https://doi.org/10.48048/tis.2022.4498

Banana Fibers as a Sustainable Acoustic Absorbing Materials: A Review

Pruktivud Chattaviriya[1], Dusanee Supawantanakul[1], Ratsamee Sangsirimongkolying[2] and Gritsada Sua-Iam[3,*]

[1]Technology Management Program, Faculty of Industrial Technology, Phranakhon Rajabhat University, Bangkok 10220, Thailand
[2]Division of Chemistry, Faculty of Science and Technology, Phranakhon Rajabhat University, Bangkok 10220, Thailand
[3]Department of Civil Engineering, Faculty of Engineering, Rajamangala University of Technology Phra Nakhon, Bangkok 10800, Thailand

([*]Corresponding author's e-mail: gritsada.s@rmutp.ac.th)

Received: 23 June 2020, Revised: 12 July 2021, Accepted: 23 July 2021

Abstract

This paper presents an investigation reviewed on various research topics of the natural fibers in worldwide and Thailand. Practically, the traditional synthetic fibers for noise absorbed purpose are human and environmental harmful, thus the natural fibers might be the alternative way for consumers. The characteristics of natural fibers commonly are lightweight, high strength, but less pollution and low cost. Furthermore, the agriculture wastes would be value-added and reduced on the particulate matters (PM) 2.5 communities' nuisance from the incineration affecting human health, environment and global warning in advance. In the present, the traditional materials using for noise absorbent are derived from synthetic fibers such as asbestos and fibers glass, mostly 20 - 45 % of asbestos fibers that World Health Organization (WHO) mentioned the hazard of asbestosis regarding on lung cancer, pleurisy lung cancer and ovarian cancer about 107,000 people per year. In general, the natural fibers are classified on 3 configurations: Cellular, fibrous and granular types which are their different properties on noise reduction. Also, this review particularly presents a sound absorption coefficient (SAC) that relates to the main importance factors (for example of physical, chemical, mechanical, etc.) including an analysis of the potential chances to utilize on the sustainability of these green natural materials, especially banana fibers in Thailand.

Keywords: Natural fibers, Banana fibers, Sustainable materials, Noise reduction, Sound absorption coefficient

Introduction

In Thailand, the high quantity of agricultural wastes (for example 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.) was available on every regions [1]. These agriculture wastes would be value-added and reduced on the particulate matters (PM) 2.5 communities' nuisance [2] from the incineration affecting human health and the environment. In fact, sound level of 90 dBA or above is harmful to the whole human hearing. Practically, the sound path control is a sound reducing method, by blocking of sound from one side to the other. In the present, a sound reducing medium or sound absorber, which is taken from the "sound absorbing material" that has the ability to reduce the sound energy due to fictional loss [3]. In present, many natural materials from waste are going to study widely on sound absorbing material, particularly apply in the field of building and construction as the alternatives to the traditional materials (i.e., fiberglass, asbestos, etc.) that WHO mentioned the hazard of asbestosis on lung cancer, pleurisy lung cancer and ovarian cancer about 107,000 people per year [4]. Furthermore, Europe, America and Asia regions also found global mesothelioma deaths that were reported by the WHO [5]. In general, the natural materials could be divided into 2 main categories: Natural materials as cotton, hemp, sheep wool, flax, clay, etc. and recycling materials as rubber, cellulose, organic plastic materials, etc. Most of the life cycle assessment (LCA) are also available and these natural fibers composites appeared to be cheaper, lighter and environmentally superior to glass fibers composites [6]. The measurements carried the samples of natural fibers and then showed similarly to traditional porous materials as the good sound absorption coefficients, especially at medium and high frequencies [7]. For mechanical properties of natural fibers composites (NFC) compared with glass fibers reinforce plastic (GFRP) showed obviously on NFC was better than GFRP in terms of stiffness and material cost, but values of tensile and impact strength less than GFRP [8]. In comparison to traditional absorbents, these new natural materials are safer and lighter and more efficient technology. The important points of these natural materials are environmental friendly, degradable, recyclable, and greenly produced on noise absorbents and these characteristics will have a great role in the market of noise absorbents soonest. To properly use these natural materials, in addition to knowledge on the benefits and suitability of absorbers for using in the intended environment, the effective factors in sound absorption such as fibers size, airflow resistance, porosity, curve, thickness, and density of absorbers were considered [9]. In this paper, an attempt has reviewed the three configurations of natural fibers, the properties of physical, chemical, and mechanical including SAC, thermal resistance, and related factors against synthetic fibers, especially banana fibers which can be available in Thailand.

Materials and methods

Acoustic absorbing material

The principle and control the sound

The sound propagation, which is a longitudinal wave normally move in the same direction as the shaking of the particles. When compressed and expanded waves reach to the human ear, such sound is heard. Generally, the phenomenon of the sound is revealed on reflection, absorption, and transmission are shown in **Figure 1** [10].

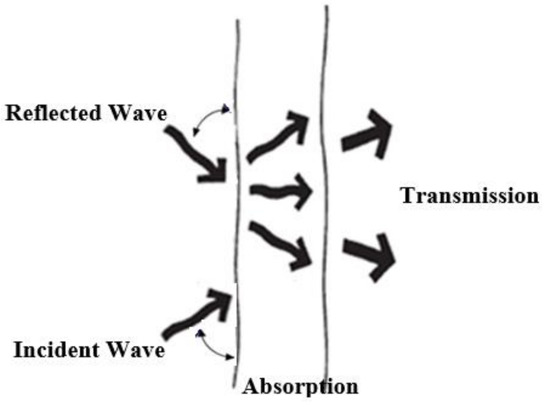


Figure 1 The phenomenon of the sound [10].

