PENA TEKNIK
JURNAL ILMIAH ILMU - ILMU TEKNIK

Vol.10, No.01, March (2025)
p-ISSN 2502-8952
e-ISSN 2623-2197
https://ojs.unanda.ac.id/index.php/jiit/index

Density Influence on Acoustic Performance of Waste Composite Materials

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Keywords:
Composite materials; sound absorption; rice husk; rice straw; sawdust

Abstract

This study aimed to determine the effect of material density on the sound absorption coefficient (SAC) of composite materials made from rice husk, rice straw, and sawdust. Rice husk, rice straw, and sawdust were made into composite materials with volume fraction variations of 30:70, 25:75, and 20:80 with a thickness of 25 mm. The samples were tested in the 200–1600 Hz frequency range using two microphones and a type 4206 impedance tube in accordance with ASTM E1050 standards. The test findings showed that the composite material made of rice straw had the best SAC at 1600 Hz with an α value of 0.72 and a volume fraction variation of 30:70, probably because it was less dense than the other materials. The maximum SAC values for the 30:70 volume fraction variation were 0.72 for the rice straw composite material at 1600 Hz, 0.42 for the rice husk composite material at the same frequency, and 0.13 for the sawdust material at 1000 I Hz. The discussion leads one to believe that the SAC is heavily influenced by the bulk density of the forming fiber material and the density that is generated by the fluctuation in volume fraction of a composite material

1. INTRODUCTION

Agricultural waste in Indonesia, especially rice straw, rice husks, and sawdust, has become a significant environmental issue. In the last five years, Indonesia's total rice production reached around 56 million tons, generating rice straw waste equivalent to about 22 million tons annually. Rice husks are also a concern, with production reaching more than 16 million tons based on BPS 2022 data (Nadiyya et al., 2022). These wastes are often burned, producing emissions that potentially pollute the air and pose a risk to public health. Research shows that the burning of agricultural waste contributes approximately 15% of the total air pollution in Indonesia, which can lead to health problems, including respiratory disorders and chronic diseases in the exposed population (Ariyanto et al., 2022).

However, Indonesia's noise pollution problem is also growing in importance. Surveys conducted over the last five years have revealed that over 80% of urban dwellers are subjected to noise levels above the permissible threshold of 70 dB. Public health is negatively impacted by this noise pollution, which leads to stress, sleep disorders, and other mental health problems (Zullaikah et al., 2022). With peak noise levels of 85 dB, Jakarta is among the cities with the highest noise levels, according to data from the Ministry of Environment and Forestry (Nabila et al., 2024). Additionally, excessive noise has an adverse effect on public health and quality of life, which can result in financial losses because of higher medical expenses (Zullaikah et al., 2022).

The importance of managing agricultural waste and noise pollution simultaneously drives innovation to utilize agricultural waste as sound-absorbing material. Research shows that agricultural waste-based materials, such as composites made from rice straw, rice husks, and wood dust, can function as effective sound insulators. The density of the material directly contributes to its acoustic performance; the higher the density, the better the acoustic performance, as demonstrated in the research by Zullaikah et al. who found a positive correlation between composite density and sound absorption capability (Zullaikah et al., 2021; Suliartini et al., 2023; Wicaksono et al., 2023).

doi http://dx.doi.org/10.51557/pt_jiit.v10i1.3037
article history: Received December 24, 2024; Received in revised from March 01, 2025; Accepted March 02, 2025;
Available online March 25, 2025.

Thus, this research needs to be more in-depth to explore the potential of agricultural waste in reducing dependence on conventional raw materials while providing solutions to existing noise pollution problems. This effort is expected to create synergy between the environment and waste utilization for the advancement of the eco-friendly industry in Indonesia.

2. METHODS

The process of composite fabrication is conducted using a mold, followed by application of pressure for a specified duration. Subsequently, an impedance tube with two microphones is used to conduct sound absorption testing in the 200 - 1600 Hz range in accordance with the ASTM E1050 standard.

2.1 Reinforcing Material

Composites are composed of two primary components, a matrix and a reinforcing substance. A variety of fibers can be used as the reinforcing material, which may be either synthetic or natural. In this research, natural fibers were utilized, specifically rice straw, rice husks, and sawdust, as illustrated in Figures 1, 2, and 3. In most cases, resins and catalysts make up the matrix, which binds the fibers together.


