

Investigation of the acoustic behavior of oil palm (*Elaeis guineensis*) frond fiber at various weights

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Abstract

The increasing demand for sustainable materials in noise control applications has driven interest in natural fiber-based sound absorbers. This study investigates the potential of oil palm frond fiber (*Elaeis guineensis*) as an alternative to synthetic acoustic materials. The fibers were extracted, dried, and hot-pressed at 200°C into 100 mm × 10 mm cylindrical samples with varying weigh of 20–60 g. Pore morphology and composition were analyzed using SEM–EDX, while sound absorption coefficients (α) were measured using an impedance tube (ISO 10534-2) across 125–4000 Hz. SEM–EDX results revealed a highly porous structure dominated by carbon (57.5%) and oxygen (41%), confirming the organic nature of the fibers. The material exhibited strong absorption in the mid- to high-frequency range (500–4000 Hz), with $\alpha = 0.99$ at 4000 Hz and a maximum NRC of 0.89 at 50 g. Optimal performance occurred at 40–50 g, with $\alpha > 0.95$ between 500 and 2000 Hz, while low-frequency absorption (<250 Hz) remained limited ($\alpha = 0.1$ –0.6). Overall, oil palm frond fiber demonstrates significant potential as a low-cost, biodegradable, and sustainable acoustic material for medium- to high-frequency applications, such as interior acoustic panels and building insulation systems.

Keywords:

Fiber, oil palm fronds, sound dampener, sound absorption coefficient, environmentally friendly material, impedance tube.

1 Introduction

The demand for acoustically comfortable environments is increasing due to rapid technological development and urbanization. High noise levels pose significant challenges frequently encountered in urban and industrial areas. Such noise can adversely affect human health, comfort, and productivity in workplaces, homes, and public spaces [1]. Efforts to address this issue have led to the development of various sound-absorbing products made from both synthetic and natural materials, including fibers derived from oil palm fronds.

Indonesia's oil palm industry continues to grow rapidly, positioning the country among the largest producers globally [2]. However, this success is accompanied by challenges, notably the generation of substantial waste from oil palm fronds (*Elaeis guineensis*) [3]. Although these materials were previously regarded as low-value waste, they have been recognized for their potential applications, including soundproofing [4].

The fiber from oil palm fronds is a natural material with a fibrous structure and the potential to effectively absorb sounds.

This natural fiber is environmentally friendly, easy to obtain, and relatively inexpensive. The attributes lead to the identification as an attractive alternative compared to synthetic-based commercial soundproofing materials which are generally more expensive and less environmentally friendly materials are often used in soundproofing. Therefore, utilizing fiber from oil palm fronds as a soundproofing material is anticipated to reduce noise pollution while supporting sustainability principles by minimizing waste from the oil palm industry [5].

Suhaeri et al. (2024) previously reported that test samples without aluminum coating exhibited a reduction in Sound Absorption Coefficient (SAC) by 0.05–0.1 (5–10%) compared to those coated with perforated aluminum. This trend can be attributed to the larger surface area of aluminum, which, relative to the total area of holes transmitting sound to the test samples, resulted in increased sound reflection [6]. Consequently, this study aims to evaluate the potential of oil palm frond fiber as a soundproofing material through experimental methods. The goal is to address the waste issue associated with the oil palm industry and to introduce a new, more sustainable, and economically viable solution for mitigating noise pollution.

2 Research methodology

2.1 Materials

The main components of the oil palm tree include the roots, trunk, fronds, leaves, flowers, palm fruits, and fruit bunches, as illustrated in Fig. 1. Fronds are compound leaves composed of a stalk (petiole), a stem (rachis), and leaflets (pinnae) arranged in a spiral pattern along the trunk. Each tree typically produces approximately 20 to 25 fronds annually. Additionally, the petiole and rachis contain natural fibers with a porous, lightweight structure, rich in lignocellulose, including cellulose, hemicellulose, and lignin. These characteristics position oil palm fronds as a promising alternative raw material for the production of composite materials, natural sound dampeners, and organic planting media. Furthermore, their microscopic structure reveals cavities and high porosity, which enhance their effectiveness in absorbing sound waves and water [7].



