การพัฒนาแผ่นดูดซับเสียงที่ได้จากเส้นใยกาบกล้วย
The Development of Sound Absorber from Banana Fiber

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บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อพัฒนาแผ่นดูดซับเสียงที่ได้จากเส้นใยธรรมชาติ (เส้นใยกาบกล้วยน้ำว้า) ใช้แทนเส้นใยสังเคราะห์ (เส้นใยหินและเส้นใยแก้ว) แผ่นดูดซับเสียงนี้ถูกนำมาทดสอบหาค่าสัมประสิทธิ์การดูดซับเสียง และค่าสัมประสิทธิ์การลดเสียง โดยกำหนดปัจจัยที่นำมาศึกษาคือ (1) ความยาวเส้นใยกาบกล้วย ขนาด 0.6, 5.0 และ 10.0 มิลลิเมตร (2) อัตราส่วนของใยกาบกล้วยต่อยิปซัม 1 : 9, 2 : 8 และ 3 : 7 โดยมวล ที่ความหนาแผ่นดูดซับเสียง 25.0 มิลลิเมตร การทดสอบเพื่อหาค่าสัมประสิทธิ์การดูดซับเสียง และค่าสัมประสิทธิ์การลดเสียง จะใช้เครื่องมือ Impedance Tube ตามมาตรฐาน ISO 10534-2 ที่ช่วงความถี่ระหว่าง 250-4,000 เฮิร์ตซ์ นอกจากนี้ยังหาลักษณะโครงสร้างและการกระจายตัวของเส้นใยกาบกล้วยกับวัสดุประสานโดยใช้กล้องจุลทรรศน์อิเล็กตรอนแบบส่องกราด ผลการศึกษาพบว่า ค่าสัมประสิทธิ์การลดเสียง เท่ากับ 0.52 ของตัวอย่างเส้นใยกาบกล้วยที่มีความยาวขนาด 0.6 มิลลิเมตร และอัตราส่วนของใยกาบกล้วยต่อยิปซัม 3:7 โดยมวล ซึ่งพบมีความพรุนและช่องว่างที่มากขึ้น เมื่อนำผลการทดสอบมาสร้างแบบจำลองทางคณิตศาสตร์ พบว่าความแปรปรวน (F-Test) มีค่านัยสำคัญเท่ากับ 0.09 และค่าระดับนัยสำคัญ (*p*-value) ของอัตราส่วนของใยกาบกล้วยต่อยิปซัมเท่ากับ 0.05 แสดงว่ามีความสัมพันธ์กับค่าสัมประสิทธิ์การลดเสียง ดังนั้นแผ่นดูดซับเสียงที่ได้จากเส้นใยกาบกล้วยจึงสามารถนำไปใช้เพื่อลดความดังของเสียงได้

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คำสำคัญ: แผ่นดูดซับเสียง, เส้นใยกล้วย, ค่าสัมประสิทธิ์การดูดซับเสียง, ค่าสัมประสิทธิ์การลดเสียง, รูปภาพจากกล้องจุลทรรศน์อิเล็กตรอนแบบส่องกราด

ABSTRACT

The aim of this study was to develop the sound absorber from natural materials (cultivated banana fiber) to substitute for synthetic materials (asbestos and fiberglass). This sound absorber was presented particularly on Sound Absorption Coefficient (SAC) and Noise Reduction Coefficient (NRC) according to following factors: (1) fiber length of 0.6, 5.0, 10.0 mm., and (2) banana fiber-gypsum with a ratio of 1:9, 2:8, and 3:7 by weight at 25.0 mm. thickness of each specimen. This experiment was determined on SAC and NRC by impedance tube method based on ISO10534-2 standard in the frequency range 250-4,000 Hz. In addition, the structural and scattering images of banana fiber and surface adhesive by using Scanning Electron Microscope (SEM) were investigated. The result showed that NRC 0.52 of banana fiber specimen in length of 0.6 mm and banana fiber-gypsum ratio of 3:7 by weight appeared more porous and space. Likewise, mathematical model from this experiment showed the variance on the significant (F-Test) to be 0.09 and *p* - value of banana fiber-gypsum ratio to be 0.05 which was interacted with the value of NCR. Hence, sound absorber from banana fiber can be applied to noise reducing purpose.

