Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

The Physical and Sound Absorption Property of Lightweight Rigid Polyurethane Composite Reinforced Bamboo Fiber for Roof Applications

Adyla Illyana Roseli[1], Nik Normunira Mat Hassan[1,*], Abdul Mutalib Leman[1], Najibah Abdul Latif[2], Yulfian Aminanda[3], Djoko Setyanto[4], Yuyun Tajunnusa[5], Yonrapach Areerob[6], Methawee Nukunudompanich[6]

1 Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub, 84600 Pagoh, Muar, Johor, Malaysia
2 Mechanical Engineering Studies, College of Engineering, Universiti Teknologi MARA Johor Branch, Pasir Gudang Campus, Jalan Purnama, 81750 Masai, Johor, Malaysia
3 Mechanical Engineering Department, Universiti Teknologi Brunei, Tungku Highway, Gadong, Brunei Darusalam
4 Atma Jaya Catholic University of Indonesia. Jalan Jenderal Sudirman 51 Jakarta (12930) Indonesia
5 Department of Civil Infrastructure Engineering, Institut Teknologi Sepuluh Nopember, Indonesia
6 Department of Industrial Engineering, School of Engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL), 1 Chalong Krung 1 Alley, Lat Krabang, Bangkok 10520, Thailand

ARTICLE INFO

Article history:
Received 10 February 2023
Received in revised form 30 June 2023
Accepted 7 July 2023
Available online 20 July 2023

Keywords:
Rigid Polyurethane; bamboo fiber; sound absorption

ABSTRACT

Rigid polyurethane (RPU) foams as roof insulation have become increasingly popular in Southeast Asian countries and have been extensively used for absorbing sound and reducing noise because of their good sound damping, viscoelasticity, and low density. In this study, the RPU foam composite reinforced bamboo fiber was investigated by physical characterization by SEM, TGA, and FTIR, and the sound absorption was measured by the Impedance Tube Test. The morphology result of the RPU foam composite indicates the size of the diameter pore influenced the sound absorption by adding bamboo fiber as a filler. The thermal degradation of the presence of lignin in the bamboo fiber at the temperature range of 400 °C to 500 °C and the total weight loss is 76 % at 429 °C temperature. FTIR spectrum shows that the peak at 2890 to 2935 cm-1 are indicated –CH stretching vibrations and characteristics for bamboo fiber can be used in polymer composites. The sound absorption of RPU 25 foam composite reinforced bamboo fiber was found 0.74 absorbance at a frequency of 1250 Hz. RPU foam reinforced bamboo fiber as a filler has the highest transmission loss RPU 35 is 21 dB at a frequency range of 1600 Hz. The findings indicate by increasing the content of bamboo fiber as filler, the diameter of the open pore of RPU 25 and RPU 35 foam composite had the potential for sound absorption to absorb at low frequency to achieve greater sound absorption for roof insulation.

1. Introduction

The roof is the most important part of the building envelope and protects it from weather load and therefore greatly affects the service life of the building. Roof insulation is a means of reducing

* *Corresponding author.*
E-mail address: normunira@uthm.edu.my

https://doi.org/10.37934/araset.31.2.268280

sound from entering the building from the outside environment and avoids unwanted noise from entering. When it comes to rain noise, it is feasible to insulate the lightweight roof structure by adding absorptive layers and damping materials [1]. The forces produced when raindrops impact a roof can be a significant source of noise, particularly for lightweight roofs [2]. The forces produced by the raindrop impacts induce vibration in the roof structure producing sound, which can be very disruptive to the occupants below if there is insufficient insulation.

Polymers such as Rigid Polyurethane (RPU) foams as roof insulation have become increasingly popular in Southeast Asian countries. RPU foams are one of the porous materials, that have been extensively used for absorbing sound and reducing noise because of their good sound damping, viscoelasticity, and low density. However, RPU foams usually show unsatisfactory sound absorption behavior particularly in the low-frequency region due to the limited sound absorption properties of a single material. Adding various functional particles or reinforced fibers such as bamboo fiber into the RPU foams has become an efficient method to promote the acoustic properties of RPU foams [3].

Bamboo fiber as natural fiber has been known as green material by its biodegradability, excellent sustainability, renewable and abundance. Apart from that, the manufacturing of natural fibrous sound absorbers involves a significantly lower carbon footprint compared to conventional synthetic sound absorbers [4]. Because of their low toxicity and human safety, the majority of bamboo fibers are potentially perfect alternatives to conventional sound absorbers. The fundamental mechanism is energy loss of sound in sound absorption of fibrous materials due to viscous effects and thermal transfer [4]. Due to the viscosity of air, the sound is dissipated by friction between the pore walls. Sound absorption is influenced by sound energy losses owing to thermal conduction between the air and the absorber [5]. At low frequencies, this is usually more relevant. Material vibrations contribute to sound energy losses as well, but they are frequently less significant than absorption as sound travels through the linked pores.

Recently, researchers have made increasing kinds of sound absorption materials. Most natural fibers are potentially ideal alternatives to conventional sound absorbers because of their low toxicity and their being harmless to human beings. Natural fibers have been known as green materials by biodegradability, excellent sustainability, renewable and abundance. Apart from that, the manufacturing of natural fibrous sound absorbers involves a significantly lower carbon footprint compared to conventional synthetic sound absorbers [4]. Because of their low toxicity and human safety, the majority of natural fibers are potentially perfect alternatives to conventional sound absorbers. Fibrous sound absorbers, like any porous material, have a variety of channels and cavities that allow sound waves to pass through the structure. The fundamental mechanism is energy loss of sound in sound absorption of fibrous materials due to viscous effects and thermal transfer [4]. Due to the viscosity of air, the sound is dissipated by friction between the pore walls. Sound absorption is influenced by sound energy losses owing to thermal conduction between the air and the absorber [5]. At low frequencies, this is usually more relevant. Material vibrations contribute to sound energy losses as well but are frequently less significant than absorption as sound travels through the linked pores.

However, noise is an undesirable sound presented by humans. Noises rise from many sources such as traffics, factories, or even household. To reduce the perturbation of noises, sound absorption must be taken as a measure. Sound absorption is a physical phenomenon where sound wave energy is attenuated inside a material resulting in the reduction of wave energy. Chanlert *et al.,* [6] defined that sound absorption as a part of a soundwave hitting a surface that does not reflect. There are many ways to attenuate sound waves such as increasing air resistance or even using destructive superposition between the incident waves and reflected waves. The term ‘acoustic material’ is commonly used and applied for material showing high levels of sound absorption. To make an acceptable sound absorbing material, several factors affecting the sound absorption property of acoustic material should be concerned such as porosity, hardness, elasticity, or even surface morphology [6].