Fig. 1. Oil palm tree.

2.1.1 Preparation of test materials

The material used in this study was oil palm fronds obtained from the plantation area as presented in Fig. 2(a). Fronds were washed thoroughly with water to remove dust, dirt, and other contaminants, split thinly, slowly hit with a round piece of wood, and subsequently combed with a steel brush to separate the fiber from the layers as presented in Fig. 2(b).

The test sample was produced by cutting the fiber to the desired size and weighing according to the parameters in Table 1. The fiber was subsequently inserted into a round mold with an inner diameter of 100 mm adjusted to the impedance tube as shown in Fig. 3. The test sample was pressed on a hot press machine at a temperature of 200°C to ensure the fiber adhered to each other by releasing a type of glucose.



Fig. 2. (a) Palm fronds, (b) fiber from fronds.



Fig. 3. Test sample manufacturing process.

2.1.2 Study parameters

The weight of the fiber used was varied at 20, 30, 40, 50, and 60 grams and pressed with a hot press machine at a thickness of 10 mm. Moreover, the SAC test was conducted in the impedance tube (Table 1).

Table 1. Test parameters

Fiber weight (grams)	Thickness of test sample (mm)	Density (ρ) kg/m ³
20	10	254.7
30	10	382.1
40	10	509.5
50	10	636.9
60	10	764.3

2.2 Study tools

2.2.1 Scanning Electron Microscopy

The porosity and density of the samples were tested using the Scanning Electron Microscopy (SEM) which was specifically the ThermoScientific brand, Prisma E type, made in the USA as shown in Fig. 4. The process was conducted by testing the samples printed at different weights and thicknesses to determine the level of sound attenuation produced.

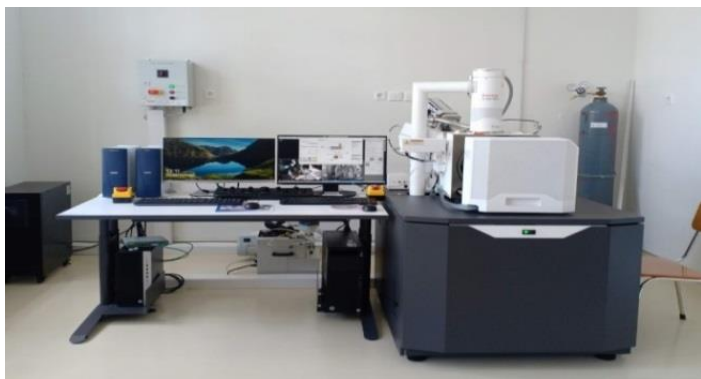


Fig. 4. SEM.

2.2.2 Impedance tube

The sound-damping performance test was conducted to measure sound absorption capability of oil palm fronds fiber-based samples. A Bruel & Kjaer type 4206 impedance tube with a diameter of 100 mm was used with reference to the ISO 10534-2 standard. The samples were inserted into the impedance tube without any extremely small gaps to the cell wall. The loudspeaker mounted close to the opposite end of the impedance tube to the test sample was used to generate broadband signals which were stationary random sound waves propagated inside the tube as plane waves. The broadband signals hit the sample and were reflected as shown

in Fig. 5. SAC (α) value was subsequently determined through sound pressure ratio produced by microphones 1 and 2, and transferred through the impedance tube as presented in Fig. 5.

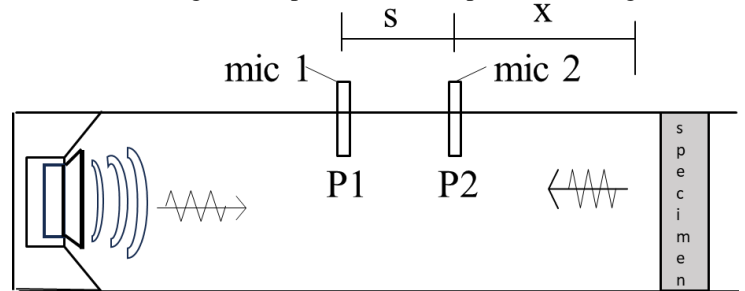


Fig. 5. The working process of the impedance tube on the test sample.