Key words: sound absorber, banana fiber, sound absorption coefficient, noise reduction coefficient, image of scanning electron microscope

INTRODUCTION

Sound level of 90 dBA or above is harmful to the whole human hearing (Ratanalak *et al*., 2017). 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 (Cheremisinoff, 1977). When a sound wave impinges the surface of the absorbing material, some sound wave would be in motion within this material. The motion of sound wave causes the fibers on vibration. The fibers vibrations allow air to flow in the gap between fiber and particles. The air motions through narrow constrictions cause some energy loss (Bies and Hansen, 2009). The losses of sound energy indicate some sound energy is absorbed within material through dissipation process. In the previous study (Allard *et al*., 1989), 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 result of the sound energy reduction due to its friction loss. Various research have shown many new natural materials for noise control as alternatives to the traditional ones (for examples of asbestos and fibre glass) that natural fibers appear to be cheaper, lighter and environmentally superior to synthetic fiber (Asdrubali, 2006). The measurements carried out samples of natural fiber have shown to porous or dissipative absorber materials as result of good sound absorption coefficients (Sound Research Laboratories Ltd, 2004), especially at medium and high frequencies (Berardi and Iannace, 2017). For mechanical properties of Natural Fiber Composites (NFC) compared with Glass Fiber Reinforces Plastic (GFRP), NFC was better than GFRP in term of stiffness and cost, but values of tensile and impact strength were less than GFRP (Pickering *et al*., 2016).

The value indicated that Arenga Pinnata panels were highly absorptive material. The best sound absorption was performed by panel added with 10 % Latex with a maximum Sound Absorption Coefficient of 0.96 at 3,000 Hz. The average Noise Reduction Coefficient for all panels was 0.40 (Ismail, 2012). Also, the research that rice straw was chosen because of its availability in local region. The manufacturing parameters were: the specific gravity of 0.4, 0.6, and 0.8, and a rice straw content (10/90, 20/80, and 30/70 by weight percentage of rice straw/wood particle) of 10, 20, and 30 weight % (Yang *et al*., 2002). A commercial urea-formaldehyde adhesive was used as the composite binder, Sound Absorption Coefficients of the 0.4 and 0.6 specific gravity boards were higher than the other wood-based materials. The utilization of fiber from Oil Palm Empty Fruit Bunch (OPEFB) to be alternative native acoustic material that are different densities and thicknesses (Or *et al*., 2017). Measurement of absorption coefficient based on ISO10534-2 found on 0.9 at frequency 1 kHz. In order to properly use these materials, in addition to knowing the benefits and suitability of absorbers for use in the intended environment, the effective factors in sound absorption such as fiber size, air flow resistance, porosity, curve, thickness and density of absorbers were considered (Ghotbi *et al*., 2015). The advantages and disadvantages of different kinds of fibrous materials in noise reduction were explained that various fibers, inorganic fibers including glass wool, carbon fiber and basalt fiber have been utilized in noise reduction with the unique advantage such as flame retardant, high temperature resistance and moisture resistance, metallic fibers were widely used in extreme environment for sound absorption (Tang and Yan, 2017). Natural fibers including kapok, hemp, coir, kenaf, sisal, banana fiber and wool are environmental-friendly and low production cost. Definitely, bananas are one of the most widely cultivated crops in Thailand, there were 547,055 Rai of banana plantations and 782 million tons of produce including total exports of 35,266 tons (Suthanukool, 2015). In previous banana fiber research, the importance key properties of physical, and mechanical implied on this porous fiber have shown on their characteristics equivalent with others natural fiber (such as sisal and kenaf) (Koizumi *et al*., 2002) including chemical compositions (cellulose and lignin influenced on the ductility and elongation values) and tensile strength (Santijitto, 2011). Banana fiber was also investigated by scanning electron microscope as a long line which this fibrous configuration comprised of many cavity or porosity within parallel fiber bundle and were coated with cellulose and lignin (Deelaman *et al*., 2016). 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 on these needs. In previous studies, there were many ways in which the natural materials can utilize in modern construction. Normally, fiber plants are often subject to fungi and parasites and are less resistant to fire than typical mineral fibers; furthermore, they often need special fiber preparations before being used (Santijitto, 2011), which reduce the inherent sustainability of the raw materials. Also, these natural fibers are often commercialized in cement panels and blocks by using some binder. These considerations suggest to the environmental impacts of all the products used during the entire process of transformation of the natural fibers into building materials. Thereby, 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, specially 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 fiber could be the potential opportunity for consumer to increase insulated compatibility with the main direct materials. In this paper, banana fiber mixed with binders as gypsum and fused silica were studied relate to (1) fiber length, (2) banana fiber-gypsum ratio, at 25 mm. thickness of each specimen.

