0.5 cm, 1 cm, and 2 cm, and 2 densities i.e., 784 kg/m^3 and 1569 kg/m^3 at constant thickness of 0.5 cm. The TOA latex adhesive glue is used as a binder and forming the sample with PVC mold 10.5cm diameter. The measurement was conducted by using the impedance tube testing according to ASTM C384-04. The results were presented and discussed in this chapter.

4.1 Characteristics of pomelo peels fibers sound absorber

The physical properties of pomelo peels fibers sound absorbers were yellowish brown, rough, and their structure likes quite hard foam. Moreover, the preparation for pomelo peel fibers used sodium hydroxide (NaOH) alkaline treatment process resulting in loss of the absorbers' smell. Due to the structure their foam, pomelo peels contain a large number of porous which increase the path which the sound energy travels through and cause the sound energy lost.

The alkaline treatment will be reduced of the fiber diameter and causes an increasing in the fiber content which provided more area of absorber. Increasing fiber content improve the sound absorption at the low frequency due to the loss of more energy by the viscous friction (Mamtaz, Fouladi et al. 2016).

According to the sample forming, the PVC mold with 10.5cm diameter is used for molding. After mixed the sample with TOA latex adhesive glue for 1:1, pressed in the mold, and left to dry. The test sample is reduced in size from the mold with 10.5cm diameter to 9.9 cm diameter due to the water which is a component of the adhesive glue evaporates. And when the sample is completely dry, it will cause a slightly bent.

4.2 Efficiency of acoustic absorption board

Pomelo peels acoustic absorption board in the thickness of 0.5 cm, 1 cm, and 2 cm at a constant density of 784 kg/m^3 were tested by standing wave tube. Results of sound absorption coefficient (α) showed in Table 4.1

Table 4.1 Sound absorption coefficient and noise reduction coefficient (NRC)

Sample Thickness (cm)	Absorption coefficient					α_{avg}	Noise reduction coefficient (NRC)
	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz		
0.5	0.83±0.02	0.80±0.06	0.27±0.02	0.75±0.18	0.46±0.03	0.62±0.25	0.66±0.06
1	0.67±0.10	0.87±0.06	0.22±0.03	0.52±0.08	0.72±0.17	0.60±0.25	0.57±0.03
2	0.90±0.03	0.94±0.02	0.37±0.02	0.49±0.2	0.74±0.06	0.69±0.25	0.67±0.06

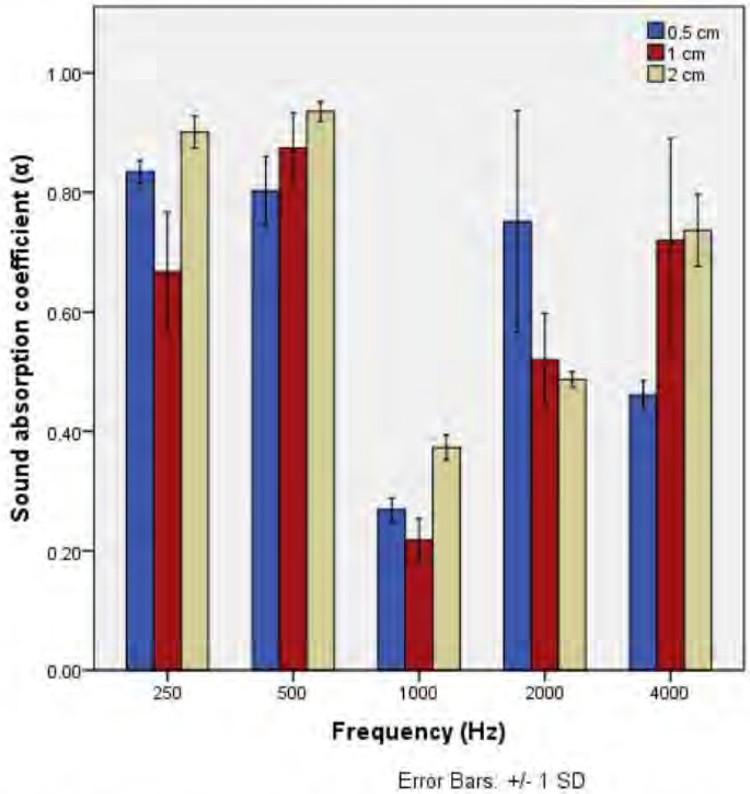

Figure 4.1 Sound absorption coefficient of pomelo peels acoustic absorption board at a constant density of 784 kg/m^3