Figure 1. Rice straw material


Figure 2. Rice husks material


Figure 3. Sawdust material

Many applications rely on the densities of rice husk, sawdust, and straw, especially in the building and materials science domains. Rice husk has a bulk density that typically ranges from 85 to 110 kg/m³, depending on its moisture content and processing methods (Milawarni, 2023; Missagia et al., 2011). In contrast, sawdust generally exhibits a higher density, which can vary significantly based on the type of wood and processing techniques, with reported values ranging from 160 to 800 kg/m³ (Rumaizah et al., 2019; Stasiak et al., 2015). Rice straw, on the other hand, has a bulk density that falls between these two materials, typically around 162 to 194 kg/m³ (Zhang et al., 2012). The rice straw's density can also be influenced by its particle size and moisture content, which are critical factors in its application as a biomass energy source or in composite materials (Zhang et al., 2012). Understanding these density variations is crucial for optimizing the use of these agricultural by-products in sustainable construction and energy applications.

Farmers in Sidrap, South Sulawesi, Indonesia, provided the rice straw used in this research. The straw had a bulk density of 110 kg/m³ and was about 50 to 70 cm long. Similarly, the rice husks were also procured from farmers in Sidrap, South Sulawesi, with a bulk density of 138 kg/m³ and dimensions of about 10 mm in length and 3 mm in width. The sawdust utilized in this study was derived from waste generated during furniture manufacturing, exhibiting a bulk density of 214 kg/m³.

2.2 Matrix

The research employs Yukalac 157 BQTN-EX polyester resin, which is useful in a number of ways: it is inexpensive, easy to get, has low viscosity, high mechanical strength, and great environmental resistance. This resin is particularly noted for its application in composite materials due to its favorable characteristics, which enhance processing and performance in various applications (Murdani et al., 2017; Sasria, 2022). Furthermore, the catalyst employed in this study is Methyl Ethyl Ketone Peroxide (MEKP), which is commonly used to initiate the curing process in polyester resins (Herwandi & Napitupulu, 2017; Sasria, 2022). Figure 4 shows the resin used in the study, whereas Figure 5 shows the catalyst.

Figure 4. Yukalac 157 BQTN-EX resin

Figure 5. Methyl Ethyl Ketone Peroxide catalyst

2.3 Fibre Treatment

Composite panels begin with materials that have undergone an initial treatment procedure; these materials include rice husk, sawdust, and straw. Initially, these materials undergo a washing procedure with distilled water to eliminate any dust and dirt contaminants. Following this, the rice straw and rice husks are subjected to solar drying for a duration of 48 hours to facilitate moisture removal. After that, after two hours in an electric oven set at 100ºC, dry the rice straw and husks. Doing so will aid in further decreasing the materials' moisture content. To make sure the rice straw will fit in the oven, it is first chopped into sections that are about 20 to 25 centimeters in length. After the oven drying phase, the rice straw is then cut into smaller pieces ranging from 3 to 5 cm to promote uniform distribution during the molding of the composite panels.

2.4 Mould for Composite Panels

The dimensions of the mold used for molding composite panels are 300 mm x 300 mm x 45 mm, and an inner limiting iron or stopper with dimensions of 280 mm x 20 mm x 25 mm is also required. Figure 6 shows the design of the composite panel mold that was used in this inquiry, while Figure 7 shows the design of the composite panel mold that was not.

Figure 6. Design of a composite panel mould

Figure 7. Mould for composite panels

2.5 Composite Panel Manufacturing

The following phase, following the preparation of the composite panel molds, is to gather the ingredients and tools needed for mixing. Three different volume fractions were employed in this investigation. The first volume fraction, which consists of fibers, was set at 30%, while the matrix constituted 70% of the total composition. The second volume fraction, also comprising fibers, was established at 25%, with the matrix making up 75% of the total composition. The third volume fraction, which consists of 20% fiber and 80% matrix. To ensure accurate measurements, a scale and graduated cylinder were employed to measure the amounts of fibers and matrix separately. Initially, the fibers and matrix must be placed in separate containers.

The catalyst used in this study was measured at 2% of the total volume of the matrix. This catalyst was subsequently added to the resin solution, followed by thorough stirring to achieve a uniform mixture between the resin and catalyst for five minutes. Afterward, the matrix was poured into the container containing the fibers, and both components were mixed by hand until they were evenly combined. Because the resin can irritate the skin and cause burning and itching, it is essential to wear gloves throughout the process.

Once the mixture of fibers and matrix is adequately blended, it is introduced into the composite panel mold, ensuring that the mixture is evenly distributed and leveled, as illustrated in Figures 8, 9, and 10. Before placing the fiber and matrix mixture into the composite panel mold, it is essential to apply a Release Agent to all mold surfaces to facilitate the removal of the composite panel after curing. After applying the release agent, the mold is closed and placed under a press. Figure 11 shows the next step, which is to put the composite panel mold under pressure for 24 hours using a 3,000 psi jack pressure load.