The sound, when falling on the surface of an object, is reflected, and then these sound waves transmitted through such an object causing a decrease in its energy. Absorption is the reduction of energy derived from vibrations that are converted into heat energy due to the friction properties of the object, particularly this phenomenon will occur on its channel or porous object. The phenomenon of transmission is caused by the energy of sound waves that hit an object. Part of the sound barrier is applied to reduce the vibration, called a value of transmission loss [3]. Therefore, the study of sound principles into the direction and nature of the sound, which is the source of the sound, can determine the way to control the sound. In general, the guidelines for noise pollution control implied that are: 1) Controlling at the noise source, which has many guidelines such as the separation of vibrated processes, noise sources relocation, sound reducer, or filter installation, etc [11]. This method can be applied on noise source owners to eliminate or reduce these noise, however, locations changing or buying on devices are needed high budget for improvement, and one of difficult implementation while the working or operations are running, 2) Controlling at the noise receiver by using personal protective equipment according to international standards (such as ISO4869-1) [12], ANSI S3.19 [13], ANSI S12.6 [14] or Thailand standard (such as TIS. 2575-2012) [15], can reduce the noise by 10 - 20 dBA, using on earplugs and by 20 to 40 dBA, using on-ear mugs. But the behavior of users needs the compromised ways to create their attitude and awareness of the noise dangers and the personal protective equipment usage and 3) Controlling at noise path, which is a noise-reducing method, by blocking sound from one side to the other side. Practically, a sound reduction medium or "sound absorber", which is taken from the "sound-absorbing material" that has enough ability to reduce the sound energy due to frictional loss [16].

Type of acoustic absorbing material

In general, sound-absorbing material can absorb sound waves by characteristics of fibers and perforated material, the ability of good sound absorber during 250 - 8,000 Hz of sound frequency, are classified on 3 types [10] as following on

1) Porous or dissipative absorber: Which sounds move through a wall inside its porous gap, can reduce the sound energy due to the friction loss. Usually, these porous materials are synthetic fibers such as glass fibers, asbestos, etc. and natural fibers, which come from agricultural fields, such as coconut coir, risk husk, sugar cane leaves, etc. Many research revealed these factors affecting on the good sound-absorbing ability that 1) Size of fibers showed less diameter and more surface area [17], 2) Rough fibers had an influence on airflow resistance as cause of its friction [18], 3) Porosity of fibers increased with the shape, size, and several holes [19], 4) Tortuosity, a measure of the path of the sound along the entire length of the pore comparing with the thickness of the absorber, was used to describe the influence of porous sound-absorbing material at high frequencies [20], 5) Thickness had high impact on the porous material at low frequency, but had less impact at high frequency [21], 6) Compression of fibers was good resulting in sound absorption due to the reduction of the tortuosity and flow resistance [22], 7) Surface impedance was the sound barrier or surface resistance as decreasing on the SAC [19], 8) Placement or position of sound absorber at the room corner surface was able to increase the SAC [23], and 9) The lower density was good sound absorption at low-frequency range (at 500 Hz), while the higher density was good sound absorption at high-frequency range (at 2,000 Hz) [24].

2) Membrane absorber: Such as plywood, plastic, paper, etc., the vibration characteristic of these membrane materials were found the same frequency as the length of the sound wave, can be applied appropriately at low frequency due to their flexibility [10].

3) Resonator or cavity absorber: Such as concrete and others, these sound-absorbing materials were classified as a resonator or often called as "Helmholtz Resonant". Normally, these materials have many cavities which comprised of the very small size of diameter, when compared with the length of sound waves (known as resonators), only the narrow frequency range was applied for application [10]. In the study, the relationship of SAC with each type of sound-absorbing materials are shown in **Figure 2** and it is found that the porous or dissipative absorber is good sound absorber in medium and high sound frequency complying on the explanation of sound when passing into the porous wall as result of the sound energy reduction due to its friction loss [10].