MATERIALS AND METHODS

1. Raw materials

1.1 The cultivated banana fiber

The type of banana for this research was the cultivated banana (Scientific name:Musa ABB CV.Kluai "Namwa") was divided as diameter of 2 - 3 mm of straight line because the cellulose molecules were arranged orderly or called "Crystalline" which affected on the strength of natural fibers (Karlinasari *et al*., 2012). After dehydration, these banana fiber was equivalent to 20-30% of moisture, with average cut length of 0.6, 5.0, and 10.0 mm, consecutively, the physical characteristics of banana fiber are presented in Figure 1.

(a) Dried banana fiber

(b) 0.6 mm banana fiber

(c) 5.0 mm banana fiber

(d) 10.0 mm banana fiber

Figure 1 The physical characteristics of banana fiber length

Banana fiber was magnified at 350x by Scanning Electron Microscope (SEM), it can be seen as a long line which this fibrous configuration comprised of many cavity or porosity of fibers within parallel fibers bundle as shown in Figure 2

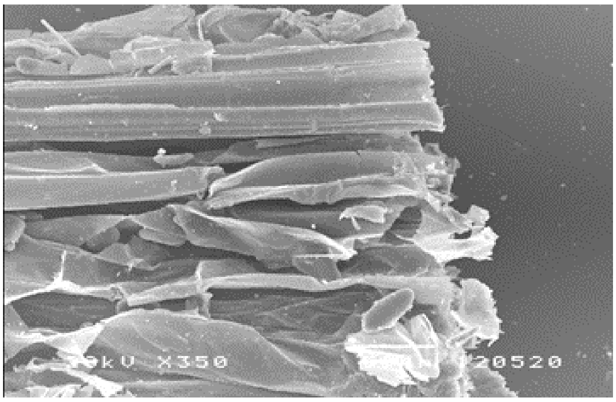


Figure 2 Longitudinal section of banana fiber by SEM image (350x)

1.2 Gypsum powder

The type of gypsum is Type 2B according to Thai Industrial Standard No.188 (TIS 188, 2004). The properties of gypsum powder or calcium sulphate dehydrate (molecular formula: $CaSO_4.H_2O$) show that the physical properties has the setting value of expansion is less than 2.0% and surface hardness that diameter of indentation is less than 5 mm. The chemical properties, SO_3 is the main component equivalent to 35.0%, CaO > 23.3%, and MgO < 0.3%, respectively. Picture of gypsum was magnified at 500x by Scanning Electron Microscope (SEM), it can be seen as stacked identical spheres as shown in Figure 3.

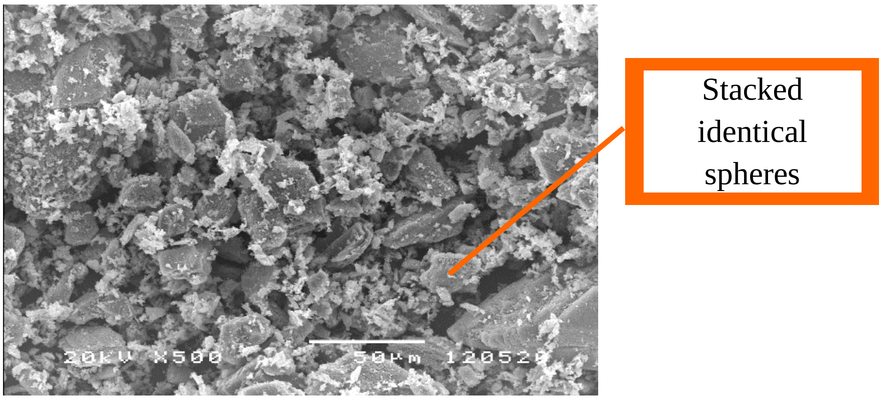


Figure 3 Gypsum by SEM image (500x)

1.3 Fused silica (SiO_2)

The general name is Fused silica as by- product of Quartz. The physical properties describe on its molecular weight: 60.1, specific gravity: 2.2-2.6, melting point: 1,710 °C, white color, and its size: 0.1-0.5 mm. Fused silica has the characteristics of strengthening and adhesive agent which the chemical properties consist of SiO_2 min: 98.5%, Al_2O_3 max: 0.1-0.5 %, and Fe_2O_3 max: 0.03%, respectively (Pluanjumpee, 2004). Picture of fused silica was magnified at 500x by Scanning Electron Microscope (SEM), it can be seen as stacked identical spheres and sharper than gypsum as shown in Figure 4.