Figure 8. Rice straw and matrix mixture

Figure 9. Rice husks and matrix mixture

Figure 10. sawdust and matrix mixture

Figure 11. Pressing procedure for moulding composite panels

Upon the conclusion of the composite panel molding procedure, the next step involves disassembling the mold and extracting the completed composite panel from it. Subsequently, allow the composite panels to thoroughly dry for a duration of 1 to 2 hours at ambient temperature.

2.6 Preparing The Sample

Following the molding of the composite panels, the subsequent phase involves the preparation of samples. Initially, as seen in Figures 12, 13, and 14, the composite material is cut into 100 mm diameter circles.

Figure 12. Rice straw composite material sample (RS)

Figure 13. Rice husk composite material sample (RH)

Figure 14. Sawdust composite material sample (SD)

2.7 Test for Sound Absorption

According to the ASTM E1050, a two-microphone impedance tube was utilized in this work to assess the absorption and impedance characteristics of the acoustic materials (ASTM E 1050, 1998). This impedance tube technique is favored in research settings due to its efficiency, as it necessitates a brief testing duration and requires only a small sample size. In this study, the Brüel & Kjaer impedance tube kit was used. It includes a 4206-type impedance tube, two 4187-type 1/4 inch condenser microphones, a 2716C amplifier, and a 3160-A-042 Xi LAN acquisition module. Through the use of PULSE LabShop software version 1.16.0, this configuration is connected to a personal computer. The basic idea behind this technique is to put the sample material at one end of an impedance tube and the sound source (loudspeaker) at the other. As they pass through the tube, the loudspeaker's haphazardly generated sound waves, interact with the sample, and subsequently reflect back, as depicted in the schematic diagram in Figure 16 (Çelikel & Babaarslan, 2017).

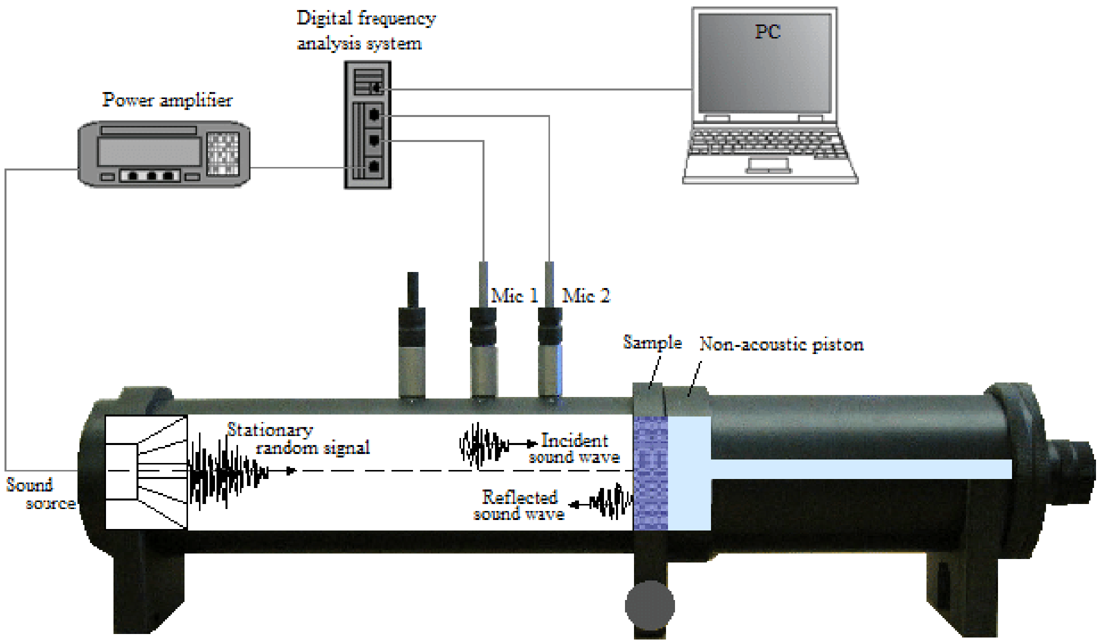

Figure 16. Brüel & Kjær impedance tube kit schematic diagram
(Çelikel & Babaarslan, 2017)

The sample used in the testing procedure has a diameter of 100 mm. The specimen is placed at one end of a tube and then linked to another tube. The adjustment process and microphone calibration follow the joining of the two tubes. Following these pre-test procedures, the sample is subjected to the sound absorption test. Sound absorption measurements will be recorded at frequencies between 200 and 1,600 Hz as part of this study. Figures 18, 19, and 20 show the sample's placement within the impedance tube, while Figure 17 shows the impedance tube used in this study.

