



## The Acoustic Performance of Natural Composites in Reducing Stress Levels: Textile Industry

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### Abstract

The porous characteristics of recycled natural fibres make them suitable for use as acoustic materials. Straw and water hyacinth fibres are natural materials that can potentially be used as composites in damping devices. This study evaluated the acoustic performance of two types of reinforced composites containing natural fibers (water hyacinth and rice straw) and gypsum adhesives in reducing stress levels in the textile industry. The evaluation was carried out through laboratory tests using impedance tubes and direct testing in a textile factory to reduce the stress level of production machine workers and operators. Rice straw and water hyacinth fibres were thoroughly mixed in proven mass ratios of 10% and 30% with water and gypsum plaster as a binder. The mixture was pressed into a mould at a pressure of 3 MPa before being heated in an oven at 900°C for 5 hours. Perforations measuring 4 to 8 mm in diameter were then made at equal distances on the panels. Acoustic panel performance tests were carried out with impedance tubes according to ISO 10534-2 standards at sound frequencies ranging from 0 to 6400 Hz. Field tests were also conducted at a textile factory, with each machine unit generating a sound source of 100 to 110 dB. Heart rate data was collected, and noise measurements were carried out before and after the panels were installed in the area around the operating machines. The results showed that the rice straw-gypsum composite with four perforations performed the best, achieving an  $\alpha$  coefficient of 1.0 at a frequency of 1500 Hz and an NRC of 0.50, indicating effective noise reduction. The installation of acoustic panels around the noise source in the textile industry reduced noise levels by up to 9.8 dB and was found to affect workers' heart rates, indicating reduced stress levels. The questionnaire results also showed a significant effect on the stress levels of workers. The use of natural fibers in composite materials has the potential to be an eco-friendly and sustainable solution for soundproofing applications.

**Keywords:** Rice Straw; Water Hyacinth; Gypsum; Composite; Sound Absorption; Stress Level; Acoustic Materials.

### 1. Introduction

Noise is any unwanted sound that interferes with human hearing. Sound has multiple frequencies and amplitudes, while noise is sound that occurs at high frequencies. Types of noise include constant, continuous, fluctuating, intermittent, impulsive, random, and impact noises. Noise affects the physiological, psychological, communication, and deafness of the workforce or listeners. It often occurs in crowded areas, such as urban areas, due to the sounds of vehicles and activities. In addition, in the manufacturing industry, noise is often caused by the operation of a group of industrial machines. In an industrial sector where production machines are commonplace, the noises that factory equipment emits

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during operation are a nuisance that can potentially affect the comfort and health of its environmental components, primarily the operators or employees who operate this factory equipment. Therefore, it is necessary to control the noise levels in the factory environment for the benefit of employees and the factory environment.

Noise from transportation, industrial, and recreational activities has auditory and non-auditory effects. The effects of noise-induced hearing loss (NIHL) stem from exposure to occupational and social noise as well as increasing age [1]. According to the Global Burden of Disease (2019) report, 1-3 million people have been affected by NIHL [2]. The United States and Europe report that 23% of adults have NIHL, while the WHO states that there are 466 million people with hearing loss globally [3]. The non-auditory effects of noise are mental health disorders [4–8], cardiovascular diseases [9–11], cognitive performance [12, 13], and sleep disturbances [14, 15].

Acoustic damping devices are one of the multiple noise control methods that have been examined to decrease noise levels. Although industries take noise levels into consideration while outlining their needs, the actual noise levels produced were most likely unanticipated due to several factors, such as the expansion of production capacity, which requires an increase in the number of operating machines. Furthermore, many small industries often do not prioritise occupational health and safety in various regions. As such, noise-absorbing devices should be installed to decrease noise levels as well as improve occupational health and safety.

Multiple aspects of acoustic damping devices, such as performance, design, materials, and efficacy; have garnered significant attention recently. Of these, field testing potential noise-absorbing materials for acoustic absorber devices is one of the most popular. Composite materials are often used in acoustic damping devices as they provide sound management and control with the use of natural and waste materials. Porous materials are, generally, preferred for sound attenuation devices. Therefore, a combination of both materials could be used to develop a damping device that effectively decreases noise levels. Perforated panels and absorption membranes; which are types of resonance materials, are commonly used as sound absorption materials in various applications. The basic working principle of perforated panels is the prioritisation of the effect of internal resonance within a certain frequency range. Porous materials are ideal sound absorbers as they are light as well as easy to handle and manufacture.