2.2.3 Hot pressure machine

The Wabash G150H hot press machine, along with supporting equipment such as molds and stoppers depicted in Fig. 3, was utilized to produce the samples shown in Fig. 6. This process involved pressing and shaping the samples to the desired thickness to ensure that their dimensions matched the diameter of the impedance tube.



Fig. 6. Hot press machine.

2.3 Experiment setup

The SAC data were collected from the samples using the impedance tube apparatus configuration, as illustrated in Fig. 7. The tests were conducted across frequencies ranging from 125 Hz to 4000 Hz.

The α value was calculated based on the ratio of sound energy absorbed by the material to the sound energy incident on its surface, as presented in Eq. (1) [8] [9] [10] [11]. This value indicates the material's ability to absorb sound at each frequency. Where, sound absorption coefficient (α) and sound reflection (R).

$$\alpha = 1 - |R|^2 \quad (1)$$

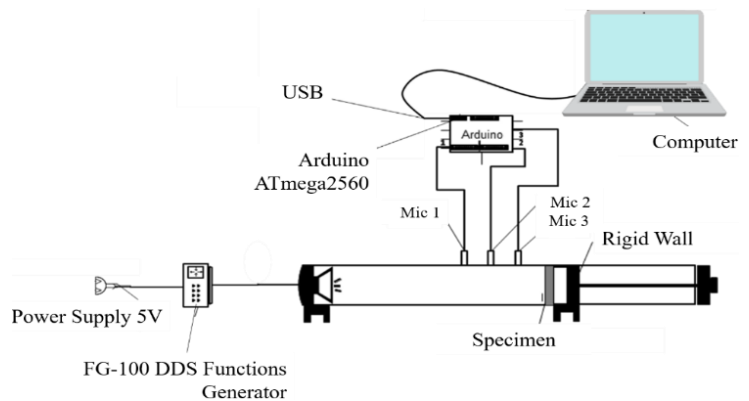


Fig. 7. Experimental device.

2.4 Noise Reduction Coefficient value

The Noise Reduction Coefficient (NRC) value was determined using the SAC. The NRC quantifies the ability of a surface to

reduce noise by absorbing sound, expressed as the percentage of sound energy that is not reflected by the test sample, with values ranging from 0 to 1. A higher NRC indicates greater effectiveness in sound absorption, with thickness and density identified as two critical influencing factors. An acoustic product with an NRC rating of 0.80 indicates that 80% of sound is absorbed while 20% is reflected. This parameter was calculated using Eq. (2) [12] [13], which facilitates easy visual comparison between different specimens based on the arithmetic mean value of the SAC at frequencies of 250, 500, 1000, and 2000 Hz.

$$NRC = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4} \quad (2)$$

Furthermore, the SAC values were used to categorize the samples into several groups, labeled A, B, C, D, E, and “not classified,” as shown in Table 2.

Table 2. Sound absorption classes [14] [15] [16]

Sound absorption class	Absorption coefficient (α)
A	0.90; 0.95; 1.00
B	0.80; 0.85
C	0.60; 0.65; 0.70; 0.75
D	0.30; 0.35; 0.40; 0.45; 0.50; 0.55
E	0.25; 0.20; 0.15
Not classified	0.10; 0.05; 0.00

3 Results and discussion

3.1 Physical characteristics of the fiber

The fiber used in this study was obtained from the fronds of oil palm tree (EG) and was observed to exhibit distinctive physical characteristics after the drying and separation processes. The visual observation showed that the materials had a brownish to dark brown color with a fairly rough surface as presented in Fig. 8. The length also varied from 25 mm to 100 mm depending on the processing and shredding methods used while the diameter ranged from 150 to 300 micrometers [17].