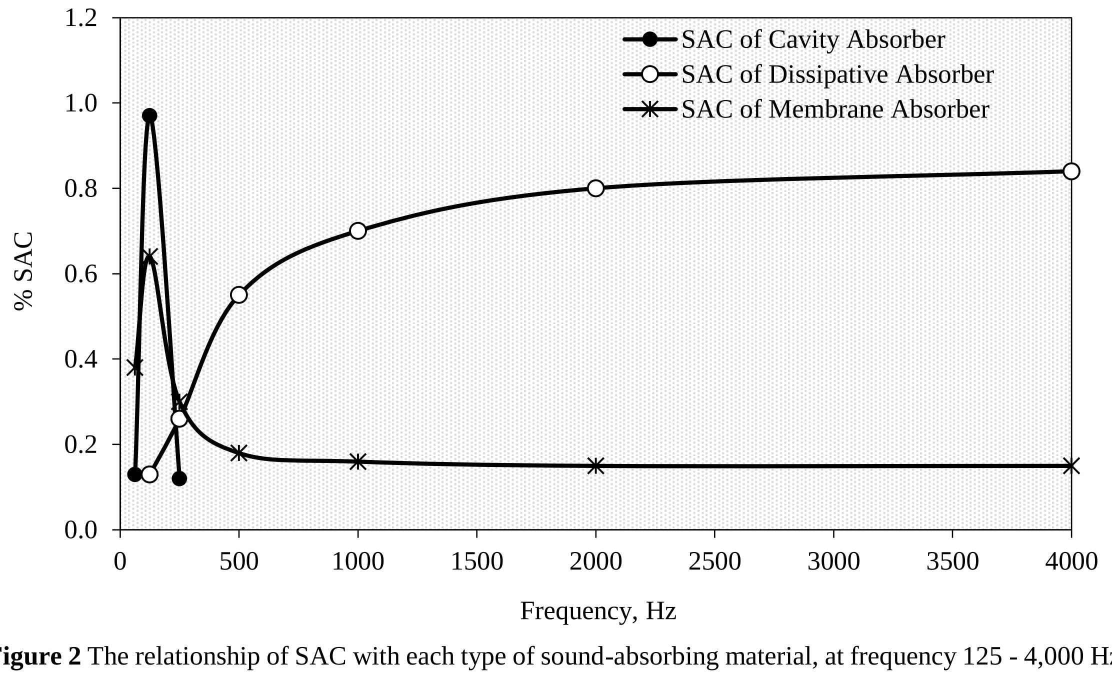


Figure 2 The relationship of SAC with each type of sound-absorbing material, at frequency 125 - 4,000 Hz [10].

The natural fibers

Various research has shown many natural fibers used for noise control as the alternative to the traditional ones (for example of asbestos and fiberglass) that NFC appear to be cheaper, lighter, and environmentally friendly superior to glass fibers composites [6]. The natural fibers are produced by plants, animals and geological processes. This paper particularly focuses on the plant natural fibers or the other name as "cellulose fibers". These plant natural fibers derived from seed, leaf, bark, fruit and stalk. The plant natural fibers as a carbohydrate comprised cellulose that was reacted by chemical bonding and the molecular formula $(C_6H_{10}O_5)_n$ is shown in **Figure 3**.

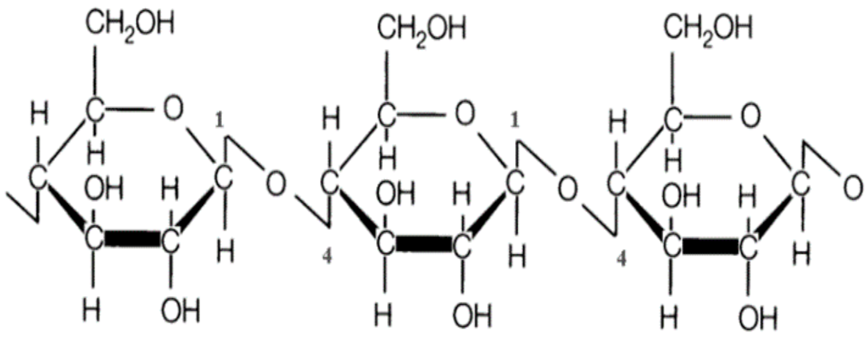


Figure 3 The structural of cellulose fibers [25].

The structure of cellulose is linked by many molecules clinging together within a long chain called "cellobiose" as the results of the higher toughness. Also, these chains of cellulose affect the strength within natural fibers, furthermore, lignin combines with hemicellulose as the result of their strength within natural fibers as well. The higher strength was influenced by the small size and high density [16] of fibers. **Figure 4** shows the arrangement of micron-sized fibers and cellulose in cell walls that can explain the strength of plant fibers [26].

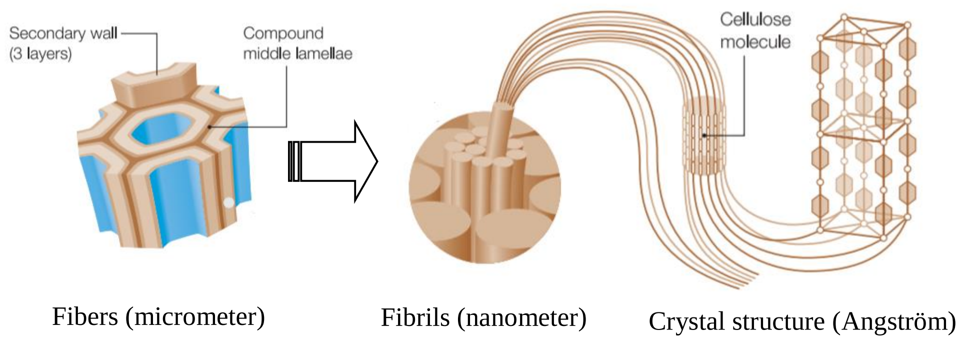
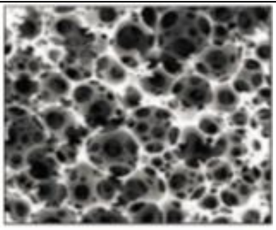
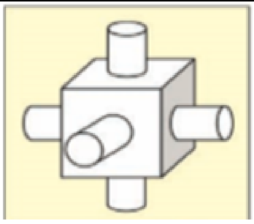
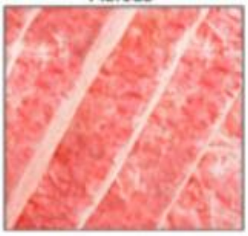
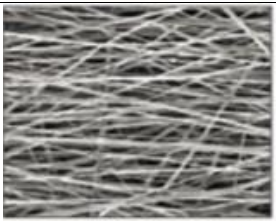
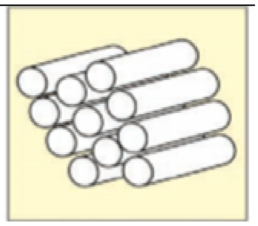
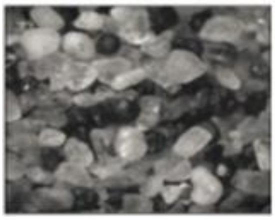
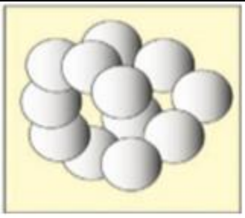


Figure 4 The arrangement of micron-sized fibers and cellulose in the cell wall of plant fibers [26].