Natural composite materials play an integral role in acoustic control. As the use and material properties of natural materials are on the rise, they present opportunities to design acoustic materials that are cheap and biodegradable. Natural materials of varying compositions, porosities, thicknesses, and other properties are generally used as composite materials in acoustic damping devices to improve and control their performance. Natural fibre materials are widely used in the acoustics industry due to their internal porosity, which makes them ideal for sound absorption as they provide more airflow resistivity. Furthermore, inherent material properties such as fibre diameter, fibre length, density, and porosity, to name a few, play a significant role in sound absorption. Berardi et al. examined the sound absorption coefficient ( $\alpha$ ) of natural fibres; such as hemp, kenaf, cotton, coconut, wood fibre, cork, and sheep wool. Other natural materials that are commonly used to make composite materials, such as coconut coir, corn husk, kenaf fibre, and wood fibre; are still in the development stage of improving their acoustic performance. Natural waste; such as rice straw and water hyacinth fibre; also has significant noise-reducing potential.

Rice straw; the second largest agricultural waste after wheat, has several potential advantages. According to multiple studies, rice straw comprises 7.36% silica, 38.7% carbon, 2.37% potassium, 1.13% calcium, 0.53% magnesium, and water in its natural state. Rice straw is preferred over coconut fibre, husk, rice, hemp, sugar cane, and other agricultural waste due to its outstanding mechanical, thermal, and acoustic properties [16-21]. The  $\alpha$  of wood-rice straw composites is 0.5 at a frequency of 2000 to 8000 Hz [22-27]. Rice straw has a noise reduction coefficient (NRC) of 0.8, which is akin to that of hemp but lower than that of hemp and cotton waste [28]. Furthermore, rice straw- methylcellulose fibre adhesive has been found to increase  $\alpha$  by 2000 to 3500 Hz and decrease the frequencies that follow [29]. Bio-foam; a mixture of 5% rice straw and polyurethane-urea; has an NRC of 0.116 [30].

Most countries consider hyacinth or *Eichhornia crassipes* a waste product [31] as it is a highly-proliferative and invasive plant that grows in tropical and subtropical regions [32]. However, in the construction industry, water hyacinth fibre is used to reinforce polymer composites [33] and to produce a cement composite [34] that has an  $\alpha$  of 0.92, which is made by blending water hyacinth fibre with recycled palm oil-based polyurethane foam (PUF) [35]. Gypsum plaster is used as a binder as it is fire retardant, provides heat and thermal insulation [18], and has an NRC of 0.12 [36]. Rice straw and water hyacinth are natural fibres that are usually mixed with cement, polymers, or wood chips. However, studies into gypsum-reinforced rice straw and water hyacinth composites are limited. Therefore, this study used gypsum as a binder to compare the use of rice straw waste and water hyacinth waste as reinforcement. Research related to natural fibers has been carried out by various researchers in the field of materials. Such as egg container waste, wood, straw, and water hyacinth. One of the studies conducted by Setyowati et al. (2021) [37] is a study related to water hyacinth fibers used as acoustic panels. In the study conducted, water hyacinth fibers were reinforced with ceramics and composites. The ceramic mixture is added to clay as a water hyacinth reinforcement. The results reviewed are the acoustic performance which shows that the absorption coefficient of water hyacinth with ceramics averages 0.29. While the resin composite has a worse absorption coefficient value of 0.10. Furthermore, research related to rice straw in the

study by Abdullah et al. (2011) [20], said that the acoustic material with rice composites has good performance, especially at frequencies above 2000 Hz and is comparable to classical synthetic absorption. In another study, water hyacinth fiber was used as a fiber-reinforced polymer composite material as a reinforcing material for concrete restraints [38, 39]. Research conducted by Jirawattanasomkul et al. (2021) [33] shows that the mechanical properties reinforced by water hyacinth are acceptable for the purposes of strengthening concrete with good environmental friendliness. From these two studies, it became a strong foundation and the finding that water hyacinth fiber reinforced by gypsum material can be used as a good and environmentally friendly acoustic panel.