Fig. 8. (a) Palm trunk, (b) palm frond.

The fiber was structurally elongated, fibrous, and quite stiff but flexible. Moreover, the assumption of a microscopic observation showed the presence of internal cavities or lumens within the fiber structure. The cavities contributed to the acoustic properties of the fiber by trapping and dissipating sound waves. The density of the fiber classified as a single material was estimated at an average of 1.25 kg/cm³ [18] but the analysis of the test panel through the cylindrical form showed that the actual density depended on the weight and thickness.

3.2 Chemical characteristics of the fiber

The fiber is chemically composed of three main components: cellulose, hemicellulose, and lignin. Literature analysis and proximate references indicate that cellulose constitutes 50.21%, hemicellulose 72%, lignin 20.5%, starch 12.19 mg/ml, glucose 5.97 mg/ml, xylose 6.61 mg/ml, and arabinose 1.09 mg/ml. Cellulose is the principal component that provides tensile strength and structural stability to the fiber, while hemicellulose, being more amorphous, contributes to flexibility. Lignin adds stiffness and enhances resistance to biological degradation.

The high lignin content also acts as a natural barrier against microorganisms; however, it can inhibit the interaction between the fiber and the matrix in composite applications. This complex chemical structure significantly influences acoustic performance, as both cellulose and lignin possess the ability to block sound waves through a combination of internal absorption and scattering. Additionally, the high pore content and surface roughness facilitate the diffusion of sound waves into the material [7] [10].

3.3 SEM test

Porosity was tested to determine the pore size and density of the fiber due to the important role of the parameter in soundproofing. The samples used for the test were initially subjected to the hot press machine process.

Fig. 9(a) shows the microscopic surface obtained through the scanning conducted using the SEM to have an uneven texture crisscrossing with pore gaps in each fiber. The visual analysis of the image displayed several holes or cavities, indicating the presence of porosity in the palm frond material. This characteristic is particularly significant for materials intended for acoustic absorption. Furthermore, no visible foreign particles or synthetic materials were present, as only natural fibers were utilized as samples, without the addition of adhesives or fillers. The porous structure of the fibers demonstrates that the material is highly effective for sound dampening.

Among the recognized benefits of porosity is sound absorption, as evidenced by the impedance tube test. Additionally, cellulose is a polysaccharide, or complex carbohydrate, composed of long chains of interconnected glucose units. It serves as a major component of plant cell walls and is commonly found in natural fibers such as cotton, wood, and oil palm fronds. Fig. 9(b) and Table 3 present the EDX test results related to the chemical element composition on the surface of the fibers.

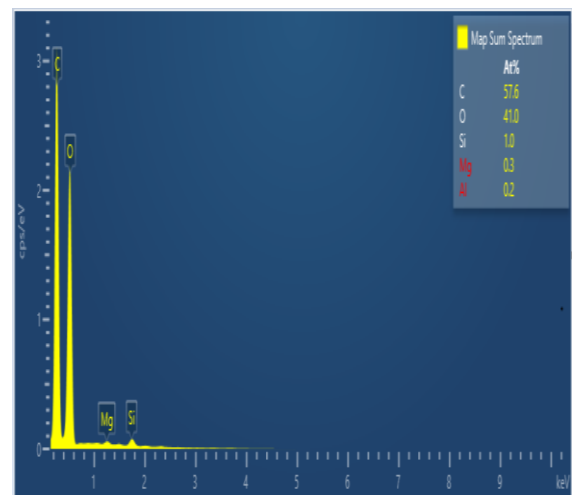
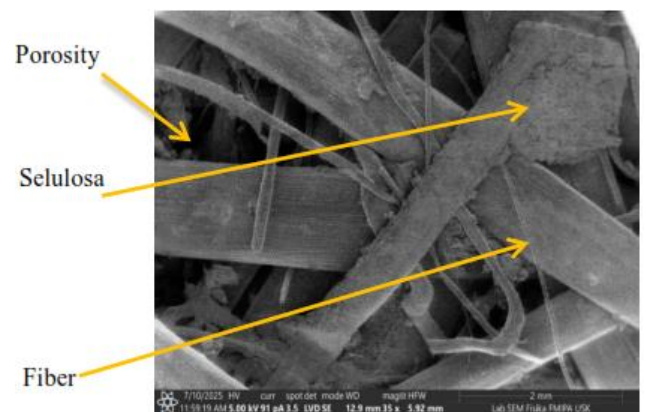