Thus, in this paper, adding bamboo fiber as an alternative filler in rigid polyurethane composite was to investigate the influence of bamboo fiber on the sound absorption properties of RPU foam composite. The bamboo fiber was characterized by its physical properties and RPU foam composite bamboo fiber was measured for the sound absorption coefficient for roof applications. The innovative product of lightweight roof applications, namely lightweight RPU composite reinforced bamboo fiber as an idea to create market value based on its potential impact, will be able to reduce sound in roof applications.

2. Methodology

2.1 Materials

To prepare Rigid Polyurethane (RPU) foams, Polyol TD and F180 Isocyanate were mixed with polyether polyol and polymeric methylene diisocyanate (PMDI) obtained from Scientifik Bersatu (M) Sdn. Bhd. The bamboo fiber used from HangTerra Bamboo Sdn Bhd. The bamboo fiber was cut approximately 3 cm as a filler for the RPU composite.

2.2 Preparation of Fabrication PU composite

To start the process, the ratio of the composite is 1:1, and two components A and B prepared. Component A consisted of polyether polyol, catalyst, surfactant, and bamboo fiber (with 0 %, 25 %, 30 %, 35 %, and 40 % by weight of polyol) and Component B consisted of polymeric methylene di-isocyanate (p-MDI) formulated with water as a blowing agent. RPU foam was fabricated using a one-shot process where components A and B were mixed inside a vessel or container. Components A were stirred by a mechanical stirrer with a rotor speed of 4000 rpm until the colour turned white, which usually took 3 minutes. Then, added bamboo fiber filler and component B and stirred for 60 seconds until homogenous. The polymerization process then began, resulting in a urethane bond produced by polyether polyol and isocyanate, resulting in greater molecular weight. Following the completion of the expansion, the RPU foam was held inside its vessel for 24 hours for the polymeric bond to be stable and cut to the specified size to be characterized as illustrated in Figure 1.

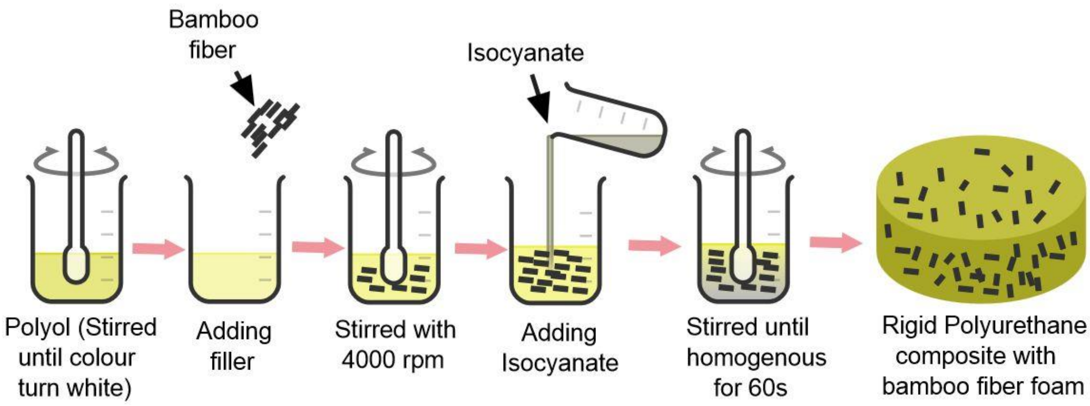


Fig. 1. The process of fabrication of RPU composite with bamboo fiber foam

3. Physical and Mechanical Characterization of Bamboo Fiber and RPU Composite Foam

3.1 Scanning Electron Microscopy (SEM)

A scanning electron microscope (SEM) is a type of electron microscope JEOL JSM-6380LA that is used as a concentrated beam of electrons to scan the surface of a sample to produce images. The SEM was observed in the laboratory of University Tun Hussein Onn Malaysia, Parit Raja, Johor followed by ASTM D3576. To prevent electrical charge collection, the test samples were coated using JFC-1600 auto fine coater. The front surface of the bamboo fiber was examined and scanned in a free-rise direction at the accelerating voltage of 10 kV followed by at 500µm 30X magnification.

3.2 Thermo-Gravimetric Analysis (TGA)

Thermogravimetric analysis (TGA) is an analytical technique for determining material thermal stability and the proportion of volatile components by monitoring the weight change that occurs as a sample is heated at a constant rate. TGA 550 TA Instrument Trios Discovery Series followed ASTM E1131 were used to determine the thermal characteristics of the bamboo fiber and conducted at the Process Control laboratory at University Tun Hussein Onn Malaysia Kampus Pagoh, Johor. The bamboo fiber sample was heated from 40 °C to 700 °C in a nitrogen environment at a rate of 10 °C/min with a flow rate of 25 ml/min.

3.3 Fourier-Transform Infrared Spectroscopy (FTIR) Analysis

Fourier-transform infrared spectroscopy Agilent Technologies Cary 630 FTIR was used followed by ASTM D6342-12 to determine the chemical structure of bamboo fiber. FTIR testing was conducted in the chemistry Analytical laboratory at University Tun Hussein Onn Malaysia Kampus Pagoh, Johor. The measurement was performed with a maximum resolution of 4 for scanning the wavelength range of about 650 to 4000 cm^{-1}.