In recent years, the natural fibers can be classified on 3 configurations; cellular type (example of organic polyester material, etc.), fibrous type (examples of wool, cane, hemp, etc.) and granular type (examples of cork, clay, sand, etc.). Each natural fibers type is demonstrated on the visual appearance, structural and molecular shape, are shown in **Table 1**.

Table 1 Three configurations of natural fibers [9].

Type	Configuration	Appearance by Visual	Structural by SEM	Molecular Shape
Cellular	Cubic cell with connecting pores			
Fibrous	Parallel fibers bundles			
Granular	Stacked spheres			

The configuration of cellular type appears in a cubic cell with connecting pores, the fibrous type has characteristics on parallel fibers bundles and granular type observes as stacked spheres. To illustrate on their absorbing mechanisms, when the cellular, fibrous and granular types of materials are exposed to incident sound waves, the air molecules at the surface of the material and within the rigid porous of fibers are forced to vibrate as a result of their loosen original energy. This is because part of the energy of the air molecules is converted into heat due to thermal and viscous losses at the walls of the interior pores and space within the fibers.

The mechanical properties are the important characteristic to discuss on the natural fibers. These investigation were shown in **Table 2** between the natural fibers (jute, hemp, wool, cotton, silk, flax and coir) with the synthetic fibers (fiberglass). Their comparison on tensile strength parameter are found that the synthetic fiber were stronger than the natural fibers, however, the properties of failure strain and stiffness/young’s modulus can be equivalent, especially on the fibrous type of fibers (wool, hemp, coir, etc.) [8].

Table 2 Mechanical properties of natural fibers and synthetic fiber [8].

Type of fibers	Failure strain (%)	Tensile strength (MPa)	Stiffness/Young’s modulus (GPa)
Jute	1.5 - 1.8	393 - 800	10 - 55
Hemp	1.6	550 - 1,110	58 - 70
Wool	13.2 - 35	50 - 315	2.3 - 5
Cotton	3.0 - 10	287 - 800	5.5 - 13
Silk	15 - 60	100 - 1,500	5 - 25
Flax	1.2 - 3.2	345 - 1,830	27 - 80
Coir	15 - 30	131 - 220	4 - 6
Fiberglass	2.5	2,000 - 3,000	70

Many studies also examined the physical properties (fibers size and density) and the chemical properties (cellulose and lignin) of natural fibers are shown in **Table 3**. The diameter of synthetic fibers was smaller than the natural fibers, except rice straw. Besides, the composition of cellulose and lignin within natural fibers (for examples of Jute and Hemp related on **Table 2**) can influence the Tensile strength and stiffness/young's modulus values in which these characteristics can apply in structural works, building, walls and others.

Table 3 The physical, chemical and mechanical properties of natural and synthetic fiber [8,26-28].

Type of Fibers	Physical Properties			Chemical Properties	
	Length (mm)	Diameter (mm)	Density (kg/m^3)	Cellulose (%)	Lignin (%)
Sisal	1,200 - 1,500	0.15 - 0.26	1,400	43 - 62	7 - 9
Kenaf	0.6 - 6.0	0.014 - 0.04	1,500	64	11 - 21
Jute	2 - 5	0.01 - 0.025	1,460	45 - 63	21 - 26
Hemp	22.0 - 30.2	0.01 - 0.05	1,480	57 - 77	8 - 10
Bamboo	1.5 - 4.4	0.088 - 0.125	610 - 870	35 - 47	22 - 30
Rice Straw	04. - 3.4	0.005 - 0.03	26 - 46	12 - 16	1,500
Sugar Cane Bagasse	0.8 - 10	0.01 - 0.4	26 - 39	19 - 22	500 - 600
Oil Palm Sludge	20 - 100	0.2 - 0.8	59.6	28.5	1,300 - 1,450
Fiberglass	-	0.006 - 0.013	-	-	-

In addition, thermal properties of natural fibers were demonstrated on **Table 4** that can be implied as good heat insulation similar to synthetic fibers.

Table 4 The thermal properties of natural fibers and synthetic fibers [6].

Type of Fibers	Hemp	Kenaf	Wood wool	Cork	Polyester	Fiberglass	Rock wool
Thermal Conductivity, λ (W/mK)	0.04	0.044	0.065	0.039	0.031	0.04	0.045

Noise Reduction Coefficient (NRC)

NRC is the arithmetic mean of SAC at frequencies 250, 500, 1,000, 2,000 and 4,000 Hz, indicating the ability of sound absorption on the surface of the material according to the equation [11].

$$NRC = (\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000} + \alpha_{4000})/5 \quad (1)$$

When

NRC Noise Reduction Coefficient

α Sound absorption coefficient

There are many measuring techniques for the sound absorption properties, for example of reverberation chamber method, impedance tube method, and tone-burst method that each method has limitations of strength and weakness are shown in **Table 5**. The reverberant chamber method is concerned with the performance of a material exposed to a randomly incident sound waveform all directions, this SAC was observed and called as "random incidence SAC", furthermore this method requires costly for a large reverberation chamber. In general, the impedance tube method was called "normal incidence SAC" because the incident sound wave strikes directly on the material within the tube [29].