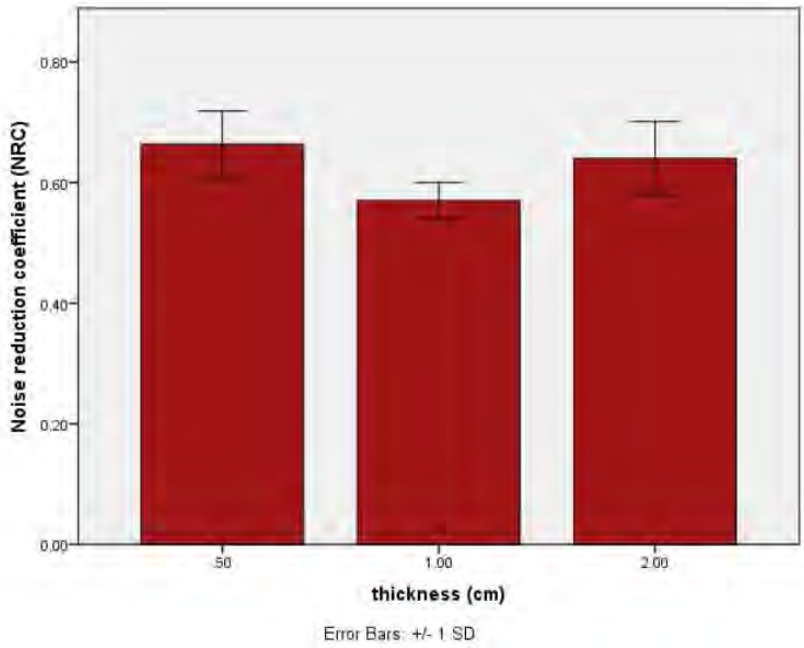

Figure 4.2 Noise reduction coefficient (NRC) of pomelo peels with different thickness

The varying densities of pomelo peels acoustic absorption board were made in 2 densities at the constant thickness of 0.5 cm which are 784 kg/m^3 and 1569 kg/m^3. Results of sound absorption coefficient (α) showed in Table 4.2

Table 4.2 Sound absorption coefficient and noise reduction coefficient (NRC) of the test samples at constant thickness of 0.5cm

Sample density (kg/m^3)	Absorption coefficient					α_{avg}	Noise reduction coefficient (NRC)
	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz		
784	0.83±0.02	0.80±0.06	0.27±0.02	0.75±0.18	0.46±0.03	0.62±0.25	0.66±0.06
1569	0.93±0.03	0.86±0.02	0.39±0.05	0.67±0.02	0.58±0.05	0.69±0.22	0.71±0.01