3.4 Impedance Tube Test

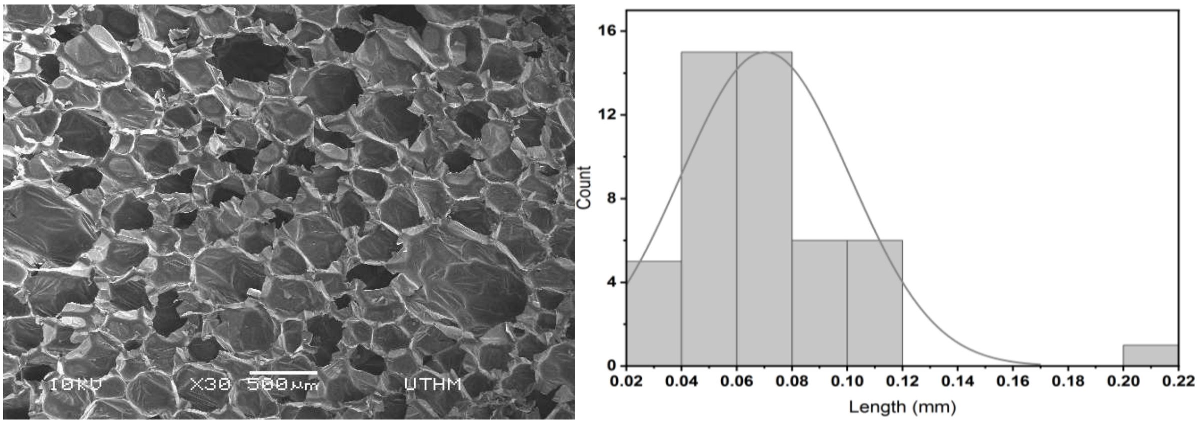
The tubes were observed in the Noise and Vibration Laboratory at the University Tun Hussein Onn Malaysia Parit Raja, Johor. The BSWA SW series Impedance Tube Test was used to determine sound absorption and transmission loss by the ASTM E 1050 and ASTM E 2611 requirements. The sound absorption and transmission loss measurements were used four microphones by the Transfer Function Process. RPU foam composite with varying weights of bamboo fiber was used to create the sample. Each sample was classified as 100 mm sizes for low frequency.

4. Results and Discussion

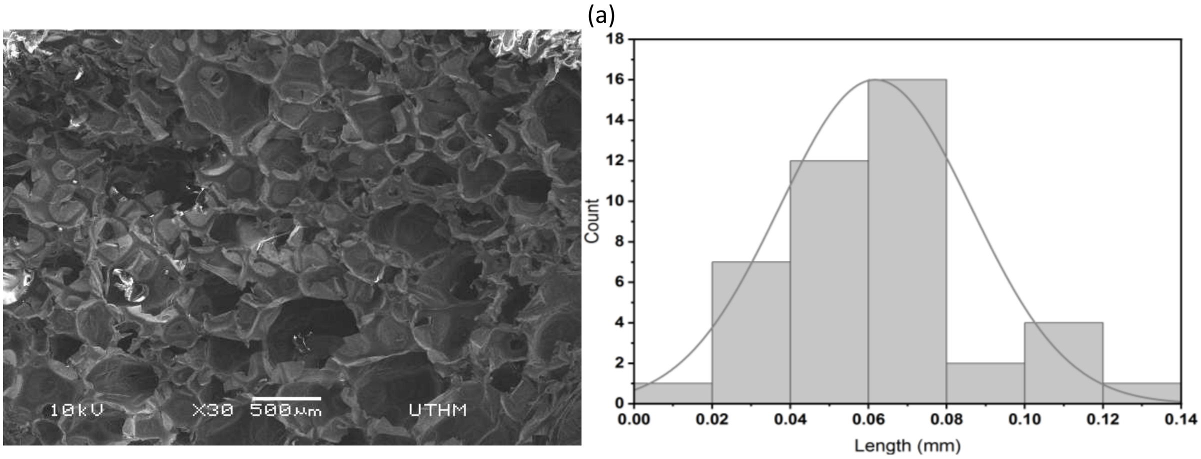
4.1 Effect of Bamboo Fiber Filler on the Diameter Pore Size of RPU Foam Composite

Figure 2 shows the SEM micrographs of RPU foam composite reinforced bamboo fiber. The SEM observations show that the diameter pore of the RPU foam becomes smaller when added the filler. The foam is made rigid or strong because the bubbles can resist a lot of pressure [7]. Compare to all RPU composites, the larger diameter pore size was found on RPU pure foams 0.0703 mm due to the RPU pure composite containing a small number of surface hydroxyl groups [8,9]. This is because large surface areas of cell walls were obtained in RPU pure composite with larger diameter pore size which might be low for sound absorption. Moreover, the porosity in RPU foam composite can be determined by the numbers of porosity which leads to lower and higher sound absorption of sound waves through the RPU foam composite foams [10].

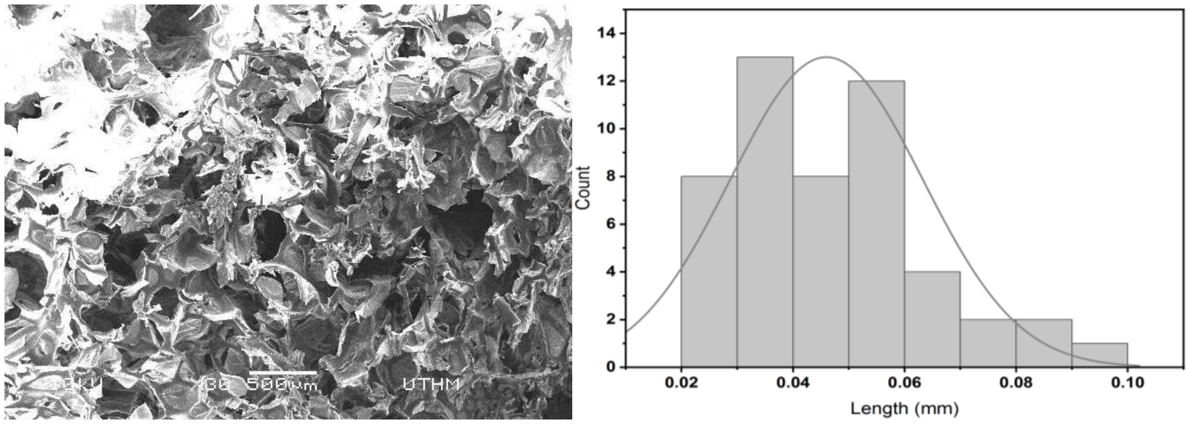
The average diameter pore RPU foam was decreased with an increasing ratio of filler of bamboo fiber from 0.0703 to 0.0351 mm summarize in Table 1. RPU pure has a spherical shape structure than the other foam. The bamboo fiber reinforced increased the viscosity, which caused a minor effect on the polymer expansion [11]. Thus, the smaller RPU foam diameter pore size distribution is 0.0617 to 0.0351 mm because of the effect of the increased bamboo fiber filler [12]. Besides, from the standard deviation RPU pure foam to RPU 30 slightly increase 20.82 to 32.20, then decrease between RPU 35 and RPU 40 from 27.03 to 22.61. Other than that, the physical characteristics of RPU foams foam composite are closely related to the development of cellular structures during the foaming processes of RPU composite foams. For instance, the distribution size and numbers of cells and pores influence how sound waves travel via cellular pathways, and the proportion of partially open porosity is essentially important in determining the ability of materials to absorb sound [10]. Hence, adding bamboo fiber to RPU foam composite has a great impact on sound absorption than RPU pure.