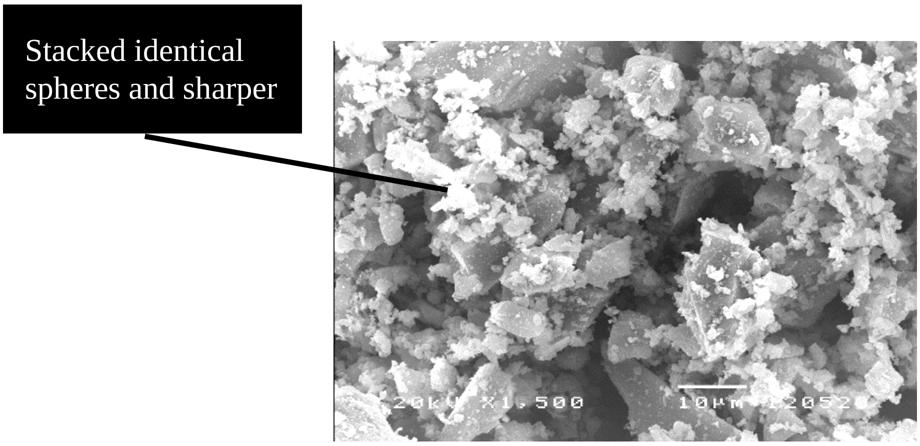


Figure 4 Fused silica by SEM image (500x)

2. Specimen preparation and analysis methods

Based on this experimental research and literature reviewing, the specimen were prepared by various factors: (1) fiber length of 0.6, 5.0, 10.0 mm., (2) banana fiber-gypsum ratio on 1:9, 2:8, and 3:7 by mass, at 25.0 mm. thickness of each specimen. The reaction between gypsum and water was able to linkage with banana fiber, especially fused silica with Si - H bonding reinforcement.

These specimens were aimed to determine on Sound Absorption Coefficient (SAC) and Noise Reduction Coefficient (NRC) by impedance tube method based on ISO10534-2 standard (ISO 10534-2, 1998) as following on Table 1 and Figure 5.

Table 1 The mixture proportions of each specimen

Specimen No.	Fiber length (mm.)	Banana fiber-Gypsum ratio (by mass)	Water-Fused silica ratio (by mass)
K1/1	0.6	1:9	5:1
K1/2	0.6	2:8	5:1
K1/3	0.6	3:7	5:1
K2/1	5.0	1:9	5:1
K2/2	5.0	2:8	5:1
K2/3	5.0	3:7	5:1
K3/1	10.0	1:9	5:1
K3/2	10.0	2:8	5:1
K3/3	10.0	3:7	5:1

(a) Specimen # K1/2 (b) Specimen # K2/3 (c) Specimen # K3/3

Figure 5 Some experimental specimens

The process of specimen preparation was started by the banana stem cutting- off step to prepare banana fibers which had determined to slit of 2-3 mm fiber diameter by cutter and then dehydrated on these banana fiber. Therefrom, fiber length reducing on 10.0 mm and 5.0 mm were consecutively cut. Eventually, a high speed grinder was applied to mill these fiber and then 30 US Mesh filter was utilized reducing fiber length to 0.6 mm. Each mixture proportion was provided on 6 specimens, which were molded into a pair of circular shape at the diameter of 9.8 cm and 2.8 cm, and 25 mm thickness for testing in low-sensitivity zone (0-1,600 Hz) up to high-sensitivity zone (1,600-6,400 Hz), respectively. After that each dried mixture consisted of 6 specimens (3 pairs of specimens) were testified to determine on their average of SAC (α) at frequencies 250, 500, 1,000 2,000 and 4,000 Hz. Also, total of 54 specimens were recorded on weight before and after drying to calculate on bulk density as below equations:

$$\text{Bulk density (g/cm}^3) = \frac{\text{Weight of Each Dried Specimen}}{\text{Volume of Each Specimen}} \quad (1)$$

In comparing sound absorbing materials for the noise control, the impedance tube method using the Kundt's tube (Or *et al.*, 2017) can be demonstrated on NRC is the arithmetic mean of SAC (α) at frequencies 250, 500, 1,000 2,000 and 4,000 Hz on the ability of sound absorption on the surface of the material as the equation (Barron, 2003)

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

When

NRC Noise Reduction Coefficient

α Sound Absorption Coefficient

In addition, each specimen was investigated on the structural of the banana fiber and banana fiber-gypsum mixtures by Scanning Electron Microscope (SEM) at 35x-150x times to analyze on the banana fiber porous, scattering and bonding. Lastly, all data from each specimen was analyzed in order to determine the correlation equation of 2 factors (Fiber length and Banana fiber-Gypsum Ratio) against NRC by multiple regression analysis.