The aim of this study was to determine the acoustic performance of acoustic damping devices made of gypsum-reinforced rice straw and gypsum-reinforced water hyacinth composites and field test them at a textile factory in Surakarta City, Java, Indonesia. The perforated panels were first arranged on several frames before their manufacturing processes were adjusted to satisfy the unique needs and conditions of the textile industry; the target market of this study. The ability of these panels to decrease the stress levels of machine operators by decreasing the noise emissions of the machines was examined. The findings of this present study that water hyacinth and rice straw, which are easily available natural waste products in Indonesia, can be used to address occupational safety and health. The data was collected in two stages. An impedance tube was used to examine the performance of the damping device in the first stage before the the stress levels of operators using the machines was collected in the subsequent field test stage.

## 2. Materials and Methods

### 2.1. Material Preparation

This present study used raw materials; specifically, rice straw and water hyacinth; from local farms in Central Java. The rice straw was cut into 10 mm lengths with scissors and crushed using a crusher. Rice straw and water hyacinth fibres, at densities of 0.276 gr/cm<sup>3</sup> and 0.363 gr/cm<sup>3</sup>, respectively were subjected to 3 MPa of pressure. The composites were produced by, first, cutting the 10 mm long rice straw and water hyacinth then crushing them with a five-mesh crusher. The rice straw and water hyacinth were then weighed before a dose-dependent amount of water was added to each. The rice straw and water hyacinth were mixed in separate containers with a gypsum reinforcement and adhesive. Lastly, a gypsum compound and water were added to each form a strong material.

The rice straw-gypsum-water mixture was then poured into a steel mould and set aside three hours before a hydraulic jack with a maximum capacity of 5 MPa was used to press the mould. This process was repeated with the water hyacinth-gypsum-water mixture. The composites were then removed and dried in the sun for a day before being heated in an oven at 900°C for five hours to homogenise the moisture. Table 1 provides the physical characteristics of the water hyacinth and rice straw composites. Multiple samples of the rice straw and water hyacinth composites were prepared to either contain 10% and 30% of rice straw and water hyacinth fibres. Solid samples as well as samples with one to four perforations were also prepared. All the samples were 20 mm thick. The  $\alpha$  of the samples was tested according to the ISO 10534-2:1998 standard. Some samples were cut to measure 30 mm in diameter and tested using two-microphone impedance according to the international ASTM 1050-98 standard. The absorption measurements were conducted at a frequency of 0 to 6500 Hz.

**Table 1. Sample preparation and characteristics of composites**

Sample	Gypsum (g)	Water (g)	Rice Straw (g)	Water Hyacinth (g)	Fraction	Design	Diameter Perforation (mm)	Depth (mm)
RS_10%_0	690	552	33.12	-	10%	No Perforation	-	20
RS_10%_1	690	552	33.12	-	10%	Perforation 1	8.46	20
RS_30%_1	536	429	99.36	-	30%	Perforation 1	8.46	20
RS_30%_4	536	429	99.36	-	30%	Perforation 4	5.40	20
WH-10%-0	690	552	-	43.56	10%	No Perforation	-	20
WH-10%-1	690	552	-	43.56	10%	Perforation 1	8.46	20
WH-30%-1	536	429	-	130.68	30%	Perforation 1	8.46	20
WH-30%-4	536	429	-	130.68	30%	Perforation 4	5.40	20

The field tests were conducted at a textile factory in Surakarta City, Java, Indonesia by placing the panels around several industrial machines. The sound acoustic panels were made separately with several frames (Figure 1). Figure 2 depicts the production space for the machinery. In one production room of the textile factory, there were 144 production machines divided into three blocks of 48 devices each. In one work shift, 16 machines were working in Block 1. The damping panels were placed in one of the production room blocks. Prior to collecting the sound attenuation data of the panels, the noise level in Block 1 was measured at several location points and the highest noise value was recorded. The machine operators also were equipped with Xiaomi® Mi Band 5 heart rate detection smartwatches to determine their

stress levels due to engine noises. The heart rate of every participant was recorded at hourly intervals to assess their stress levels. The heart rate data was collected both before and after the installation of the damping device. Apart from heart rate data, the participants were also required to answer a questionnaire once every hour to monitor the compatibility of the heart rate data and their subjective evaluations. The field test was conducted over a 30-day period. IBM® SPSS Statistics was used to process the questionnaire data and determine if there was a correlation between the noise generated by the industrial machines and the stress levels of the operators.