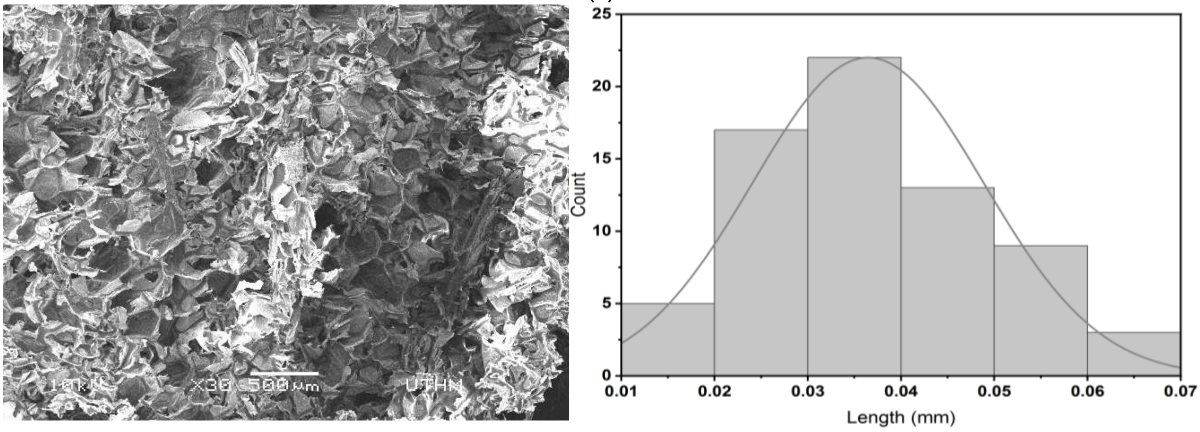
(a)



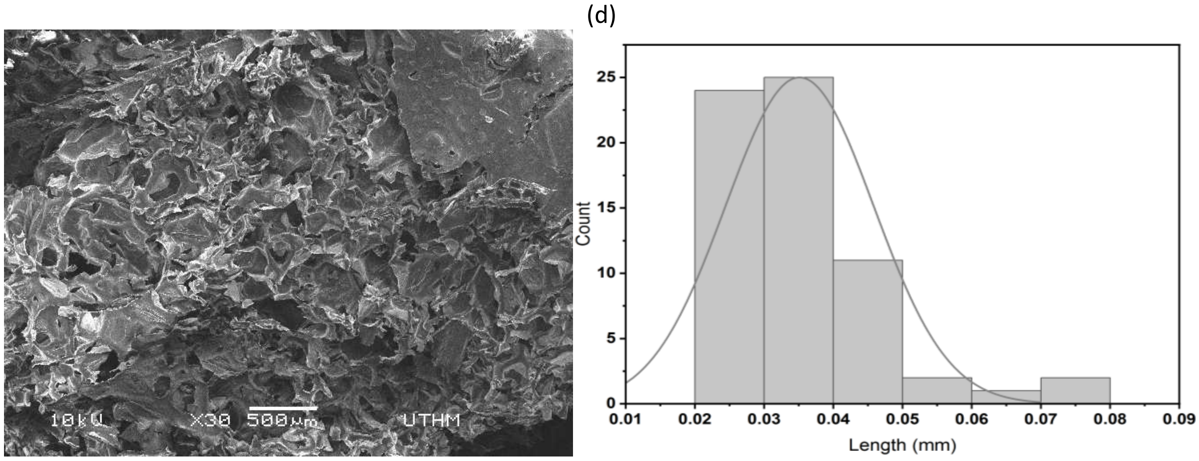
(b)



(c)



(d)



(e)

Fig. 2. The morphology of RPU composite foam (a) RPU pure, (b) RPU 25, (c) RPU 30, (d) RPU 35, and (e) RPU 40 reinforced bamboo fiber

Table 1
The average diameter pore size of RPU foam composite reinforced bamboo fiber

Bamboo Fiber Filler (wt %)	Average diameter pore size (mm)	Average Standard Deviation
RPU Pure	0.0703	20.82
RPU 25	0.0617	10.89
RPU 30	0.0460	32.20
RPU 35	0.0364	27.03
RPU 40	0.0351	22.61

4.2 Thermo-Gravimetric Analysis of the Bamboo Fiber

The thermal degradation of bamboo fiber as a filler was investigated by TGA thermal analysis. The weight loss and derivative weight temperature curves are depicted in Figure 3. As shown in Figure 3, the thermal profiles of bamboo fiber are characterized by three stages. Thermal degradation of bamboo fiber shown in the first stage up 100 °C to 250 °C weight loss is 11 % at temperature 214 °C. This might be due to the corresponding evaporation of water [13] and the dissolved of moisture of small molecules in the bamboo fiber [14].