RESULTS AND DISCUSSIONS

1. The sound absorption coefficient and noise reduction coefficient

This NRC value imposes highly absorbing material characteristics on incident sound. Also, the value of NRC: 0.4 - 1.0 indicated at the high level of noise absorption (Cowan, 1994). Results of specimens testing in Figure 6, the percent of Sound Absorption Coefficient (SAC), average at the frequency range 250-4,000 Hz were found that specimen K1/3 equivalent to 78.46% at 1,000 Hz and maximum equivalent to 83.99 % at 4,000 Hz. Particularly, the percent of SAC related to size of the banana fiber 0.6 mm. that displayed the less length and the rational of banana fiber- gypsum on 3:7 by mass as result in the higher SAC. At 250 Hz - low frequency, all specimen found the percent of SAC was similar and very low. It is observed on specimen K3/3 that fiber size 10.0 mm and the rational of banana fiber- gypsum on 3:7 by mass as result of the percent of SAC more than 40.00% at 2,000, 4,000, 1,000 Hz and Average frequency, respectively.

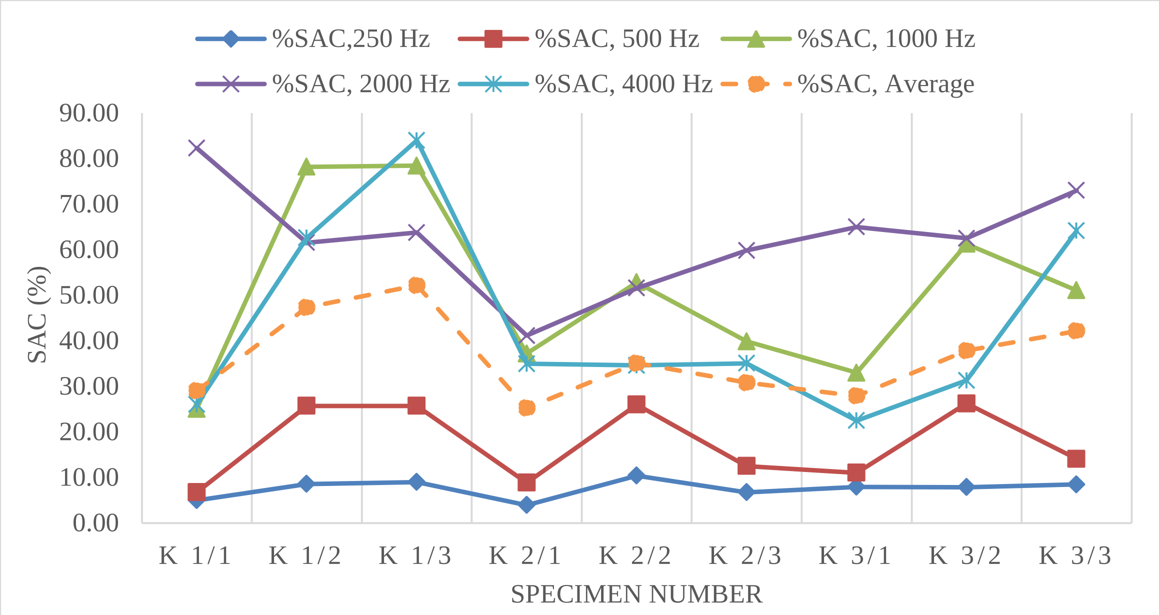


Figure 6 Sound absorption coefficient of different frequencies

The average of Noise Reduction Coefficient (NRC) showed on Figure 7 that the result of specimen K1/3 (fiber size 0.6 mm and the ratio of banana fiber-gypsum equivalent to 3: 7 by mass) was indicated the sound absorption ability to 0.52, the specimen K1/2 (fiber size 0.6 mm and the ratio of banana fiber-gypsum equivalent to 2: 8 by mass) was equivalent to 0.47, and the specimen K3/3 (fiber size 10.0 mm and the ratio of banana fiber-gypsum equivalent to 3: 7 by mass) was equivalent to 0.42, consecutively. This experiment can explain that the more rational of banana fiber and gypsum can influence on the sound absorption ability. However, the result of specimen K2/3 (fiber size 5.0 mm and the ratio of banana fiber-gypsum equivalent to 2: 8 by mass) was indicated the sound absorption ability to 0.31 due to the specimen preparation or other factors needed to investigate in advance.