Figure 1. The acoustic panels developed and installed in the textile factory

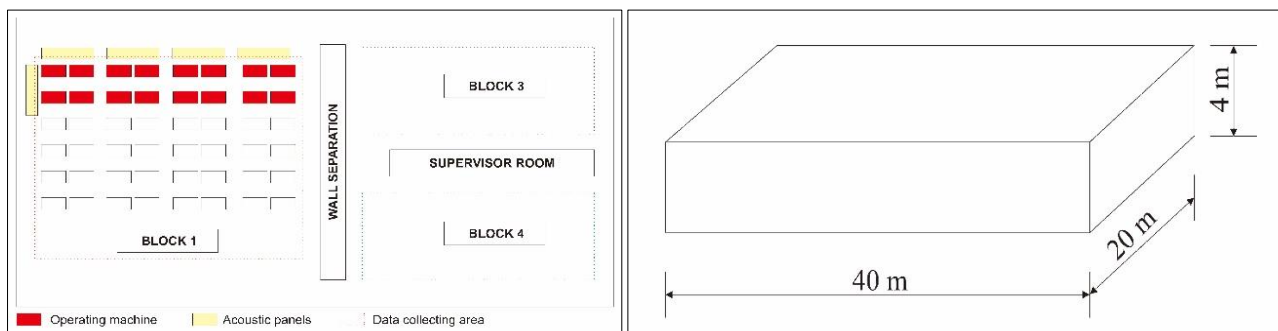


Figure 2. The layout of production machines in the textile factory

## 2.2. Methodology

The research was started by making samples, as shown in the material preparation section above. Furthermore, lab-scale testing is carried out on samples that are ready by adjusting the sample size on the impedance tube test equipment. The objective of this study was to investigate the acoustic performance of gypsum-reinforced rice straw and water hyacinth composites in reducing stress levels in the textile industry. The study was conducted in two phases: (1) laboratory testing of the acoustic properties of the composites using an impedance tube, and (2) field testing of the composites installed in a textile factory to measure their sound attenuation performance and their effect on workers' stress levels. To evaluate the acoustic properties of the gypsum-reinforced rice straw and water hyacinth composites, an impedance tube was used. The impedance tube was calibrated using a reference microphone, and the composites were placed at the end of the tube to measure their sound absorption coefficient and transmission loss. The impedance tube measurements were conducted in a reverberation-free laboratory environment at room temperature and atmospheric pressure. The sound pressure level (SPL) in the textile factory was measured using a calibrated sound level meter. To assess the effect of the composites on workers' stress levels, heart rate data was collected using smartwatches worn by the workers. The smartwatches recorded the workers' heart rates continuously during their work shifts. To gather subjective data on the workers' stress levels, a questionnaire was designed consisting of questions related to the workers' perception of the noise level and stress level during their work shifts. The questionnaire was administered to the workers after they had completed their work shift. The flow of research conducted is shown in the following flowchart (Figures 3 to 5).