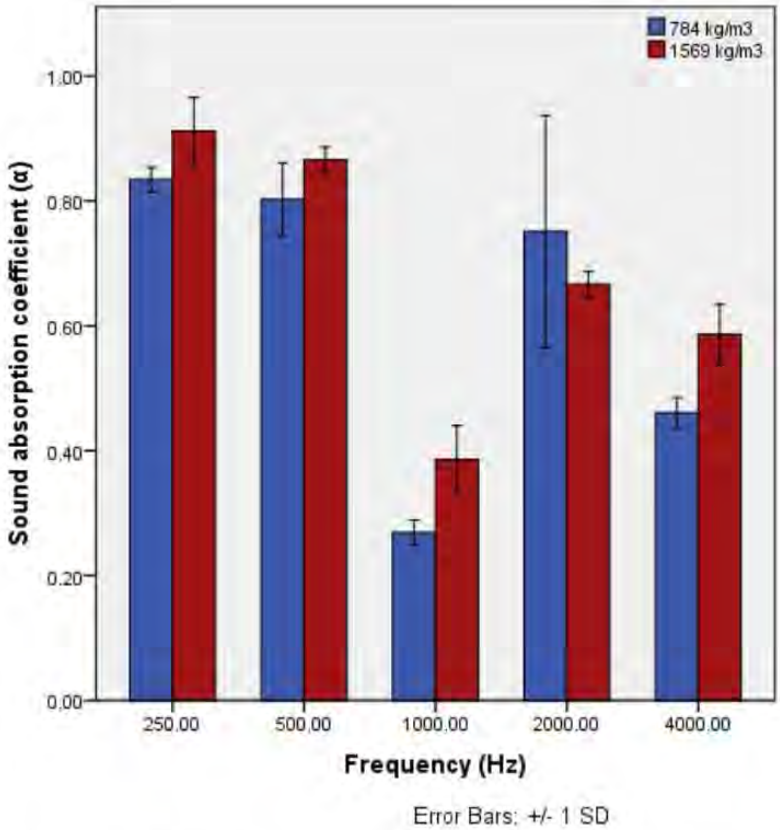

Figure 4.3 Sound absorption coefficient peels acoustic absorption board at constant thickness of 0.5cm.

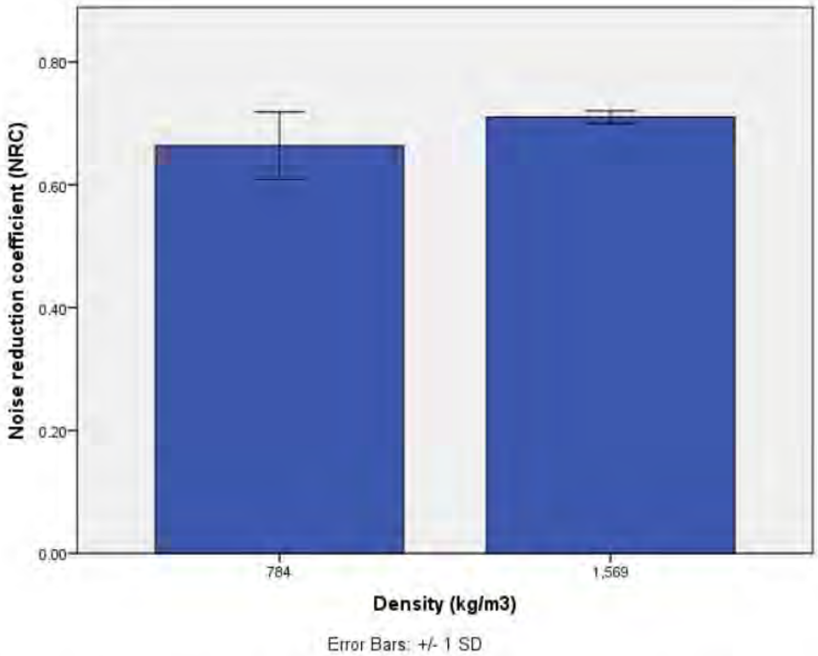

Figure 4.4 Noise reduction coefficient (NRC) of pomelo peels with different density

4.2.1 sound absorption coefficient (α)

The test samples with varying thicknesses were made at a constant density of 784 kg/m^3. The results were shown in Figure 4.1. The peak of the sound absorption coefficient is responsible for 0.94 at the frequency of 500 Hz for 2 cm thickness. All the thickness of the test samples showed similar absorption value at all frequencies and there was no correlation between the average sound absorption coefficient (α) and the thickness of the test sample with a significance level of 0.05. However, the 0.5 cm thick samples showed better absorption which accounted for 0.75 at the frequency of 2000 Hz more than others.