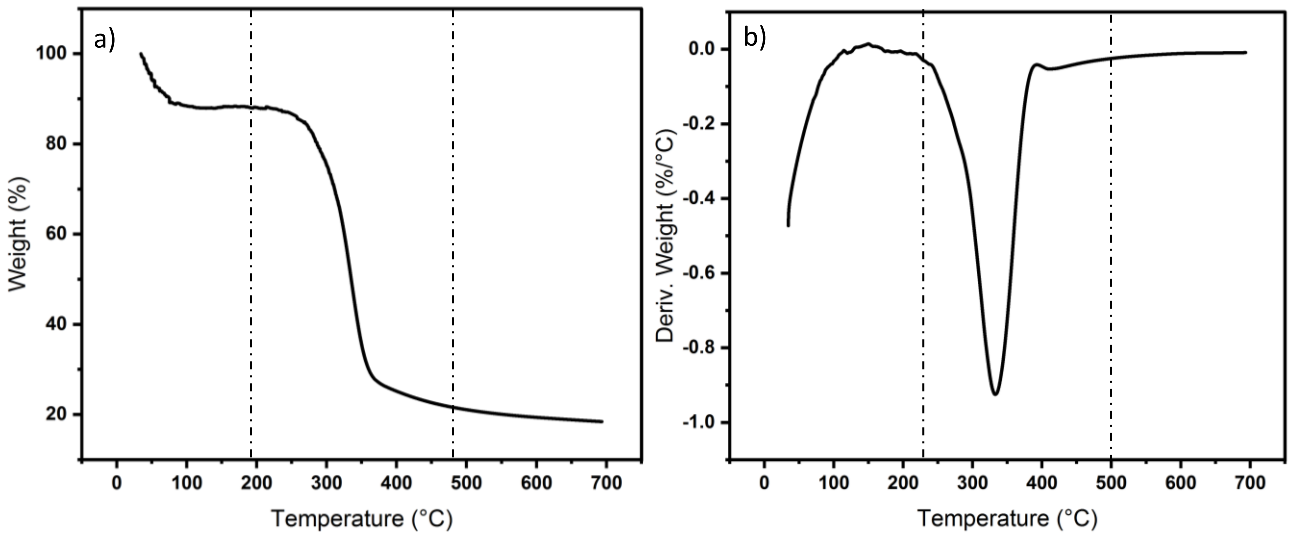


Fig. 3. Thermo-gravimetric curve a) Weight loss b) derivative of bamboo fiber

The summary of the thermal degradation of bamboo fiber is shown in Table 2. In the second stage, the weight loss occurred at a temperature of range 250 °C to 400 °C at 341 °C is 56 % indicating the thermal degradation of cellulose of bamboo fiber [14]. The thermal degradation shows an effect on the bamboo fiber which in increasing temperature from 214 °C to 341 °C and weight loss about 45 % different. This promotes increasing temperature due to the removal of some hydroxyl substances [9]. At the third stage, from 400 °C to 500 °C the weight loss increased by 76 % at a temperature of 429 °C attributed to the degradation of the presence of lignin in the bamboo fiber [15]. Bamboo fiber shows good thermal stability, such developed materials may be can successfully use in polymer composite as insulation in building and construction materials such as for roof applications.

Table 2
TGA results curve of bamboo fiber

Sample	Transition Temperature Range (°C)	Temperature of Maximum rate of weight loss (°C)	Weight loss (%)
Bamboo Fiber	100 – 250	214.03	11.83
	250 – 400	341.08	56.48
	400 – 500	429.85	76.48

4.3 Fourier-Transform Infrared Spectroscopy (FTIR) Analysis

The FTIR spectrum for the bamboo fiber in the spectra from 4000 to 400 cm^{-1} is shown in Figure 4. Table 3 summarises the main peaks of bamboo fiber. The spectrum of the bamboo fiber –OH stretching vibration 3100 – 3500 cm^{-1} may be due to intermolecular hydrogen bonding with absorbed such as alcohols found in cellulose, hemicellulose, lignin, and carboxylic acids [16,17]. The peaks at 2890 to 2935 cm^{-1} are indicated –CH stretching vibrations and characteristics as natural fibers. The presence of peaks at 1640 to 1735 cm^{-1} may be related to the C=O stretching as shown in Table 3. However, the deformation 1025 to 1035 cm^{-1} C-O and 810 to 833 cm^{-1} C-H possible stretching of ester groups in grass lignin. According to Guan *et al.,* [18], the stretching in spectra is because the bond from hemicellulose was completely cleaved. On the other, the C-O and C-H deformation present the bamboo fibers.

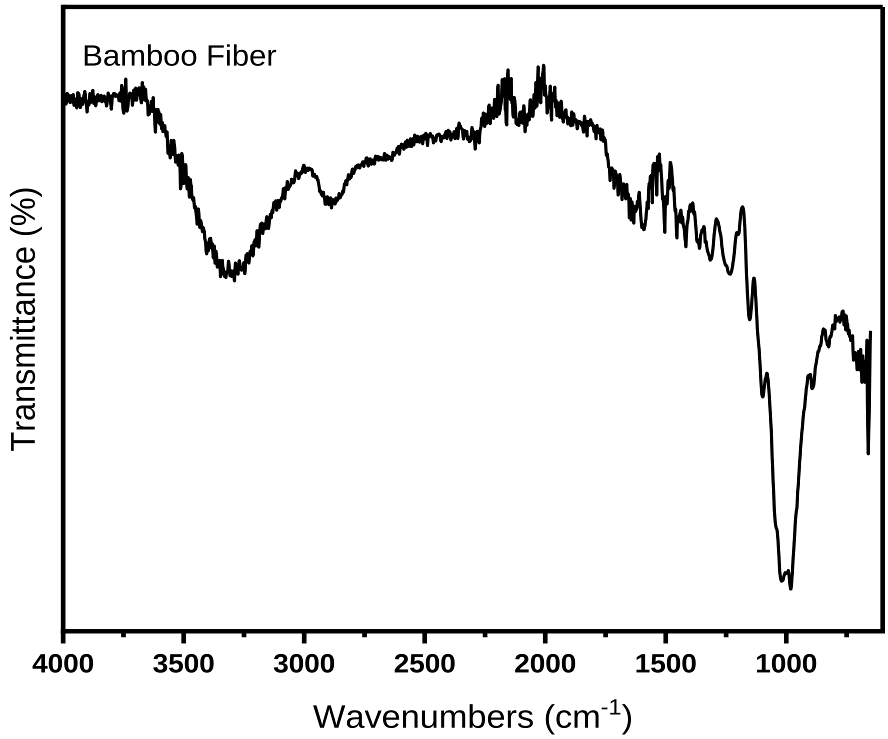


Fig. 4. Fourier transform infrared spectroscopy of bamboo fiber

Table 3
FTIR infrared spectrum of bamboo fiber [19,20,17]

Wavenumbers (cm^{-1})	Functional group	Vibration Type	Cause
3100 - 3500	-OH	Stretching vibration	Cellulose, hemicellulose
2890 - 2935	-CH	Stretching vibration	-
1640 - 1735	C=O	Stretching vibration	Lignin, hemicellulose
1221 - 1230	C-O C-O	Stretching vibration	lignin
1025 - 1035	C-O	Stretching vibration	Cellulose, lignin, hemicellulose
810 - 833	C-H	-	Out of hydroxyl

4.4 Impedance Tube Test
4.4.1 Sound absorption coefficient

The sound absorption coefficient bar graph of the rigid polyurethane foam composites reinforced various weight bamboo fiber of 25%, 30%, 35%, and 40% was determined as a function of the sound frequency depicts in Figure 5. The bar graph measured data in the low frequency range of 200 – 1600 Hz where human sensitivity to noise is high [21]. Figure 5 shows the sound absorption coefficient of the five different RPU foam composites and it is obvious that the sound absorption coefficient is impacted by the contents of bamboo fiber filler. Also, it might be because the morphology of the diameter pore with added different filler can change the sound absorption. It can be found that the frequency range of 200 – 1600 Hz, the bar graph of the sound absorption coefficient of the RPU pure foam was low than the other RPU foam. But, at a frequency of 200 Hz, the lowest sound absorption is RPU 35, 0.01 absorbance.