Figure 17. The Impedance tube kit from Brüel & Kjaer


Figure 18. Mounted composite sample of rice straw


Figure 19. Mounted composite sample of rice husk

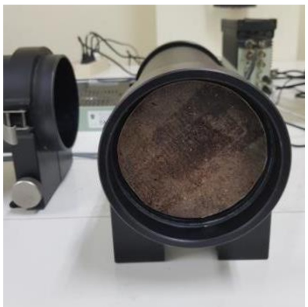
Figure 20. Mounted composite sample of sawdust

3. RESULT AND DISCUSSION

The authors of this study plotted the density against the SAC to show how the two variables relate to one another. The specific gravity of the fiber materials utilized, which include rice husk (RH), sawdust (SD), and rice straw (RS), indirectly affects density. Figure 21 and Table 1 show the noise absorption coefficients produced by the composite materials of sawdust, rice straw, and rice husk with a volume fraction of 30:70 and a thickness of 25 mm (T25), for example.

Table 1. SAC of composite materials with 30:70 fraction volume

Frequency (Hz)	SAC (α) 30 : 70		
	RS	RH	SD
200	0.12	0.06	0.01
300	0.22	0.13	0.01
400	0.36	0.25	0.01
500	0.48	0.39	0.02
600	0.47	0.40	0.02
700	0.43	0.32	0.03
800	0.41	0.24	0.05
900	0.39	0.20	0.09

Frequency (Hz)	SAC (α) 30 : 70		
	RS	RH	SD
1000	0.37	0.18	0.13
1100	0.36	0.17	0.12
1200	0.37	0.17	0.10
1300	0.36	0.19	0.07
1400	0.42	0.21	0.06
1500	0.51	0.28	0.07
1600	0.72	0.42	0.11

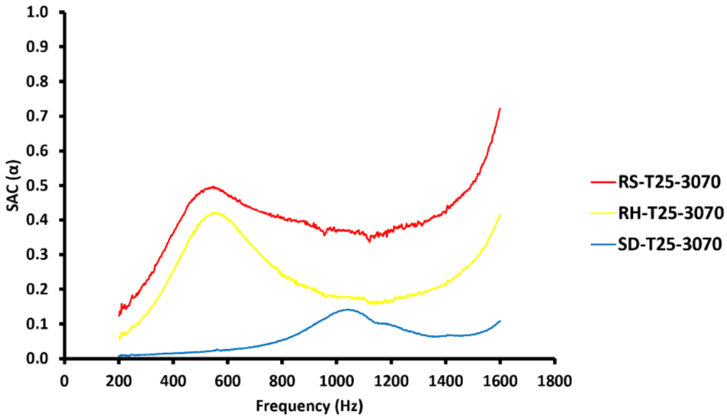

Figure 21. SAC of composite materials with 30:70 fraction volume

Based on Table 1 and Figure 21, it can be observed that rice straw composite materials exhibit the highest noise absorption coefficient across all frequencies, achieving a maximum value of α at 1600 Hz of 0.72. This is followed by rice husk composite materials, which have the second highest noise absorption coefficient, reaching a peak value of α at 1600 Hz of 0.42. Lastly, sawdust composite materials demonstrate the lowest noise absorption coefficient, with max α value at 1000 Hz of 0.13. Figure 22 and Table 2 show the noise absorption coefficients produced by rice husk (RH), sawdust (SD), and rice straw composite (RS) materials with a volume fraction of 25:75 and 25 mm (T25), respectively.

Table 2. SAC of composite materials with 25:75 fraction volume

Frequency (Hz)	**SAC (α)**			**Frequency (Hz)**	**SAC (α)**		
	25 : 75				**25 :75**		
	RS	**RH**	**SD**		**RS**	**RH**	**SD**
200	0.04	0.02	0.01	1000	0.23	0.15	0.06
300	0.07	0.04	0.01	1100	0.23	0.14	0.09
400	0.12	0.07	0.02	1200	0.23	0.14	0.10
500	0.20	0.11	0.02	1300	0.25	0.15	0.12
600	0.28	0.17	0.02	1400	0.27	0.15	0.11
700	0.30	0.24	0.03	1500	0.32	0.16	0.10
800	0.28	0.19	0.04	1600	0.41	0.20	0.11
900	0.26	0.15	0.05				