For the density, the test samples of pomelo peels were made in 2 densities at the constant thickness of 0.5 cm which are 784 kg/m^3 and 1569 kg/m^3. Figure 4 .3 shown the test sample with higher density provide good performance absorption and can be achieved good performance at lower frequencies (250-500 Hz). The peak of the sound absorption coefficient is responsible for 0.93 at the frequency of 250 Hz for the test samples with density of 1569 kg/m^3. However, there was no correlation between the average sound absorption coefficient (α) and the density of the test sample with a significance level of 0.05.

Another factor that affects the sound absorption coefficient value is the binder. The addition of binder is significantly increase in airflow resistivity which reduced the adsorption values. Wassilieff (1996) found the absorption coefficient from pure wood fibers without binder provided similar performance to mineral fibers which accounted for 0.9 at the high frequency.

According to the results, it can be seen strong resonance at the frequency of 1000 Hz which occurred in all of the test sample. This phenomenon is also found in the acoustic absorber from wooden parts (Berardi and Iannace 2015).

4.2.2 Noise reduction coefficient (NRC)

Table 4.1 showed that the 2 cm thickness test samples achieved good performance absorption at NRC value of 0.67±0.06. The statistical analysis showed the thickness that made the NRC difference was 1 cm and 2 cm (a significance level of

0.05). It can be observed that increasing thickness can be improved sound absorption and also noise reduction.

The results were compared with commercial sound absorber which is ½-1inch polyester urethane foam. The 2 cm thickness of sample showed similar absorption performance to polyester urethane foam with the NRC value of 0.67±0.06.

For the density as shown in Table 4.2, the test samples with density of 1569 kg/m^3 achieved good performance absorption at 0.71±0.01 but there was no statistically significant difference between variable densities with NRC (the significance level is 0.05). The results might be the excessive density of the test sample. The excessive density decreases the porosity of the sample which improves the ability for reduce sound according to tortuosity of sound propagation (Lim, Putra et al. 2018) and also increases the flow resistivity. This causes the NRC does not increase significantly when increasing the density.

The results could be demonstrated that pomelo peels fibers sound absorber can be efficient sound absorber due to the great value of NRC (>0.40) and suitable as a sound absorbing material inside the building also help improve the scenery.

4.3 Production cost of pomelo peels fibers sound absorber

The 2 cm of pomelo peels fibers sound absorber is cost about 270 Baht /1 m^2 (does not include production costs) which consists of pomelo peels waste for free, sodium hydroxide (NaOH) 50 Baht, and 2 kg of binder (TOA Latex Adhesive Glue LA-22S) 220 Baht. When compared with the commercial sound absorber, it is found that the sound absorber from pomelo peels fibers be cheaper than rock wool which cost about 600 Baht/1 m^2.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 The 2 cm thickness of pomelo peel fibers sound absorber at a constant density of 784 kg/m^3 provided the maximum absorption performance which achieved NRC at 0.67±0.06 while the 0.5 cm and 1 cm provided 0.66±0.06 and 0.57±0.03 respectively.

5.1.2 At the constant thickness of 0.5 cm with the difference density, the pomelo peel fibers sound absorber with 784 kg/m^3 and 1569 kg/m^3 provided no statistically significant difference with a significance level of 0.05 which achieved NRC at 0.66±0.06 and 0.71±0.01 respectively.

5.1.3 Increasing thickness can be improved sound absorption and also noise reduction.

5.1.4 Increasing density might be improved sound absorption. However, the excessive density does not help to improve the acoustic properties.

5.2 Recommendations

5.2.1 A binder used to mold the sample for measurement sound absorption coefficient should be material that is easy to dry and contain low water content. Due to drying time.

5.2.2 The test should be performed at multiple fibers and adhesive ratios which indicates that the sound absorption values cause from fiber or adhesive. And make the only adhesive sample for the control.