Table 5 The comparison of the methods for testing the SAC.

Testing methods	Objective	Strength	Weakness	Reference
Reverberation Chamber Method	High accuracy of testing result	Precisely in architectural design	Need testing area, amount of samples and long testing duration	ASTM C-423-09a [30]
Impedance Tube Method	Need for primary material testing	Quick and accuracy	Only in normal (perpendicular angle)	ASTM C384-90a [31] ASTM E1050-90 [32] ISO10534-2 [33]
Tone-Burst Method	Testing need to find out various reflection angle	The good reflection angle adjusting	Need testing area, amount of samples and long testing duration	ISO354 [34]

In comparing sound-absorbing materials on the noise control, the impedance tube method by using the Kundt's tube equipment in **Figure 5** can determine on NRC at frequency range 125 - 4,000 Hz which highly confided on the material characteristics its absorbed incident sound. It was noted that the impedance tube method corresponding to the frequency of 125 - 4,000 Hz was commonly reliable and flexible measurement by Kundt's Tube [35]. Besides, the value of NCR between 0.4 - 1.0 was indicated on the high ability of noise absorption [36].

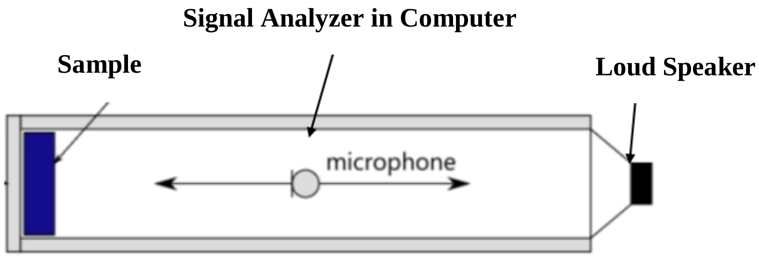


Figure 5 The Kundt's tube [35].

Many studies are searching on the characteristics and properties of the natural fibers, especially noise absorption at various frequencies. In the previous research, the performance of each natural type of fibers, especially on the fibrous plant (for examples of hemp and kenaf) would be applied to noise absorption at a human hearing frequency as shown in **Table 6**. Other factors also were studied effecting on NRC that are density, thickness, and flow resistance, the fibrous type was influenced by the NRC.

Table 6 The NRC and other parameters of plant fibers against the traditional fibers [6,7,27].

Type of natural fibers	Cellular (Jute)	Fibrous (Hemp)	Fibrous (Kenaf)	Granular (Cork)	Glass wool	Rock wool
Fibers Diameter, (μ)	20	22	21	-	6 - 13	3 - 10
Thickness (m)	-	0.03	0.06	0.03	-	-
Density (kg/m^3)	-	50	50	100	-	-
NRC, 500 Hz	0.5	0.21	0.31	0.02	0.41	0.46
NRC, 1,000 Hz	-	0.47	0.67	0.21	0.50	0.81
NRC, 1,600 Hz	-	0.67	0.84	0.91	0.80	0.90
NRC, 2,000 Hz	-	0.75	0.87	0.78	0.90	0.91
Flow Resistance (Rayl/m)	-	1,400 ± 170	2,700 ± 290	1,000 ± 150	-	-

There are quite a numbering of research relate to the sound absorption deriving from tropical plants, the value of NRC was indicated at the high level of noise absorption, especially the frequency of human hearings (1,000 - 2,000 Hz) as shown in **Figure 6**. This NRC investigation exposed on 3 of natural materials (bamboo, cannabis and coconut fibers) at 1,000 Hz more than 0.6. By the way, these fibers were disclosed on NRC value more than 0.7 at 1,000 Hz, consequently. However, rice straw is commonly found in Thailand regions, still was indicated at the low level of noise absorption, thus this kind of natural material need to be investigated for noise reducing advantage in advance.

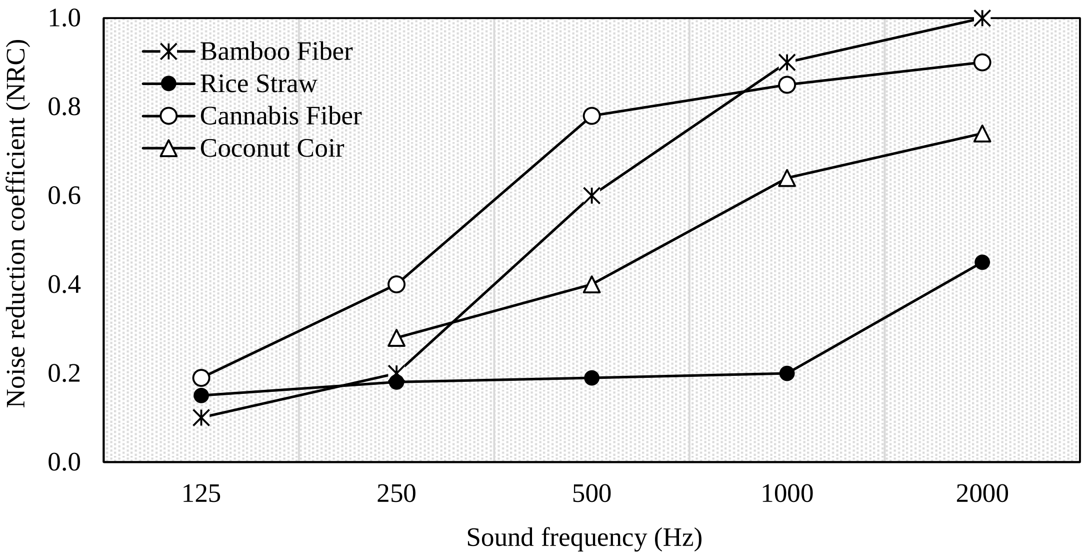


Figure 6 The NRC of natural materials [6,9].