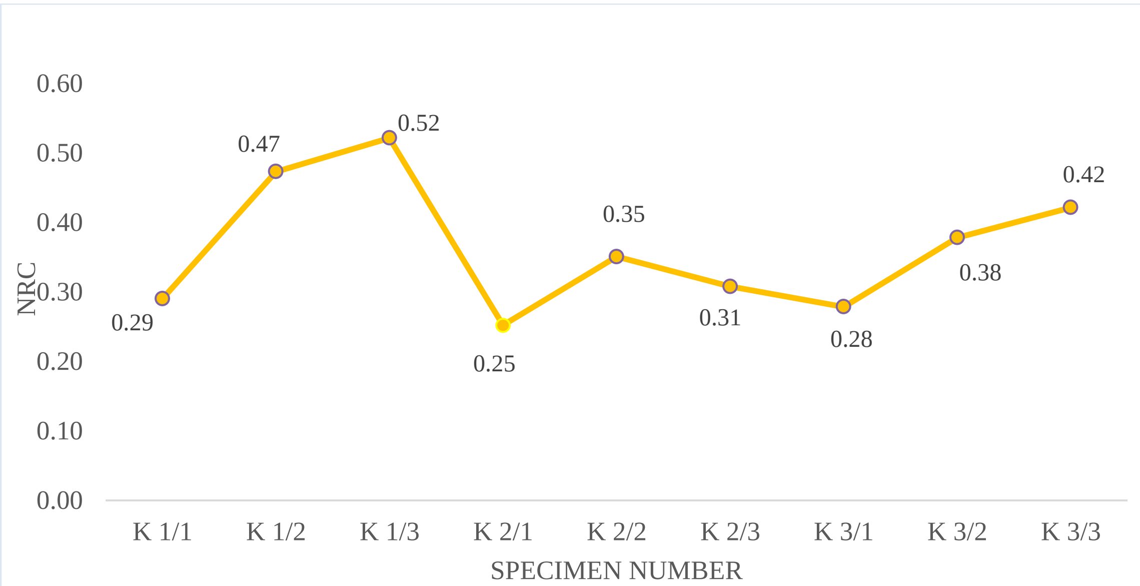


Figure 7 Noise Reduction Coefficient (NRC)

The bulk density as displayed on Figure 8 and its average was found 0.98 g/cm^3. The ratio of banana fiber-gypsum was equivalent to 3: 7 by mass of each specimen size (K1/3, K2/3 and K3/3) that was obviously less density than others ratio of banana fiber-gypsum was equivalent to 2:8 (K1/2, K2/2 and K3/2) and 1:9 (K1/1, K2/1 and K3/1), respectively.

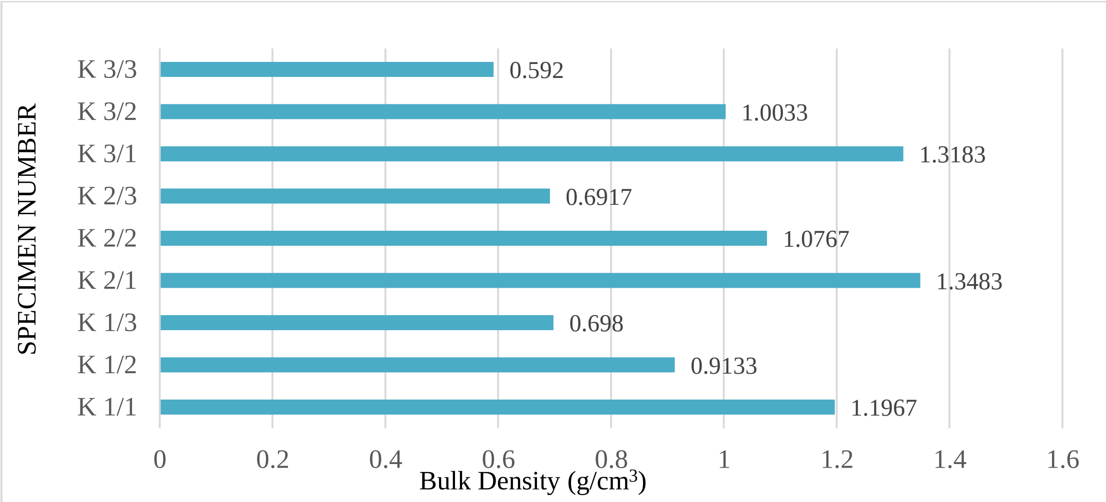
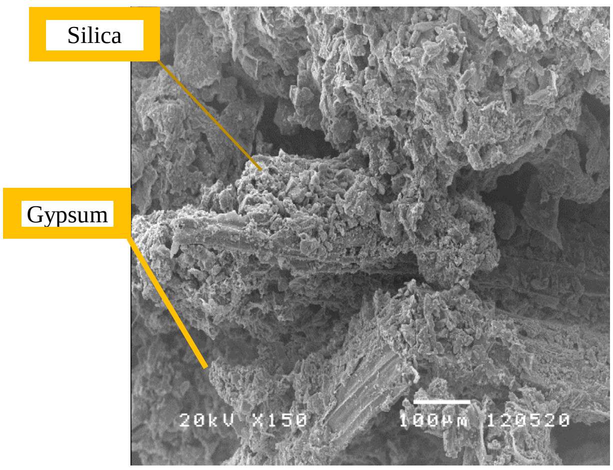