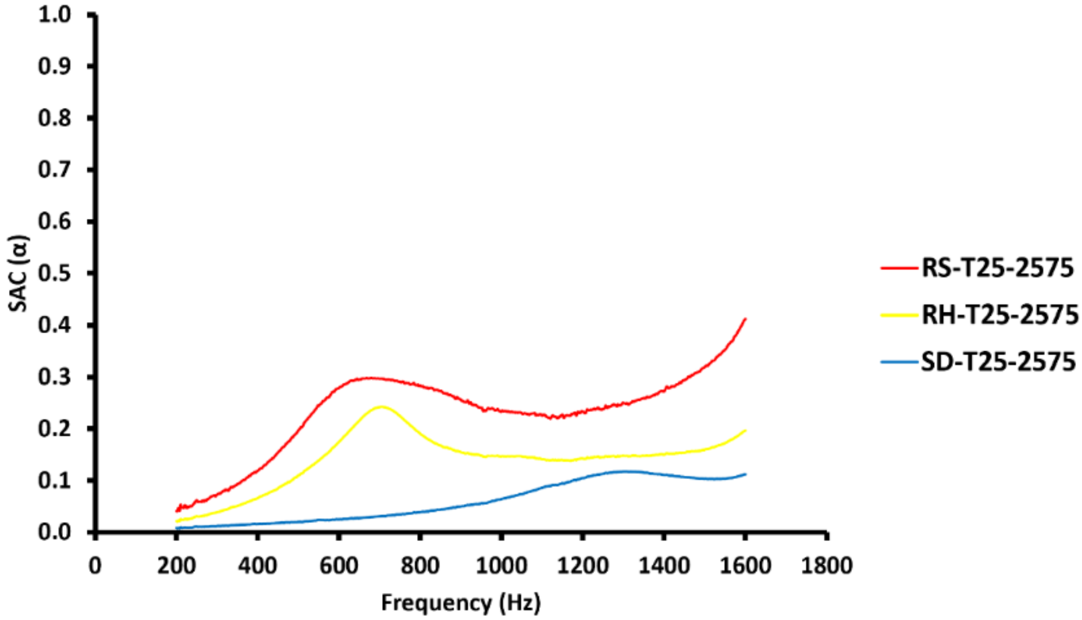

Figure 22. SAC of composite materials with 25:75 fraction volume

Based on the findings presented in Table 2 and Figure 22, The best noise absorption coefficient across all frequencies is clearly demonstrated by rice straw composite materials, achieving a maximum value of α at 1600 Hz of 0.41. This is followed by rice husk composite materials, which have the second highest noise absorption coefficient, reaching a peak value of α at 700 Hz of 0.24. Lastly, sawdust composite materials demonstrate the lowest noise absorption coefficient, with a maximum α value at 1300 Hz of 0.12.

Based on the data presented in Table 1, Figure 21, Table 2, and Figure 21, we can conclude that each constituent material used in the composite significantly influences metrics for the composite material's sound absorption coefficient (SAC). We are aware that the bulk density of the sawdust and rice husk materials is higher than that of the rice straw material, which is lower at 110 kg/m³. The next densest material is sawdust, with a bulk density of 214 kg/m³, followed by rice husk material with a density of 138 kg/m³. Ultimately, it may be said that a composite material's SAC is directly proportional to its bulk density, and that the reverse is also true.

Composites' overall mass density significantly influences their sound absorption coefficients, with optimal density levels being crucial for maximizing acoustic performance. Higher bulk densities often correlate with reduced porosity, leading to diminished sound absorption capabilities due to the smaller pore sizes that are essential for effective sound wave dissipation (Chanlert et al., 2022; Lyu et al., 2019). For instance, studies have shown that composites with increased flow resistivity and tortuosity, resulting from higher bulk density, hinder sound wave propagation, causing more energy loss through friction (Jang, 2023; Prabowo et al., 2019). Conversely, materials with lower bulk density tend to exhibit higher porosity, which enhances their sound-absorbing abilities (Chanlert et al., 2022). Additionally, the relationship between density and sound absorption is complex "while higher density can improve performance at certain frequencies, it may also lead to suboptimal absorption at others, particularly in low-frequency ranges" (Lyu et al., 2021; Sakagami et al., 2019). Therefore, careful consideration of bulk density is essential in the design of composite materials aimed at optimizing sound absorption properties.

Figure 23 and Table 3 show the corresponding results for the sound absorption coefficient values produced by rice straw composite material with a 25 mm thickness and volume fraction variations of 30:70, 25:75, and 20:80, respectively.