As shown in **Table 7**, each fibers were described on their key points of the acoustic absorbing ability, especially fibrous type.

Table 7 The highlight of the acoustic absorption of each natural fibers [37].

No.	Fibers	A highlight of the acoustic absorption of each natural fibers
1	Bamboo	Bamboo fiber has good absorption properties
2	Coconut	The sound absorption coefficient of polyester/coconut fiber composite increases with an increased amount of coconut
3	Sugar cane bagasse	Sound absorption coefficient is mostly influenced by the resin type
4	Palm	Sound absorption coefficient increases with the increase of the flow resistivity and frequency
5	Cotton and cellulose	Natural fiber in thermoplastic could decrease density and increase sound absorption
6	Tea-leaf fibers felts	Tea-leaf fiber exhibits better sound absorption than polyester and polypropylene nonwovens

The banana fibers

Sources in Thailand

Bananas are one of the most widely cultivated crops in Thailand. In 2015, there were 547,055 Rai of banana plantations and 782 million tons of products including total exports of 35,266 tons [38]. Bananas are in the Musaceae family and the scientific name is Musa Sapientum L Banana stalks [39] are found in the ground, called Rhizome, in which as the bud and develop as suckers. The banana stem comes from compression of leaf sheath caused by the growth point of the underground trunk. And this growth point will develop into a flower until it becomes leaf [40], as shown in **Figure 7**. Thailand is a wide variety of banana genes, so there are wild bananas and bananas grown in general, more than 50 edible species [38], and most of the banana is consumed domestically with exports of 3 common bananas: Cultivated, Pisang mas and cavendish in Thailand [41].

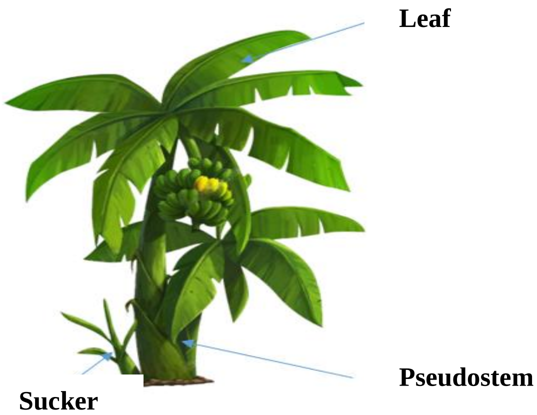


Figure 7 The characteristics of the banana tree [40].

Structural images of banana fibers

When using the general microscope to see longitudinal images of banana fibers (came from pseudostem), these banana fibers are comprised of bubbles which are common throughout the stem of banana as shown in **Figure 8**. Normally, these banana fibers composed of a set of continuous filaments and air passageways, where sound energy strikes these fibers caused to lose their energy due to frictions.

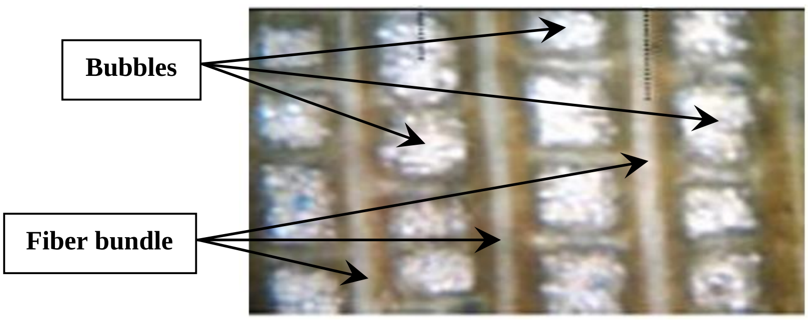


Figure 8 Longitudinal images of banana fibers which came from pseudostem [42].

When using a Scanning Electron Microscope (SEM) that was 100 times magnified, it can be seen as a long line in which this fibrous configuration comprises of many cavity or porosity of fibers within parallel fibers bundle as shown in **Figure 9**(**a**). Furthermore, the characteristic of banana fibers surface was coated with cellulose and lignin at 350 times magnified as shown in **Figure 9**(**b**) similar to the research study of separating banana fibers to enhance agricultural waste [43].