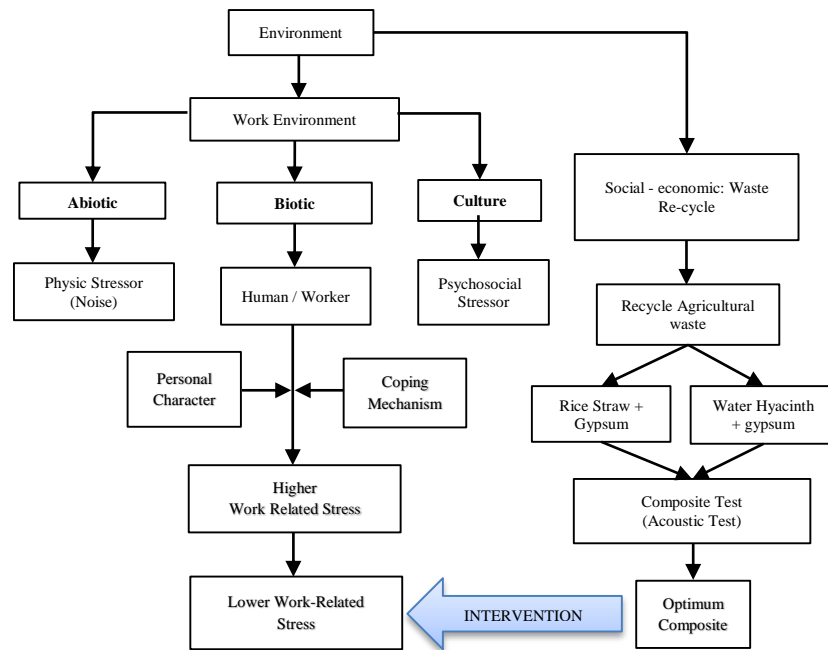


Figure 3. Environmental frame work to stress level

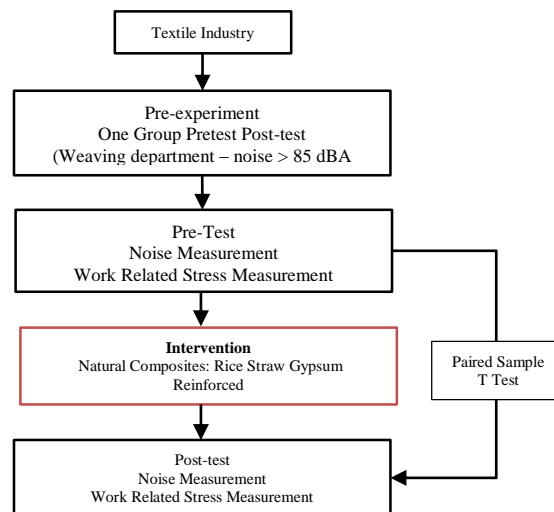


Figure 4. Pre-experimental one group pre-test and post-test design in textile industry

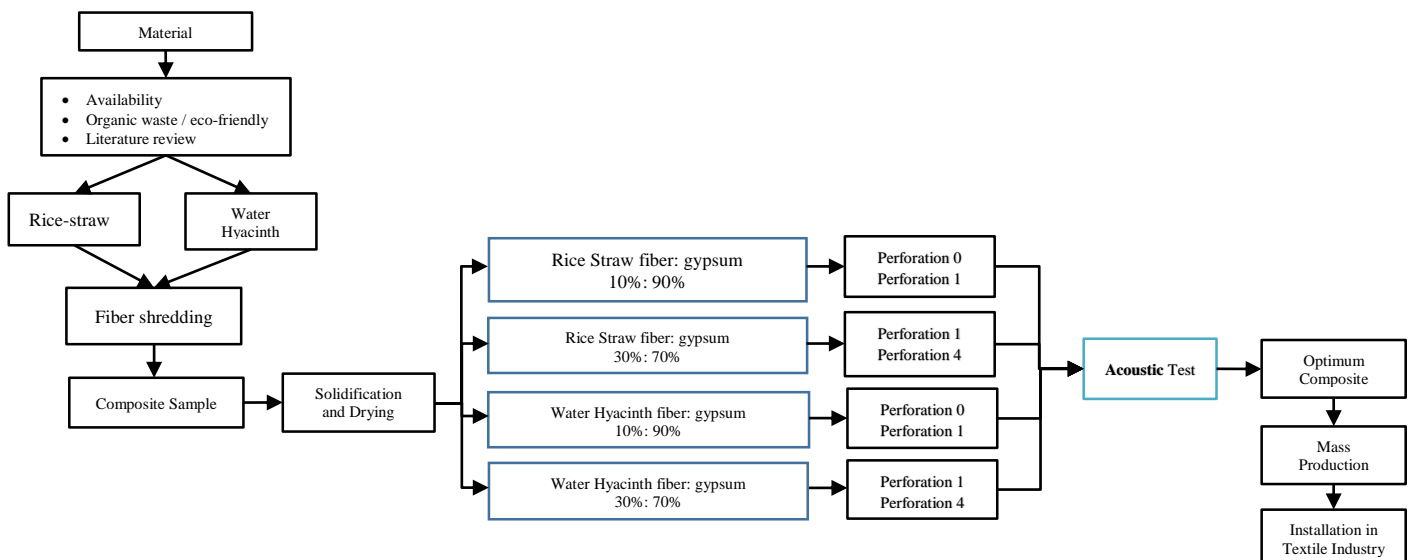
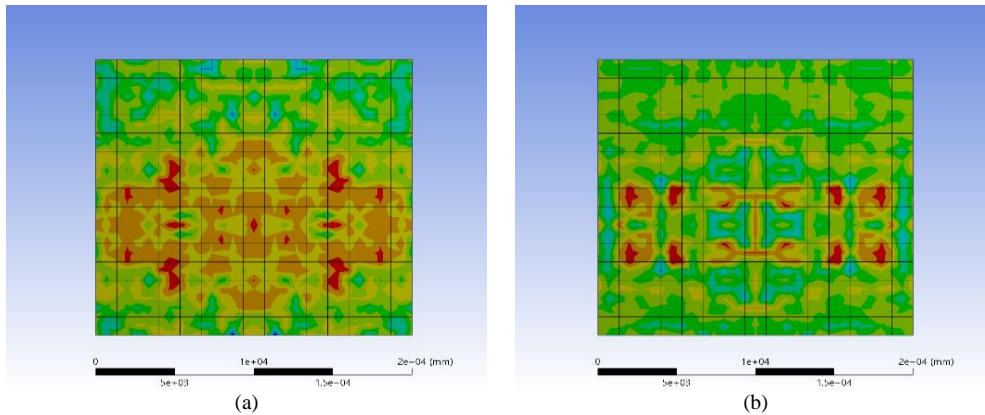