Table 3. SAC of rice straw composite material with 30:70, 25:75, and 20:80 fraction volume

Frequency (Hz)	SAC (α)			Frequency (Hz)	SAC (α)		
	RS				RS		
	30 : 70	25 : 75	20 : 80		30 : 70	25 : 75	20 : 80
200	0.12	0.04	0.01	1000	0.37	0.23	0.08
300	0.22	0.07	0.01	1100	0.36	0.23	0.11
400	0.36	0.12	0.01	1200	0.37	0.23	0.12
500	0.48	0.20	0.02	1300	0.36	0.25	0.10
600	0.47	0.28	0.02	1400	0.42	0.27	0.09
700	0.43	0.30	0.03	1500	0.51	0.32	0.10
800	0.41	0.28	0.04	1600	0.72	0.41	0.14
900	0.39	0.26	0.05				

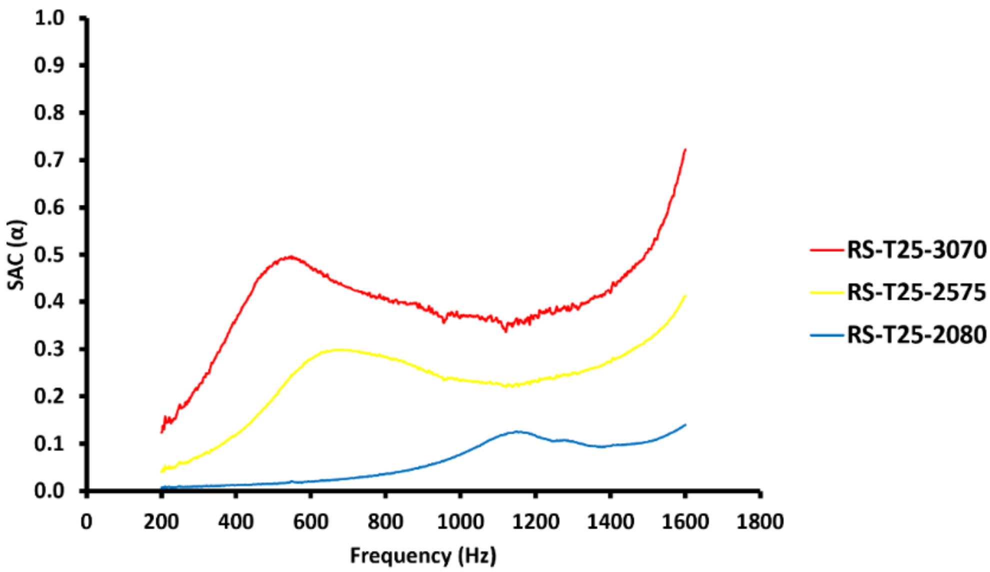

Figure 23. SAC of rice straw composite material with 30:70, 25:75, and 20:80 fraction volume

From the data shown in Table 3 and Figure 23, we can see that the rice straw composite material with a volume fraction variation of 30:70 has the highest SAC at every frequency compared to the volume fraction variations of 25:75 and 20:80, with the highest noise absorption coefficient at a frequency of 1600 Hz with an α value of 0.72. This is followed by the volume fraction variation of 25:75, which has the second-highest noise absorption coefficient, with the highest noise absorption coefficient at a frequency of 1600 Hz with an α value of 0.41. Lastly, the volume fraction of 20:80 has the lowest noise absorption coefficient, with the highest noise absorption coefficient at a frequency of 1600 Hz with an α value of 0.14. The comparison data of the noise absorption coefficients produced by the rice husk composite material (RH) with a thickness of 25 mm, and with volume fraction variations of 30:70, 25:75, and 20:80 are shown in Table 4 and Figure 24, respectively.

Table 4. SAC of rice husk composite material with 30:70, 25:75, and 20:80 fraction volume

Frequency (Hz)	SAC (α) RH		
	30 : 70	25 : 75	20 : 80
200	0.06	0.02	0.01
300	0.13	0.04	0.02
400	0.25	0.07	0.02
500	0.39	0.11	0.03
600	0.40	0.17	0.05
700	0.32	0.24	0.07
800	0.24	0.19	0.10
900	0.20	0.15	0.13

Frequency (Hz)	SAC (α) RH		
	30 : 70	25 : 75	20 : 80
1000	0.18	0.15	0.15
1100	0.17	0.14	0.14
1200	0.17	0.14	0.12
1300	0.19	0.15	0.10
1400	0.21	0.15	0.09
1500	0.28	0.16	0.09
1600	0.42	0.20	0.13