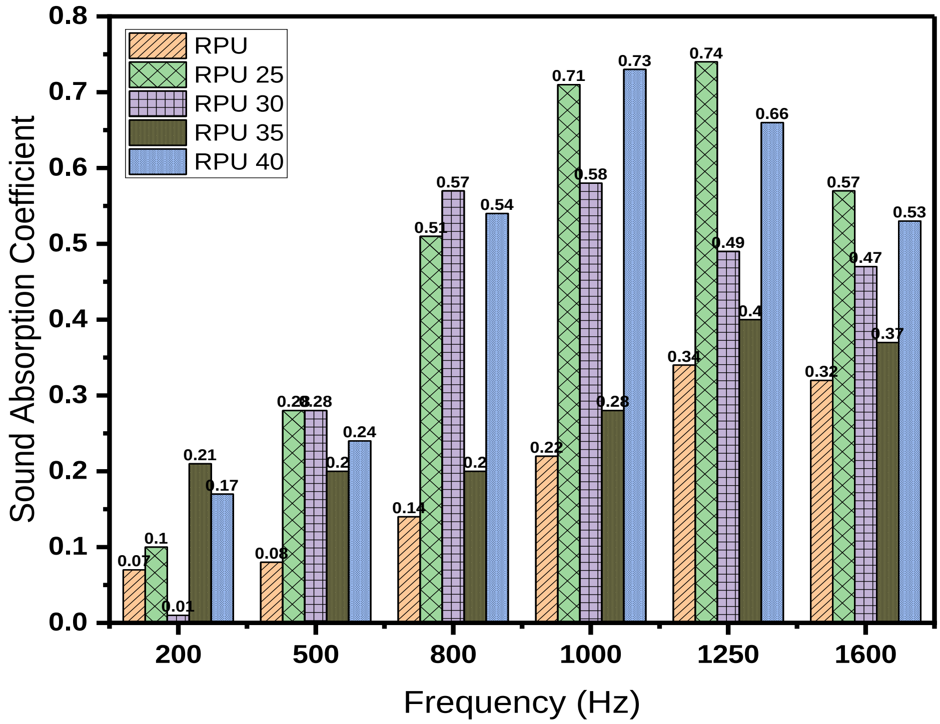


Fig. 5. Sound Absorption Coefficient of RPU composite reinforced bamboo fiber at low frequency

Meanwhile, the sound absorption coefficient of the RPU foam that was filled with bamboo fiber increased at a frequency of 1250 Hz with 0.74 absorbances. It means that better sound absorption properties are acquired at low frequency by adding the content of bamboo fiber filler. Contrarily, Figure 5 found that the RPU foam composites are different from RPU pure, and the values of absorption are better at 800 – 1600 Hz. Also, it may be due to as discussed in 4.1, the size and number of pores influencing open porosity diameter pore which leads to the sound propagating more easily absorbing and dissipating more energy [5].

4.4.2 Transmission loss (TL)

The sound transmission loss (TL) of RPU foam composite reinforced bamboo fiber is shown in Figure 6. The results indicate all the RPU foam samples with 20 mm thickness. In the frequency of 200 Hz, the RPU pure and RPU 35 is the greatest of TL which is 26 and 17 dB. From the range 200 – 1600 Hz, the TL of RPU 25 is steadily increasing from 5 to 12 dB. The RPU 30 decreased by 3 dB at a frequency of 500 Hz and steadily increased from a frequency range of 800 – 1600 Hz 9 dB to 13 dB and the difference in the value is 4 dB. From the observation, RPU foam that had bamboo fiber filler has the highest TL is RPU 35 21 dB at a frequency range of 1600 Hz. It shows that RPU foam with bamboo fiber filler could deliver much more improvement for a frequency below 1600 Hz and a thickness of 20 mm.

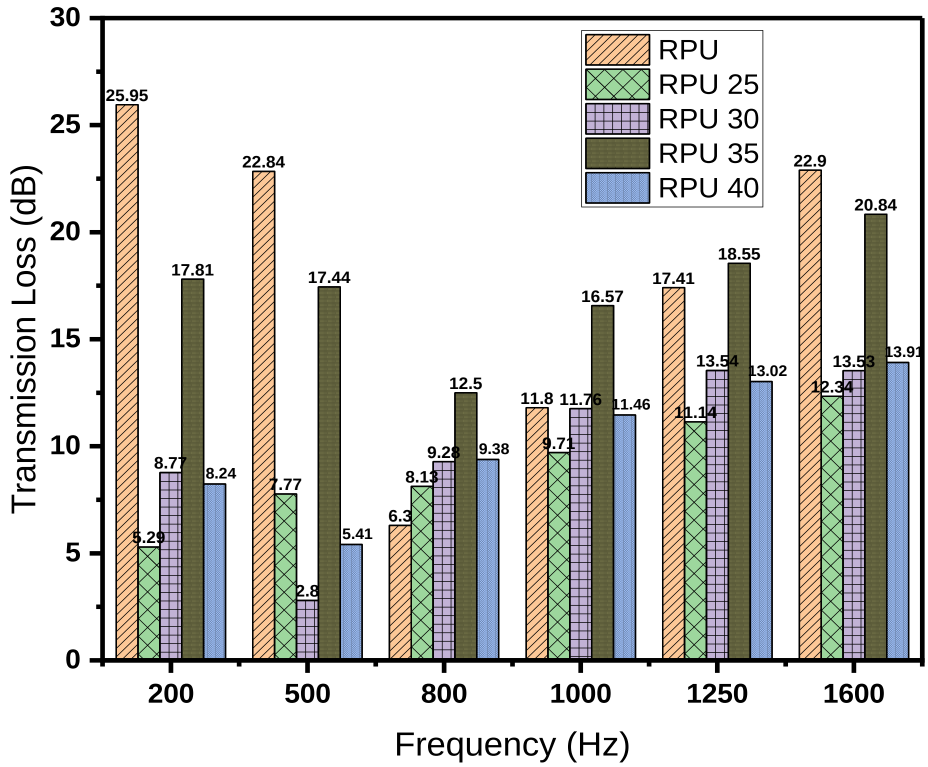


Fig. 6. Transmission Loss of RPU composite reinforced bamboo fiber at low frequency