5.2.3 Other techniques can be used for easy forming and measurement such as make the materials for coating the surface.

5.2.4 Consider a larger sample size for more accurate results.

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APPENDIX A

Table A.1 Sound absorption coefficient of the test samples at the frequency of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz (thickness: 0.5cm, 1cm, and 2cm) at constant density of 784 kg/m^3

Sample		**Absorption coefficient at frequency of**				
Thickness	**no.**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
0.5 cm	1	0.85	0.81	0.27	0.69	0.45
	2	0.81	0.74	0.29	0.61	0.44
	3	0.83	0.85	0.25	0.96	0.49
1 cm	1	0.76	0.90	0.23	0.51	0.53
	2	0.69	0.91	0.24	0.45	0.77
	3	0.56	0.81	0.18	0.60	0.86
2 cm	1	0.91	0.92	0.40	0.47	0.80
	2	0.87	0.95	0.36	0.49	0.73
	3	0.92	0.94	0.36	0.50	0.68

Table A.2 Sound absorption coefficient of the test samples with the varying densities (784 kg/m^3 and 1569 kg/m^3) at the frequency of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz and constant thickness of 0.5 cm.

Sample (0.5 cm thick)		**Absorption coefficient at frequency of**				
Density	**no.**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
784 kg/m^3	1	0.85	0.81	0.27	0.69	0.45
	2	0.81	0.74	0.29	0.61	0.44
	3	0.83	0.85	0.25	0.96	0.49
1569 kg/m^3	1	0.96	0.85	0.33	0.67	0.56
	2	0.92	0.89	0.40	0.69	0.64
	3	0.91	0.85	0.43	0.65	0.55

APPENDIX B

Table B.1 The relationship between the average sound absorption coefficient (α) and the thickness of the test sample.

Correlations		**Thickness**	**Sound absorption coefficient (α)**
Thickness	Pearson Correlation	1	.129
	Sig. (2-tailed)		.398
	N	45	45
Sound absorption coefficient (α)	Pearson Correlation	.129	1
	Sig. (2-tailed)	.398	
	N	45	45

*The significance level is 0.05.

Table B.2 The relationship between the average sound absorption coefficient (α) and the density of the test sample.

Correlations		**Density**	**Sound absorption coefficient (α)**
Density	Pearson Correlation	1	.145
	Sig. (2-tailed)		.444
	N	30	30
Sound absorption coefficient (α)	Pearson Correlation	.145	1
	Sig. (2-tailed)	.444	
	N	30	30

*The significance level is 0.05

Table B.3 The differentiation of variable thicknesses with noise reduction coefficient (NRC) by one-way ANOVA.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.020	2	.010	7.002	.027
Within Groups	.009	6	.001		
Total	.028	8			

*The significance level is 0.05

Table B.4 Multiple Comparisons of variable thicknesses with noise reduction coefficient (NRC) by one-way ANOVA.

Tukey HSD		Mean Difference	Std. Error	Sig.	95% Confidence Interval	
Thickness	**Thickness**				**Lower Bound**	**Upper Bound**
0.50 cm	1.00 cm	.09444	.03079	.050	.0000	.1889
	2.00 cm	-.00996	.03079	.944	-.1044	.0845
1.00 cm	0.50 cm	-.09444	.03079	.050	-.1889	.0000
	2.00 cm	-.10441*	.03079	.034	-.1989	-.0099
2.00 cm	0.50 cm	.00996	.03079	.944	-.0845	.1044
	1.00 cm	.10441*	.03079	.034	.0099	.1989

* The mean difference is significant at the 0.05 level.

Table B.5 The differentiation of variable densities with noise reduction coefficient (NRC) by independent-Samples t-test.

	Density	N	Mean	Std. Deviation	t	Sig.
NRC	784 kg/m^3	3	.6633	.05508	-1.444	.222
	1569 kg/m^3	3	.7100	.01000	-1.444	.278

*The significance level is 0.05

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