Figure 5. Laboratory research flowchart



The layout of the production room and a sketch of the room used for the data collection showed that it had a length, width, and height of 20×40×4 m, respectively. With these dimensions and with the number of machines in operation, simulations were used to predict the distribution of acoustic pressure and sound pressure levels in Block 1 (Figure 6). Figures 6-a and 6-b show the prediction of the pressure distribution from the resulting engine sound sources. Figure 6-a shows an image of the sound pressure level in decibel units in the room used for testing while Figure 6-b shows the resulting pressure distribution in MPa. The sound distribution predicted in the simulation was used to identify ideal locations to collect the highest and lowest sound data. The purpose of identifying and collecting data at the location with the lowest sound was to compare and statistically test the heart rate and questionnaire data of participations in that location with their counterparts in other parts of the factory.



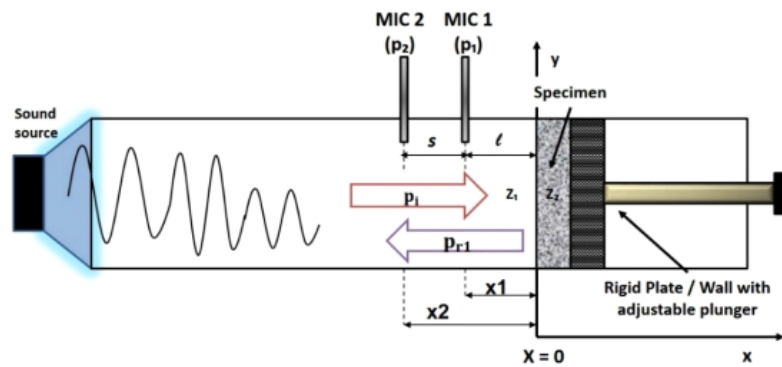
**Figure 6. Description of predicted (a) sound pressure level and (b) pressure in the textile factory room**

Figure 7 shows the installation of the sound attenuation panels in the field and the data collection process. Each panel was 3 m long and 2 m high with a composite thickness of 3 cm. Rice straw-gypsum acoustic panels with one to four perforations were installed. The impedance tests results indicated that the rice straw-gypsum acoustic panel with four perforations performed the best.



**Figure 7. The installation of acoustic panels and data collection process**

Figure 8 illustrates an impedance tube test of a sample by generating plane waves from the sound source in the impedance tube. A sound source, usually a loudspeaker, is attached to one end of the impedance tube while a sample of the tested material is placed at the other end. The speaker generates random fixed broadband sound waves, which are propagated as plane waves and bounce off after hitting the sample. The decomposition of the selected sound wave pattern into components that travel forward and backward in the tube produces a standing wave interference pattern. By simultaneously measuring the sound pressure at two fixed locations (mics 1 and 2) and calculating the complex transfer function, it is possible to determine the complex reflection coefficient,  $\alpha$ , and normal acoustic impedance of the specimen.