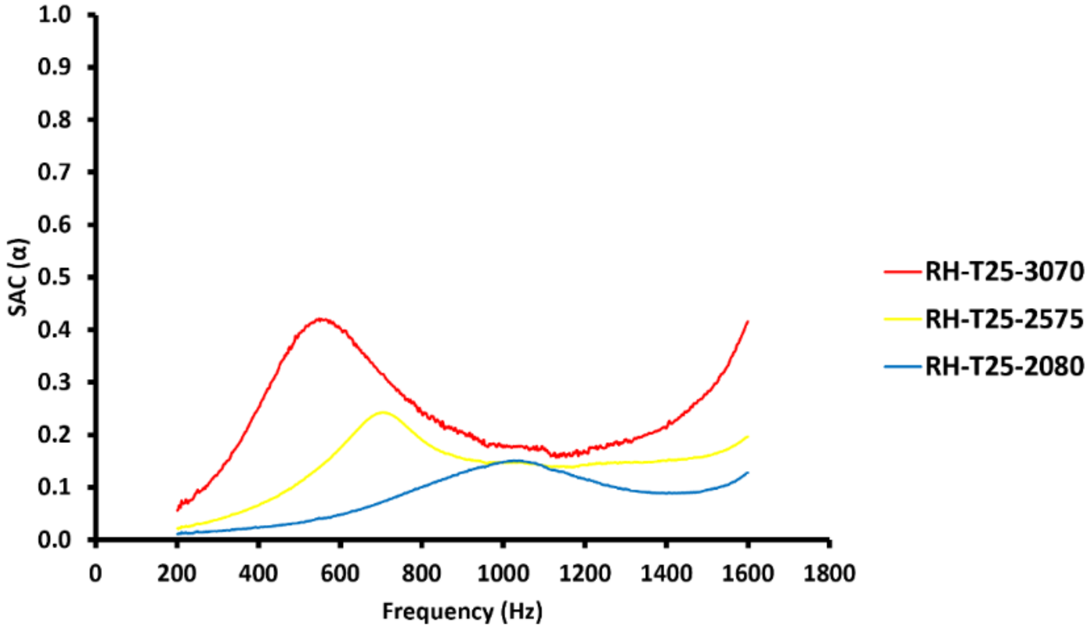

Figure 24. SAC of rice husk composite material with 30:70, 25:75, and 20:80 fraction volume

From the data shown in Table 4 and Figure 24, at all frequencies, the 30:70 volume fraction variation of the rice husk composite material has the highest noise absorption coefficient (NAC), in comparison to the 25:75 and 20:80 volume fraction variations. The highest noise absorption coefficient, with an α value of 0.42, was observed at 1600 Hz. Right after that comes the 25:75 volume fraction fluctuation, which has the second-highest noise absorption coefficient. The maximum noise absorption coefficient, with an α value of 0.24, occurs at a frequency of 700 Hz. Finally, at a frequency of 1000 Hz, with an α value of 0.15, the noise absorption coefficient is maximum for the volume fraction of 20:80, which also has the lowest value overall. After that, Table 5 and Figure 25 exhibit the comparison data of the noise absorption coefficients produced by the sawdust composite material (SD) with a thickness of 25 mm and with volume fraction changes of 30:70, 25:75, and 20:80, respectively.

Table 5. SAC of sawdust composite material with 30:70, 25:75, and 20:80 fraction volume

Frequency (Hz)	SAC (α)			Frequency (Hz)	SAC (α)		
	SD				SD		
	30 : 70	25 : 75	20 : 80		30 : 70	25 : 75	20 : 80
200	0.01	0.01	0.00	1000	0.13	0.06	0.03
300	0.01	0.01	0.01	1100	0.12	0.09	0.04
400	0.01	0.02	0.01	1200	0.10	0.10	0.04
500	0.02	0.02	0.01	1300	0.07	0.12	0.04
600	0.02	0.02	0.01	1400	0.06	0.11	0.05
700	0.03	0.03	0.01	1500	0.07	0.10	0.07
800	0.05	0.04	0.02	1600	0.11	0.11	0.09
900	0.09	0.05	0.03				