(a) (b)

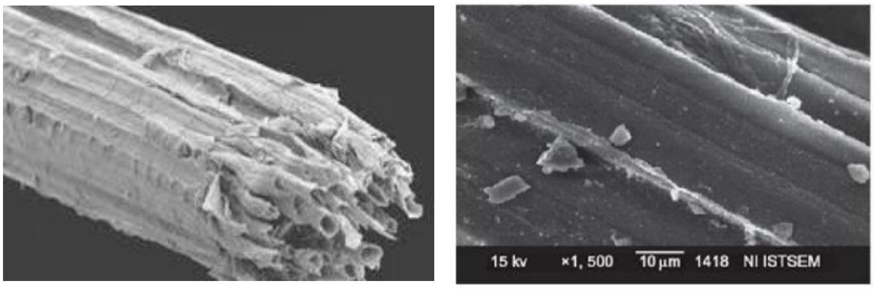


Figure 9 SEM micrographs of banana fiber morphology: (a) The porous banana fibers at 1,000× [42] and (b) Fibrous configuration of banana fibers at 1,500× [43].

Properties of banana fibers

The physical, chemical and mechanical properties of banana fibers as fibrous type were studied and found these properties were equivalent with others natural fibers (such as sisal and kenaf), which the size of its fibers showed on the less diameter as result in the higher SAC [24], however fiberglass has less diameter and higher tensile strength than banana fiber are shown in **Table 8**.

Table 8 The banana fibers properties: Physical, chemical and mechanical [28].

Type of Natural Fibers	Physical Properties			Chemical Properties		Mechanical Properties
	Length (mm)	Diameter (mm)	Density (kg/m^3)	Cellulose (%)	Lignin (%)	Tensile Strength (MPa)
Banana Fibers	5 - 3,000	0.15 - 0.26	1,500	56 - 63	15	550
Fiberglass	-	0.006 - 0.013	-	-	-	2,000 - 3,000

According to physical, chemical and mechanical properties of banana fibers including the content of cellulose and lignin (for examples of nature fibers: Jute and hemp related on **Table 2**) can influence the tensile strength values in which these characteristics can apply in structural works, building, walls and others. Also, **Table 9** illustrated on banana toughness value in term of bundle strength and deforming value in term of elongation, especially on the type of cultivated banana.

Table 9 The banana fibers properties: Bundle strength and elongation [44].

Type of Banana	Bundle Strength (kg/g)	Elongation (%)
Pisang mas banana	1,350.8	12.97
Cultivated banana	1,418.8	21.26
Cavendish banana	1,037.1	13.41

For a value of noise reduction coefficient and bending strength were observed on the development of banana fibers reinforced paper pulp bio-composites and are shown in **Table 10**, at frequency ranges between 250 and 4,000 Hz with the average value of 0.55. Previously, the study of concrete block mixed with banana fibers that were replaced cement in 25 % by weight has the density, compressive strength and water absorption is 1,376 kg/m^3, 62.25 kg/cm^2 and 32.86 %, respectively [42].

Table 10 The banana fibers properties: NRC and bending strength [45].

Sample cut length (cm)	Fibers volume fraction	Thickness (cm)	Noise Reduction Coefficient (NRC)	Bending strength (MPa)	Bulk Density (kg/m^3)
3.5	0.20	6.0	0.55	0.685	154

Application of banana fibers in sustainable material

A variety of natural fibers for building applications are commercial in the present because of the characteristics of their low density, good mechanical properties, easy processing, occupational health benefits, high quantity availability, low price and reduced environmental impacts for their production. Particularly, the sound-absorbing material is effective in reducing noise levels within the space by converting sound waves into heat [16]. Most of the available sound-absorbing materials are fibrous materials. The role of natural fibers (for example of rice straw, sisal, banana fibers, etc.) are sustainable materials and environmentally friendly technologies for their recycling become a great concern for material development. Indeed, as an acoustical panel applied for interior finishes, the performance involving durability as exposed to typical environmental conditions, water and temperature, are important of considerations. Hence, the construction industry using a combination of natural fibers with main direct materials in many building components such as roof, wall, panels, and others are beneficial applications. Therefore, once the use of these natural materials (for example of coconut coir, banana fibers and others) increases, the manufacturing costs will be reduced and then these natural fibers will become a more available alternative to synthetic materials, which cause of energy and resources depletion. The end of life disposal strategies and environmental friendly technologies for their recycling become a great concern for natural material development. Recently, active noise absorption and passive control have been used for the development of hybrid sound absorbers [46]. Active control technologies have been developed as the only method for noise reduction in low frequencies. Therefore, a hybrid active/non-active absorber can absorb the noise in a wider frequency range. The basis of work of these absorbers is a device with layers of porous material with passive absorbing characteristics combined with an intensifying layer for active control, which can be controlled by using digital techniques. In the previous research [47], the compound material provided the possibility of high noise absorption in high and average frequencies which was among the characteristics of passive melamine foam. Although noise absorption in low frequencies is created by active classic elimination mechanisms, efficient improvement of noise absorption characteristics has been performed by element finite 3-D techniques. Thereby, it is possible to produce an efficient noise absorbent that is thin and light-weighted. A previous investigation by Tholkappiyan *et al*. [45] confirmed that banana fibers are applied to the composite material component. This composite was made from paper pulp bio-composites, banana fibers demonstrated good bending strength. Furthermore, single banana fibers have moderate tensile strength [28] that almost similar to jute and hemp fibers [8]. Owing to its mechanical and physical properties, banana fibers are flexible to be used in broadly engineering applications. Regarding features offered, banana fibers are appropriate for an alternative engineering material, with a focus on minimizing the use of local materials and resources, recycling of wastes, maximum use of local skills, and environmental prevention and energy conservation.