4.4.2 Noise reduction coefficient (NRC)

The Noise Reduction Coefficient (NRC) is represented by the amount of sound energy absorbed by a particular surface. The sound absorption coefficient is used to calculate NRC commonly to determine sound rooms of qualified acoustical tests. The NRC is replaced by sound absorption average at low four specific frequency usually 200 Hz, 500 Hz, 800 Hz, and 1600 Hz. The sound absorption average is a single number rating of sound absorption of material identical to NRC. Therefore, NRC can calculate using the formula in Eq. (1). Figure 7 shows the average noise reduction coefficient of RPU foam composite bamboo fiber for RPU-Pure, 25, 30, 35, and 40.

$$\text{NRC} = \frac{\alpha_{200}+\alpha_{500}+\alpha_{800}+\alpha_{1600}}{4} \quad (1)$$

Figure 7 displays the average NRC of RPU foam composite with different ratios of bamboo fiber. The noise reduction coefficient of RPU foam composite considerably increases from RPU-Pure until RPU 40 is 0.15 to 0.24. The highest value of NRC of RPU foam composite was RPU 25 and 35 at 0.37 and the lowest value at 0.15 for RPU pure. As a result, the most suitable testing for noise reduction coefficient is RPU 25 and 35 bamboo fiber as filler at 0.37 as compared to the other RPU foam composite. Eventually, the results from RPU foam composites confirm (Olcay & Kocak) that adding the bamboo fiber influences sound absorption and has a higher noise reduction coefficient than RPU pure.

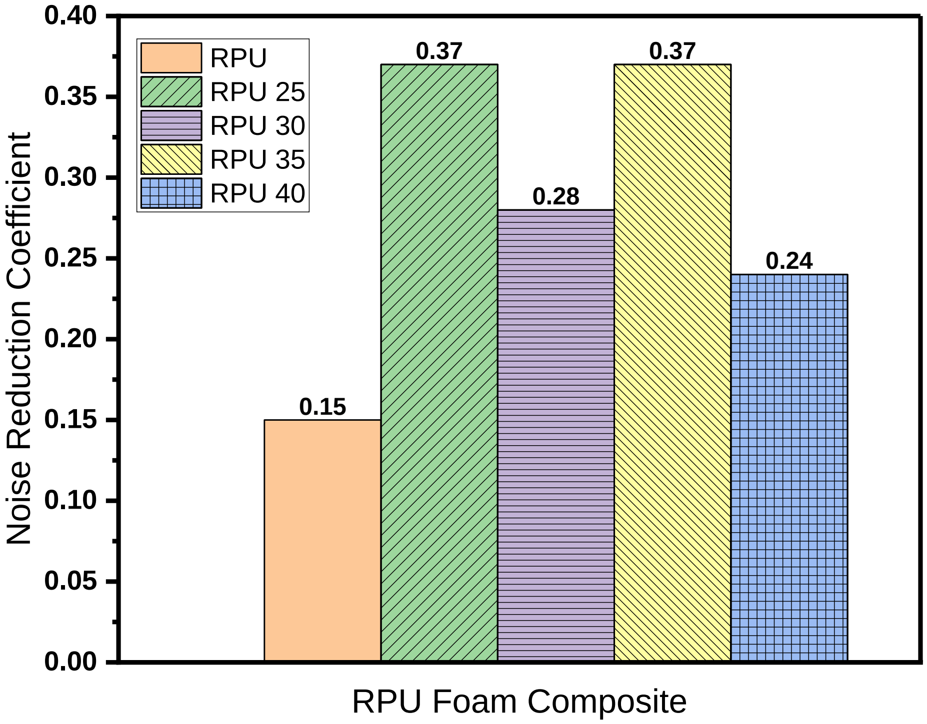


Fig. 7. Noise reduction coefficient of RPU foam composite with bamboo fiber

5. Conclusions

In this study, the rigid polyurethane composite reinforced bamboo fiber was successfully measured by physical characterization and sound absorption. The results morphology of RPU foam composite show that different ratio of bamboo fiber gives different size of open diameter pore and exhibited influenced the sound absorption ability of RPU foam. Thermal analysis of weight loss increases 76 % within the temperature range from 400 – 500 °C, at temperature 429 °C presence of lignin of the bamboo fiber degradation. The sound absorption of RPU 25 foam composite filled with bamboo fiber gives 0.74 absorbances at a frequency of 1250 Hz. RPU foam exhibited the highest transmission loss of RPU 35 is 21 dB at a frequency range of 1600 Hz. The requirement for better sound absorption of the bamboo fiber can be achieved at low frequency. In conclusion, by increasing the ratio of the bamboo fiber as a filler at 25% and 35%, the open diameter pore of RPU 25 and RPU 35 foam composite shows a better potential for sound absorption to absorb for use in roof applications.

Acknowledgement
This research was supported by Universiti Tun Hussein Onn Malaysia through International Grant (W025) Asia Technological University Network (ATU-Net) Young Researcher Grant 2022 (YRG 2022) and Ministry of Higher Education (MOHE) through Fundamental Research Grant Scheme (FRGS/1/2022/TK02/UTHM/03/4).