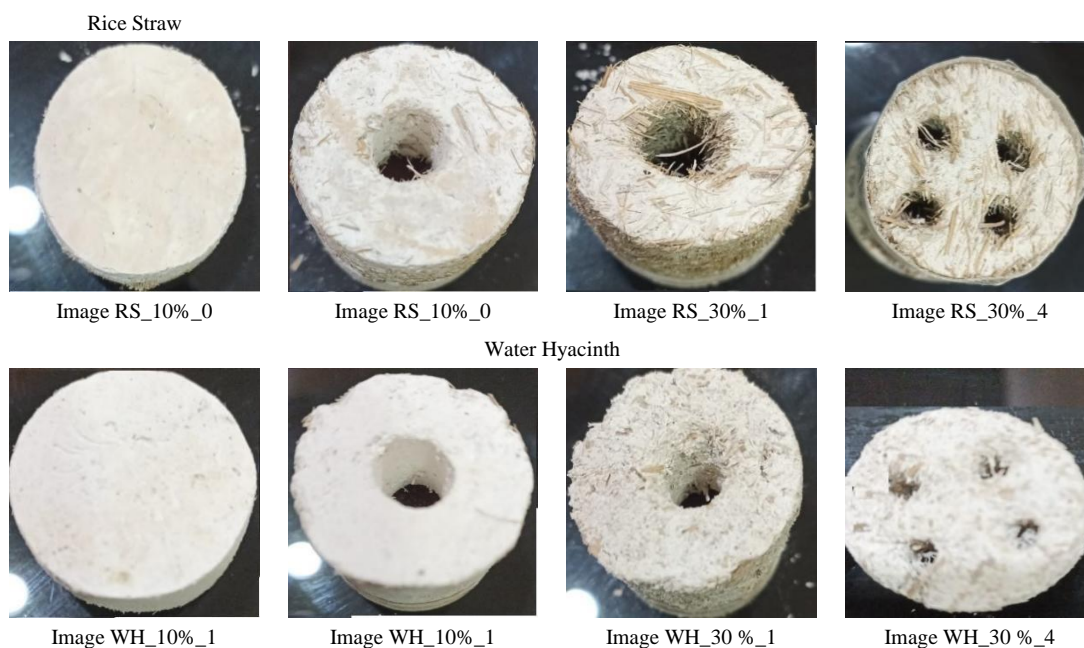
**Figure 8. A schematic diagram of the plane wave generated during acoustic measurement with a two-microphone impedance tube**

A sound level meter (Benetech GM1356) was used to measure the SPL before and after the installation of the acoustic absorber panels. The meter was calibrated before each measurement, and measurements were taken at different locations in the textile industry to evaluate the overall effectiveness of the panels. Each measurement was taken for a duration of 30 seconds, and the average value was recorded. The heart rate (HR) measurements were taken using a band Xiaomi® Mi Band 5 smartwatch worn by the workers before and after the installation of the panels. The HR data were collected using a heart rate monitor Xiaomi® Mi Band 5 smartwatch and analyzed to assess the stress levels of the workers. The band was placed around the worker's chest, and the data were recorded for a duration of 5 minutes. Then the data collected from the SPL measurements and HR measurements were stored on a computer to be analyzed. The data were saved in CSV format for further analysis.

### 3. Result and Discussion

#### 3.1. Tube Impedance Test Results

An impedance tube was used to determine the acoustic performance of four types; (1) solid, (2) 10% fibre with one perforation, (3) 30% fibre with one perforation, and (4) 30% fibre with four perforations; of both the rice straw-gypsum composite and the water hyacinth-gypsum composite. The tests were conducted using a Bruel & Kjaer® 4206 Impedance Tube Kit (Norcross, GA, USA), which comes with two types of tubes; namely, a large 100-mm tube for measuring a frequency range of 50 to 1600 Hz and a small 29-mm tube for measuring a frequency range of 500–6400 Hz. The experiments in this present study were conducted using only the small 29-mm tube. Figure 9 depicts the composite samples used for the tube impedance tests. Rice straw and water hyacinth fibres were chosen for their high cellulose content. Cellulose is insoluble in water and present in all wood-containing molecules. Linear cellulose molecules are crystalline, insoluble, and difficult to degrade chemically and mechanically. These characteristics were taken into consideration in the choice of rice straw and water hyacinth as reinforcement in polymer composites [40].