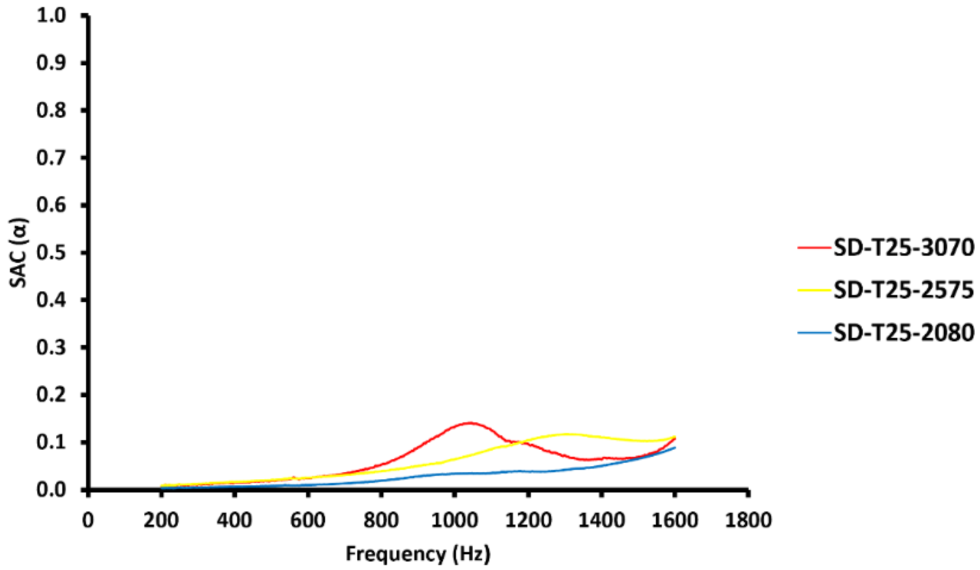

Figure 25. SAC of sawdust composite material with 30:70, 25:75, and 20:80 fraction volume

From the data shown in Table 5 and Figure 25, in the mid-frequency region, particularly at a frequency of 1000 Hz with a value of α equal to 0.13, the composite material of sawdust exhibits the highest sound absorption coefficient (SAC), as can be seen from the volume fraction fluctuation of 30:70. The noise absorption coefficient is highest at a frequency of 1300 Hz, with a value of α equal to 0.12, for the high-frequency range, in the material with a volume percent variation of 25:75, and when reaching the highest frequency of 1600 Hz, the composite materials with volume fraction variations of 30:70 and 25:75 have the same α value of 0.11. Finally, the composite material with a volume fraction variation of 20:80 is the material with the lowest noise absorption value, with the highest noise absorption value at a frequency of 1600 Hz with a value of α equal to 0.09.

From the data of composite materials with variations in the volume fraction between the fibers and the matrix, it can be concluded that the greater the matrix ratio, the higher the SAC produced by the composite material. The SAC of composite materials, particularly those incorporating fibers and polyester resin, is significantly influenced by the volume fraction of fibers and the type of resin used.

Research indicates that increasing the fiber volume fraction generally enhances the SAC due to increased porosity and surface area, with optimal results often found at specific ratios, such as 30% for banana fibers (Fauziah et al., 2022). Additionally, the inherent properties of the fibers, such as density and length, play a critical role in acoustic performance, with different fibers yielding varying SAC values (Indrawati, 2023). For instance, coir fibers exhibit distinct acoustic absorption characteristics compared to other natural fibers, although specific comparisons with date palm fibers require further investigation (Taban et al., 2021).

Furthermore, the interaction between fiber characteristics and resin content is crucial "higher fiber content can lead to improved sound absorption, particularly at lower frequencies" (Süvari & Dulek, 2019). Overall, the relationship between fiber volume fraction and SAC is complex, necessitating careful optimization to achieve desired acoustic properties in composite materials (Hassan et al., 2021; Lyu et al., 2019).

4. CONCLUSIONS

At a frequency of 1600 Hz, the composite material made of rice straw yields the maximum SAC value (α = 0.72) with a volume fraction variation of 30:70. This is because rice straw material has a lower bulk density compared to rice husk and sawdust materials. The smaller the bulk density value of a material, the higher the porosity of the material, which will improve the sound absorption coefficient value. The 30:70 volume fraction variation is an excellent ratio and has the highest SAC value, namely an α value of 0.72 for the rice straw composite material at a frequency of 1600 Hz, 0.42 for the rice husk composite material at a frequency of 1600 Hz, and 0.13 for the sawdust composite material at a frequency of 1000 Hz. The volume fraction variation also significantly affects the sound absorption coefficient value indirectly. The more resin used, the higher the density of a composite material, as a consequence, the composite material's porosity will decrease and the sound absorption coefficient will be lower. Therefore, it can be concluded that the bulk density of the forming fiber material and the density formed by the variation in volume fraction of a composite material significantly affect the resulting sound absorption coefficient.

5. ACKNOWLEDGMENTS

I wish to extend my sincere gratitude to all my esteemed colleagues who have participated and provided invaluable assistance throughout the research process.

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