References

[1] Mónica, Macieira, Paulo Mendonça, Joao Miranda Guedes, and António PO Carvalho. "Roof replacement of a heritage building using transparent solutions: Room acoustic performance comparison." *International Journal of Architectural Heritage* 16, no. 2 (2022): 284-301. https://doi.org/10.1080/15583058.2020.1777593

[2] Schmid, G., M. J. Kingan, L. Panton, G. R. Willmott, Y. Yang, Carolina Decraene, Edwin Reynders, and A. Hall. "On the measurement and prediction of rainfall noise." *Applied Acoustics* 171 (2021): 107636. https://doi.org/10.1016/j.apacoust.2020.107636

[3] Chen, Shuming, and Yang Jiang. "The acoustic property study of polyurethane foam with addition of bamboo leaves particles." *Polymer composites* 39, no. 4 (2018): 1370-1381. https://doi.org/10.1002/pc.24078

[4] Yang, Tao, Lizhu Hu, Xiaoman Xiong, Michal Petrů, Muhammad Tayyab Noman, Rajesh Mishra, and Jiří Militký. "Sound absorption properties of natural fibers: A review." *Sustainability* 12, no. 20 (2020): 8477. https://doi.org/10.3390/su12208477

[5] Wenbo, Z. H. U., C. H. E. N. Shuming, W. A. N. G. Yebin, Z. H. U. Tongtong, and Yang Jiang. "Sound absorption behavior of polyurethane foam composites with different ethylene propylene diene monomer particles." *Archives of Acoustics* 43, no. 3 (2018): 403-411.

[6] Chanlert, P., and P. Ruamcharoen. "Sound absorption properties of rigid polyurethane foam composites with rubber-wood sawdust as a natural filler." In *Journal of Physics: Conference Series*, vol. 1719, no. 1, p. 012062. IOP Publishing, 2021. https://doi.org/10.1088/1742-6596/1719/1/012062

[7] Defonseka, Chris. "5. Properties and foaming technology of polyurethane foam." In *Flexible Polyurethane Foams*, pp. 53-66. De Gruyter, 2019.

[8] Qiu, Chongpeng, Xuelun Zhang, You Zhang, Qi Tang, Zihui Yuan, Cornelis F. De Hoop, Jiwen Cao *et al.,* "Bamboo-based biofoam adsorbents for the adsorption of cationic pollutants in wastewater: methylene blue and Cu (II)." *ACS omega* 6, no. 36 (2021): 23447-23459. https://doi.org/10.1021/acsomega.1c03438

[9] Qiu, Qunlei, Xin Yang, Penghao Zhang, Danyu Wang, Miao Lu, Zhongqiang Wang, Gaiping Guo, Jianxiang Yu, Huafeng Tian, and Jian Li. "Effect of fiber surface treatment on the structure and properties of rigid bagasse fibers/polyurethane composite foams." *Polymer Composites* 42, no. 6 (2021): 2766-2773. https://doi.org/10.1002/pc.26011

[10] Choe, Hyeon, Jae Heon Lee, and Jung Hyeun Kim. "Polyurethane composite foams including CaCO3 fillers for enhanced sound absorption and compression properties." *Composites Science and Technology* 194 (2020): 108153. https://doi.org/10.1016/j.compscitech.2020.108153

[11] Olcay, Hilal, and Emine Dilara Kocak. "The mechanical, thermal and sound absorption properties of flexible polyurethane foam composites reinforced with artichoke stem waste fibers." *Journal of Industrial Textiles* 51, no. 5_suppl (2022): 8738S-8763S. https://doi.org/10.1177/1528083720934193

[12] Oushabi, A., S. Sair, Y. Abboud, O. Tanane, and A. El Bouari. "An experimental investigation on morphological, mechanical and thermal properties of date palm particles reinforced polyurethane composites as new ecological insulating materials in building." *Case studies in construction materials* 7 (2017): 128-137. https://doi.org/10.1016/j.cscm.2017.06.002

[13] Shan, Chan Wen, Maizlinda Izwana Idris, and Mohd Imran Ghazali. "Study of flexible polyurethane foams reinforced with coir fibres and tyre particles." *International Journal of Applied Physics and Mathematics* 2, no. 2 (2012): 123-130. https://doi.org/10.7763/IJAPM.2012.V2.67

[14] Tang, Qiheng, Lu Fang, and Wenjing Guo. "Effects of bamboo fiber length and loading on mechanical, thermal and pulverization properties of phenolic foam composites." *Journal of Bioresources and Bioproducts* 4, no. 1 (2019): 51-59. https://doi.org/10.21967/jbb.v4i1.184

[15] Strąkowska, Anna, Sylwia Członka, and Agnė Kairytė. "Rigid polyurethane foams reinforced with poss-impregnated sugar beet pulp filler." *Materials* 13, no. 23 (2020): 5493. https://doi.org/10.3390/ma13235493

[16] Glória, Gabriel Oliveira, Ygor Macabu de Moraes, Frederico Muylaert Margem, Carlos Maurício Fontes Vieira, and Sérgio Neves Monteiro. "Evaluation of giant bamboo fibers components by infrared spectroscopy." In *70º Congresso Annual da ABM*. 2015.

[17] Ibáñez García, Ana, Asunción Martínez García, and Santiago Ferrándiz Bou. "Study of the influence of the almond shell variety on the mechanical properties of starch-based polymer biocomposites." *Polymers* 12, no. 9 (2020): 2049. https://doi.org/10.3390/polym12092049

[18] Guan, Ying, Bing Zhang, Xian-Ming Qi, Feng Peng, Chun-Li Yao, and Run-Cang Sun. "Fractionation of bamboo hemicelluloses by graded saturated ammonium sulphate." *Carbohydrate polymers* 129 (2015): 201-207. https://doi.org/10.1016/j.carbpol.2015.04.042

[19] Faruk, Omar, Andrzej K. Bledzki, Hans-Peter Fink, and Mohini Sain. "Biocomposites reinforced with natural fibers: 2000–2010." *Progress in polymer science* 37, no. 11 (2012): 1552-1596. https://doi.org/10.1016/j.progpolymsci.2012.04.003

[20] Mohammed, Layth, MOHAMED NM Ansari, Grace Pua, Mohammad Jawaid, and M. Saiful Islam. "A review on natural fiber reinforced polymer composite and its applications." *International journal of polymer science* 2015 (2015). https://doi.org/10.1155/2015/243947

[21] Darras, Kevin, Péter Batáry, Brett Furnas, Antonio Celis-Murillo, Steven L. Van Wilgenburg, Yeni A. Mulyani, and Teja Tscharntke. "Comparing the sampling performance of sound recorders versus point counts in bird surveys: A meta-analysis." *Journal of applied ecology* 55, no. 6 (2018): 2575-2586. https://doi.org/10.1111/1365-2664.13229