Fig. 9. (a) SEM and (b) Energy Dispersive X-ray (EDX) results.

Table 3. Percentage content of chemical elements in the fiber

Element	Chemical name	Atomic content (%)
C	Carbon	57.5
O	Oxygen	41
Si	Silicon	1.0
Mg	Magnesium	0.3
Al	Aluminum	0.2

Several chemical elements are present in the fiber, with carbon (C) constituting 57.5% and oxygen (O) comprising 41%. This trend indicates a high concentration of carbon and oxygen in fiber derived from pure oil palm fronds, absent of any filler or adhesive mixtures. This is attributable to the fiber being a biomaterial rich in cellulose, hemicellulose, and lignin, all of which are organic compounds primarily composed of carbon and oxygen. The 1% silicon (Si) content is associated with natural silica commonly found in plant tissues, particularly in the rigid components of oil palm fronds, such as the trunk and fronds. Additionally, the 0.3% magnesium (Mg) and 0.2% aluminum present are beneficial for fibrous plants like oil palm fronds. The magnesium content can be traced back to the soil minerals incorporated in the chemical composition of the fiber.

EDX results confirmed that the fiber sample is a biomass-based material, predominantly composed of carbon and oxygen, consistent with the characteristics of natural fibers. This composition underscores the potential use of the fiber as a base for absorbent materials, given its contribution to pore structure and chemical bonding mechanisms that facilitate sound wave absorption. Furthermore, the material may serve as a natural acoustic panel in construction, as the chemical structure and pore morphology of lignocellulosic fibers enhance sound wave absorption. This absorption occurs through the conversion of acoustic energy into heat energy, influenced by viscous-thermal losses within the fiber's microstructural pores.

3.4 Fiber damping capacity

The α coefficient is the primary parameter used to evaluate the acoustic performance of materials. The test results indicated that the value increased with frequency. Specifically, the α value was relatively low, ranging from 0.109 to 0.437 at low frequencies of 125–250 Hz, but rose sharply to 0.91 at 2000 Hz within the medium frequency range of 500–2000 Hz, peaking at 0.9998 at 4000 Hz. Subsequently, the performance gradually declined at higher frequencies.

Fig. 10 illustrates that all α values are low at 125 Hz, indicating that the fiber is less effective at absorbing low frequencies, particularly at weights of 20 grams and 40 grams. The results demonstrated that 30 grams yielded the best performance at this frequency, with a value of 0.5891. The low absorption at these frequencies can be attributed to the necessity for thicker materials or specialized resonators.

The α value began to increase at the low to medium frequency of 250 Hz, with the 50 gram sample achieving the best result of 0.8366. This suggests that the addition of mass enhances the fiber's effectiveness in sound absorption. Within the medium frequency range of 500 Hz to 1000 Hz, most α values exceeded 0.8, indicating very good absorption capacity. The highest value of 0.9568 was recorded for the 40 gram sample at 500 Hz, while the 20 gram sample reached 0.9998 at 1000 Hz, and the 40 gram sample recorded 0.9796 at the same frequency. This group was classified as optimal for sound absorption.

Moreover, very high α values exceeding 0.87 were recorded at frequencies ranging from 2000 Hz to 4000 Hz across all weights. Notably, the 20 gram and 30 gram samples exhibited maximum values of 0.9995 and 0.9996, respectively, at 4000 Hz. This trend indicates that lighter materials are also highly effective at absorbing high-frequency sounds, as short wavelengths are easily trapped by the porous structure of the fiber.