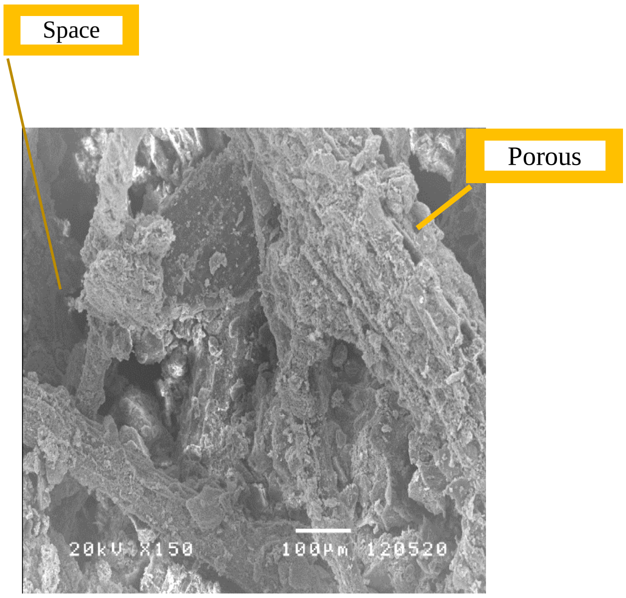
Figure 8 Bulk Density

2. The structural of the banana fiber and binders (gypsum and fused silica)

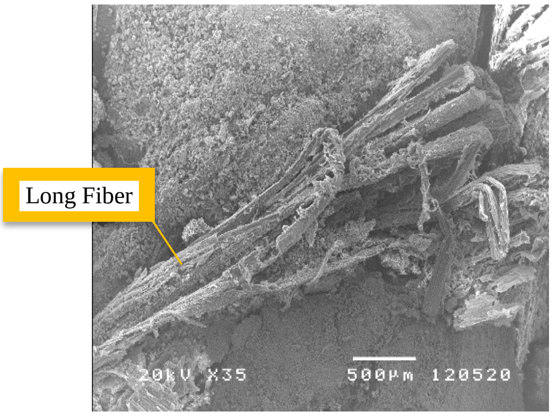
When using a Scanning Electron Microscope (SEM) magnified at 35x-150x times, these fiber can be seen distinctly as a porous fiber with binders scattering and bonding. These configuration were presented on Figure 9.