Challenge of banana insulation fibers

To meet living environment requirements and increasing social perception, the natural material might be greater chances. Thus, the continued development of technologies is forced to support these needs. In previous studies, there were many ways in which natural materials can utilize in modern construction. Normally, fibers plants are often subject to fungi and parasites and are less resistant to fire than typical mineral fibers; furthermore, they often need special fibers preparations before being used [28], which reduces the inherent sustainability of the raw materials. Also, these natural fibers are often commercialized in cement panels and blocks by using some binders. These considerations suggest the environmental impacts of all the products used during the entire process of transformation of the natural fibers into building materials. In previous banana fibers research, the important key properties of physical, and mechanical implied on these porous fibers have shown on their characteristics equivalent with other natural fibers (such as sisal and kenaf) [24] including tensile strength [28]. Particularly, the chemical properties of the content of cellulose and lignin [28] might be reinforced on anti-microorganism without surface treatments. Thus, the role of acoustic material such as room acoustics, industrial noise control, interior lining in automotive, building, enclosure, ducts, aircraft, etc. is the interesting expected study in advance, especially the special characteristics of thermal resistance, moisture resistance, extended weather ability and increased durability.

These attractive features of banana fibers are low cost, strong and durable in any typical environment condition such as wet, temperature. Therefore, banana fibers could be the potential opportunity for consumers to increase insulated compatibility with the main direct materials.

Discussion

When a sound wave impinges the surface of the absorbing material, some sound waves would be in motion within this material. The motion of the sound wave causes the fibers on vibration. The fiber's vibrations allow air to flow in the gap between fibers and particles. The air motions through narrow constrictions cause some energy loss [16]. The losses of sound energy indicate some sound energy is absorbed within material through the dissipation process. In the previous study [19], the porous or dissipative absorber is a great sound absorber in medium and high sound frequency complying on the explanation of sound when passing into the porous wall as a result of the sound energy reduction due to its friction loss. Many research revealed the important factors affecting sound-absorbing ability that were 1) Size of the fibers showed the less diameter and more surface area as a result of the higher SAC [17], 2) Airflow resistance of fibers that were very rough effecting on airflow resistance higher due to an increase of its friction [18], 3) Porosity of materials consist frictional drag; thereby the sound energy propagated is converted to heat. Porous materials are excellent in sound absorption and good heat insulator. Its open pores allow restricted airflow through the material thus absorbing sound and also preventing efficient heat exchange [19], 4) Tortuosity is a measure of the "non-straightness" of the pore structure of the porous material. Therefore, it was used to describe on the influence of porous sound-absorbing material at high frequencies [20], 5) thickness effected on the porous material at low frequency, but less impact at high frequency [21], 6) Compression of fibers was good resulting in sound absorption due to the reduction of the tortuosity and flow resistance [22], 7) Surface impedance was the sound barrier or surface resistance as decreasing on the SAC [19], 8) Placement or position of sound absorber at the room corner surface was able to increase on the SAC [23], 9) Density as one of the important factors when dealing with the sound absorption behavior of the material that the lower density was good sound absorption at low-frequency range (at 500 Hz), while the higher density was good sound absorption at high-frequency range (at 2,000 Hz) [24]. As a result of micron-sized fibers and cellulose in cell walls that can also practically explain the strength of plant fibers [26]. Furthermore, it is demonstrated that natural fibers in the type of cellulose, fibrous, and granular were selected to study the physical, chemical and mechanical properties including cellulose and lignin amount [9]. Pickring *et al.* [8] found the diameter of synthetic fibers mostly was smaller than the natural fibers, furthermore, the composition of cellulose and lignin within natural fibers can influence on the ductility and elongation values [28]. Comparing the natural fibers and the synthetic fibers on tensile strength property [8] was found the synthetic fibers stronger than the natural fibers, however, the valve of failure strain and stiffness/young's modulus can be equivalent, especially on the fibrous type of fibers (for examples of wool, hemp, coir, etc.) including thermal properties of the natural fibers too [6]. The testing to determine the coefficient of noise reduction (NRC) by using the acoustic material testing according to the ISO10534-2 international standard at the frequency between 125 - 2,000 Hz, were found especially the natural fibers in a straight line such as kenaf fibers were good absorber [6, 27]. Banana is a native fruit to South Asia and Southeast Asia, banana fibers were investigated by SEM as a long line in which this fibrous configuration comprised of many cavity or porosity within parallel fibers bundle and was coated with cellulose and lignin [42-43]. According to the physical, chemical and mechanical properties of banana fibers including the content of cellulose and lignin that can influence on the ductility and elongation values, especially on the cultivated banana type [44]. For the value of NRC and bending strength were observed on the development of banana fibers reinforced paper pulp bio-composites at frequency ranges between 250 and 4,000 Hz with the average value of 0.55 [45]. The results of the absorbing material are depending on its variable parameter which is potentially influencing the result. However, to determine the effectiveness of each material, it needs to complete its characterization and an experiment to evaluate their sustainability.

Conclusions

This study provided a comprehensive review of banana fibers as a sustainable acoustic absorbing material. The natural sustainable materials, made from by-product materials, are quite a valid alternative to traditional synthetic materials. Many fibrous materials (for example of rice straw, coconut coir, banana fibers, etc.) have shown the good sound-absorbing performances and heat insulation as well. These materials are also lightweight and are not harmful to human health and environmental impacts. The other criteria (for example of porosity, flow resistance, etc.) need to be studied and confirmed using these newly developed natural materials. In this paper, the alternative absorber by natural fibers is an interesting approach for our living and is involved to prevent natural depletion, environmental pollution and sustainable material in nearly future.

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