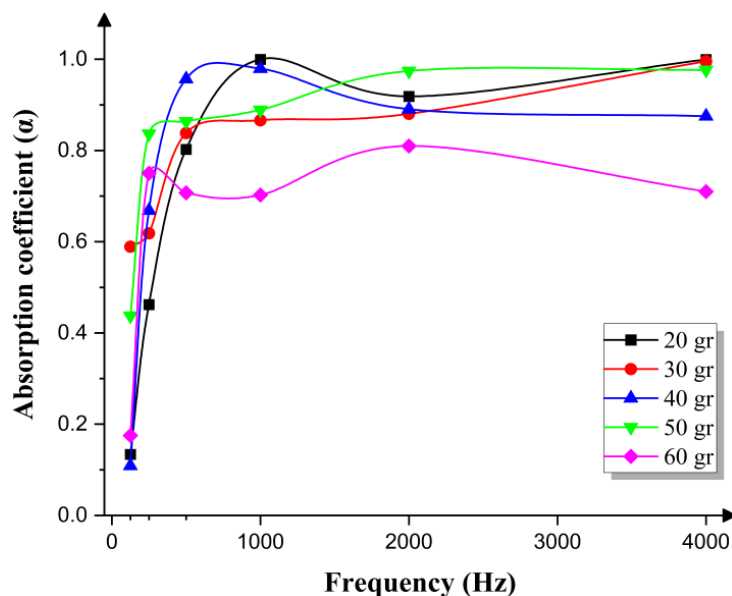


Fig. 10. Sound absorption capacity (α) of the fiber.

The fiber from palm fronds was observed to have excellent absorption performance, specifically at medium to high frequencies. The optimal performance was identified at 40 to 50 grams which produced $\alpha > 0.95$ at 500–2000 Hz. The effectiveness was reduced at 60 grams because excessive density inhibited sound penetration into the pores of material. At low frequencies such as 125 Hz, all samples were less effective at absorbing sound.

Table 4 presents the performance of the fiber based on weight variations. It is evident that sound absorption is suboptimal at 20 grams, optimal at 30 and 40 grams for the frequency range of 500 to 1000 Hz, generally effective at 50 grams, and decreases at 60 grams. This trend indicates that the fiber derived from oil palm fronds exhibits effective sound absorption characteristics at medium to high frequencies, a phenomenon commonly observed in natural fiber materials with a porous structure. The pores and lumens within the fiber function as microchannels, allowing sound energy to penetrate and be converted into heat through molecular friction. At lower frequencies, such as 125 to 250 Hz, sound waves possess longer wavelengths, making them difficult to absorb by materials with low thickness and density. Consequently, the α value remains relatively low within this frequency range. This limitation can be addressed by increasing the fiber's thickness or by incorporating an additional absorbing layer. Furthermore, density significantly impacts performance, as the damping capacity improves when thickness is held constant and fiber weight is increased, particularly at high frequencies. The optimal combination of thickness and density results in a higher SAC.

Table 4. Fiber interpretation table

Fiber weight (grams)	Performance	Information
20	Very good at high frequencies, bad at low frequencies	Too thin, too low
30	Stable and high enough at all frequencies	Quite optimal
40	Highest at 500 – 1000 Hz	Optimal for medium
50	Even and very high	Overall optimal
60	Decreased in all frequencies	Dense reduces porosity

3.5 NRC value

Eq. (2) was used to determine the NRC value using the average α value at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 2000 Hz. The result for each test sample weight is presented in the Fig. 11 [14] [19] [13].

The highest NRC value of 0.8909 was recorded at a weight of 50 grams, indicating that the sample absorbed 89% of sound, while the remaining 11% was reflected. This trend demonstrates that a weight of 50 grams is the most effective for sound absorption. In

contrast, the NRC value for 60 grams was 0.7675, revealing that only 76.75% of sound was absorbed, with 23.25% reflected. This suggests that an increase in weight does not consistently enhance sound absorption. It is possible that excessive thickness or density may lead to internal reflection or a saturation effect, as increased density can reduce porosity. Consequently, there exists a non-linear relationship between material weight and sound absorption capability. The experiment indicated that the optimal weight of fiber for sound absorption is approximately 47 grams.