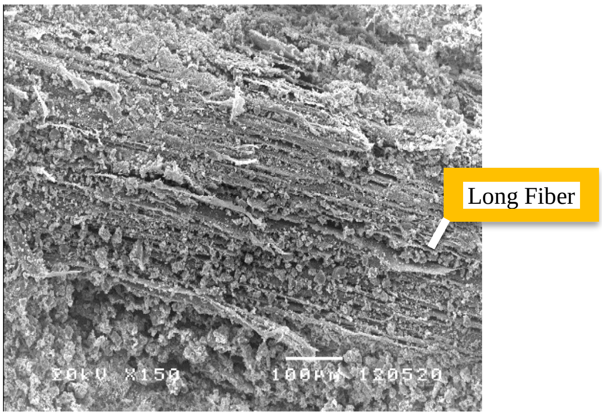
(a) Specimen # K1/2 at 150x



(b) Specimen # K 1/3 at 150x



(c) Specimen # K2/1 at 35x



(d) Specimen # K 3/1 at 150x

Figure 9 SEM image of some specimen types

These investigation revealed that the fine banana fiber indicated as the short fibrous, more porosity and space area. The specimen # K1/3 indicated apparently on Figure 9 (b) as the short fibrous, was interfered between binders (gypsum and fused silica which was shown on Figure 9 (a) of the specimen # K1/2) with porous, and also appeared on space area into this specimen. Thus, size of the fibers had small length and more surface area as result in the higher sound absorption coefficient and this porous material indicated as excellent in term of sound absorption that be enable to explain on natural fiber have shown to porous or dissipative absorber materials as result of good sound absorption coefficients (Sound Research Laboratories Ltd, 2004). For SEM picture 9 (c), the specimen # K2/1 found binders were being scattered on the long fibrous. Also, the 9 (d) picture of the specimen # K3/1 found these binders were being scattered on the long fibrous and found obviously space area into this specimen.

3. Multiple regression analysis

To determine on the correlated equation of 2 variable factors (when x_1: Fiber length and x_2: Banana fiber-Gypsum Ratio) and Noise Reduction Coefficient (y) was showed as following on this mathematical model

$$y = 0.2564 - 0.0069x_1 + 0.7169x_2 \quad (3)$$

This correlation coefficient was equivalent to 0.54 between the experimental values and the predicted valued by this mathematical model. The analysis of variance (ANOVA) was summarized on the significant F to be 0.09 and p - value, banana fiber-gypsum ratio of 0.05 and p - value, intercept of 0.2564 as the interested keyword.

The testing to determine on the coefficient of noise reduction by using the acoustic material experimentation according to the ISO10534-2 international standard were found especially the natural fibers in a straight line such as banana fibers was good absorber. For value of Noise Reduction Coefficient from this study were distinguished on the development of banana fiber reinforced gypsum at frequency ranges between 250 Hz and 4,000 Hz with the average value of the sound absorption ability to 0.52. In fact of 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 result of the sound energy reduction due to its friction loss. Furthermore, this research also revealed the importance factors effecting on sound absorbing ability that (1) size of the fibers presented the less one as result in the higher sound absorption coefficient, (2) density was also the important factor when dealing with the sound absorption behavior of the material, (3) the ration of banana fiber - gypsum according to the above mathematical model presented the influence on Noise Reduction Coefficient. In addition, the effective factors in sound absorption such as fiber size, porosity and density of absorbers were considered (Ghotbi *et al*., 2015) and The utilization of native acoustic material are different densities and thicknesses (Or *et al*., 2017). However, the intercept value of 0.2564 could be implied that the other influence factors will be subjected to research later.

CONCLUSION

In this research, the experimentation to determine on the Noise Reduction Coefficient by using the acoustic material examination according to the ISO10534-2 standard at the frequency range 250-4,000 Hz, demonstrated on specimen # K1/3 (the mixture proportions of fiber size 0.6 mm and ratio of banana fiber-gypsum equivalent to 3: 7 by weight) which the Noise Reduction Coefficient was indicated the good sound absorption ability to 0.52. Accordingly, Noise Reduction Coefficient value of 0.4 - 1.0 was announced on the high level of noise absorption. In addition, the percent of Sound Absorption Coefficient was equivalent to 83.99% at high-sensitivity zone (4,000 Hz) became apparently positive outcome for the research in advance. In addition, the higher bulk density varied on the lower ratio of banana fiber-gypsum. By using Scanning Electron Microscope, the specimen # K1/3 was found as the short fibrous, was interfered between binders (gypsum and fused silica) with porous, likewise appeared on space area into this specimen. Finally, mathematical model presented the variance on the significant F to be 0.09 and p - value belonging banana fiber-gypsum ratio to be 0.05 that implied the linkage with the value of Noise Reduction Coefficient. The SEM investigation revealed that the fine banana fiber indicated as the short fibrous, more porosity and space area influence on Noise Reduction Coefficient. Likewise, the scattering and bonding of banana fiber with binders influence on the strength of sound absorber needed to be more investigation on mechanical properties. Furthermore, the other parameters and variations effecting on Noise Reduction Coefficient might be investigated to develop in sound absorber from banana fiber in advance. Owing to its noise absorbing properties, banana fibers are flexible to be used in broadly engineering applications. Regarding to features offered, banana fiber is appropriate for an alternative engineering material, with a focus on; (i) Minimizing the use of local materials and resources, (ii) Recycling of wastes, (iii) Maximum use of local skills, and (iv) Environmental prevention and Energy conservation.

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