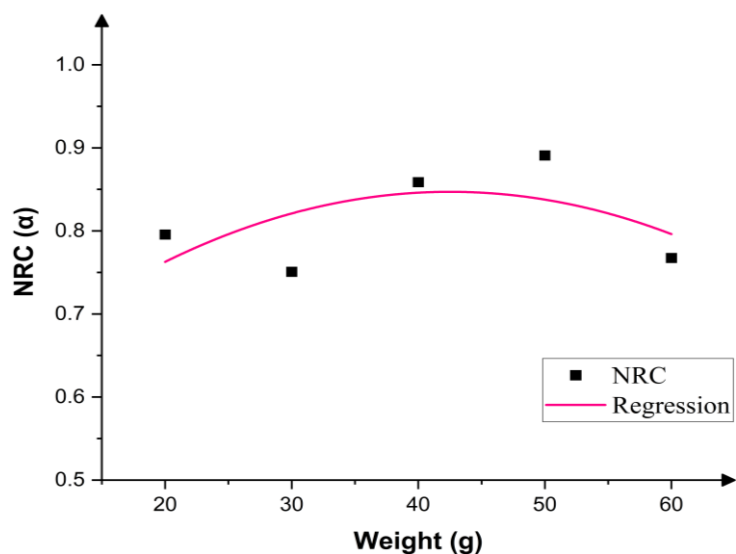


Fig. 11. NRC diagram.

Fig. 11 can be utilized to develop a second-degree polynomial regression curve illustrating the relationship between material weight and NRC value. The dashed blue line represents the regression model, which estimates the general trend of the data. The curve peaks at around 47-50 grams, indicating the optimal weight for maximum sound absorption. Beyond this peak, the NRC value decreases, suggesting that additional weight is no longer effective and may even diminish acoustic efficiency. Thus, the regression results reveal a quadratic or parabolic relationship between weight and NRC. This leads to the conclusion that the ideal weight for achieving the highest sound absorption is between 47 and 50 grams. The model has been confirmed as suitable for estimating the optimal weight of acoustic materials derived from oil palm frond fiber.

The α value of fiber extracted from oil palm fronds (*Elaeis guineensis*) in Bandung is notably higher than that of fiber from coconut and date palm. This difference is significantly influenced by the porosity of the fiber from oil palm fronds. A substantial variation is observed at 2000 Hz, where the sample from oil palm fronds (EG) has a value of 0.903, which is markedly different from the other samples (Table 5).

Table 5. Comparison of sound absorption values of fiber from oil palm fronds with coconut and date palm

Frequency (Hz)	Palm leaf fiber size (α)	Coconut fiber size (α)	Date fiber size (α)
125	0.289	0.11	0.13
250	0.667	0.14	0.17
500	0.834	0.19	0.19
1000	0.847	0.20	0.21
2000	0.903	0.40	0.43
4000	0.911	0.51	0.70

4 Conclusions

In conclusion, the comparison of SAC values obtained from fibers sourced from coconut and date palm indicated that oil palm exhibited a relatively good sound absorption capability at weights ranging from 30 to 50 grams and at medium to high frequencies

(500 Hz - 4000 Hz). However, the SAC value decreased at a weight of 60 grams and a thickness of 10 mm, likely due to a reduction in material porosity resulting from increased density.

The results indicated that the performance of fiber derived from oil palm fronds was lower at low frequencies (<250 Hz) compared to that of coconut and date palm fibers. Notably, the advantages of oil palm frond fiber include its acoustic performance, sustainability, availability, and safety in application. Additionally, the material is associated with low production costs due to its extraction from agricultural waste, making it suitable for large-scale applications and environmentally friendly projects.

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