**Figure 9. The rice straw-gypsum composites and the water hyacinth-gypsum composites used in the impedance test**

Plant structures and cells comprise lignin, cellulose, and other fibres. Lignocellulosic biomass, consisting of 10–25% lignin, is a natural polymer that is abundantly available in nature. Lignin is insoluble in water, remains stable, and acts as a binding agent between cellulose and hemicellulose [41]. Lignin is a critical material between one component and another in plants. Plants with lignin and fibre are analogous to building structures that use concrete with steel frames [42]. Figure 10 shows the impedance testing of the acoustic samples. Impedance tests were conducted to evaluate the characteristics and performance of the composite samples before they were mass-produced and installed in the textile industry.



Figure 10. The impedance testing of composite samples

As seen in Figures 11 to 16, the examined test results included  $\alpha$ , reflection coefficient, and the impedance ratio of each material and their variations. The addition of perforations to the 10% rice straw-gypsum composite changed its  $\alpha$ . The  $\alpha$  of the solid rice straw-gypsum composite reached 0.32. However, the addition of one perforation increased the  $\alpha$  of the 10% rice straw-gypsum composite to 0.89 at a frequency of 1500 Hz, decreased it to 0.24 at a frequency of 3000 Hz, and increased it again to 0.60 at a frequency of 6400 Hz. The 30% rice straw-gypsum composite and one perforation achieved a maximum  $\alpha$  of 1.00 at a frequency of 1750 Hz, which decreased to 0.47 at a frequency of 3000 Hz then increased to 0.91 at a frequency of 6400 Hz. Meanwhile, the  $\alpha$  of the 30% rice straw fibre with four perforations reached 1.00 at a frequency of 1500 Hz, which then decreased at 3000 Hz then increased to 0.91 at 3000 to 6400 Hz.

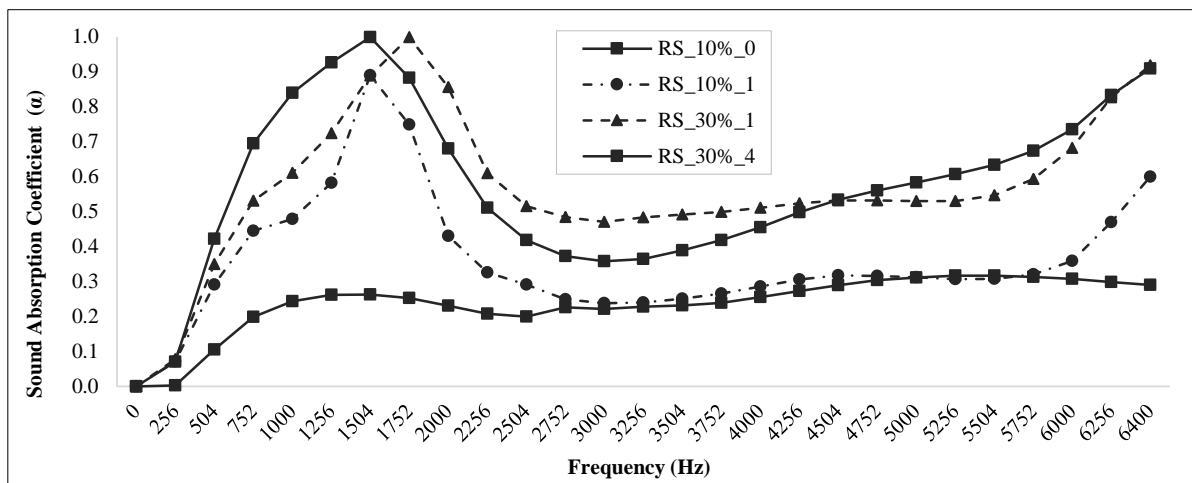


Figure 11. The sound absorption coefficient ( $\alpha$ ) of the rice straw-gypsum composite

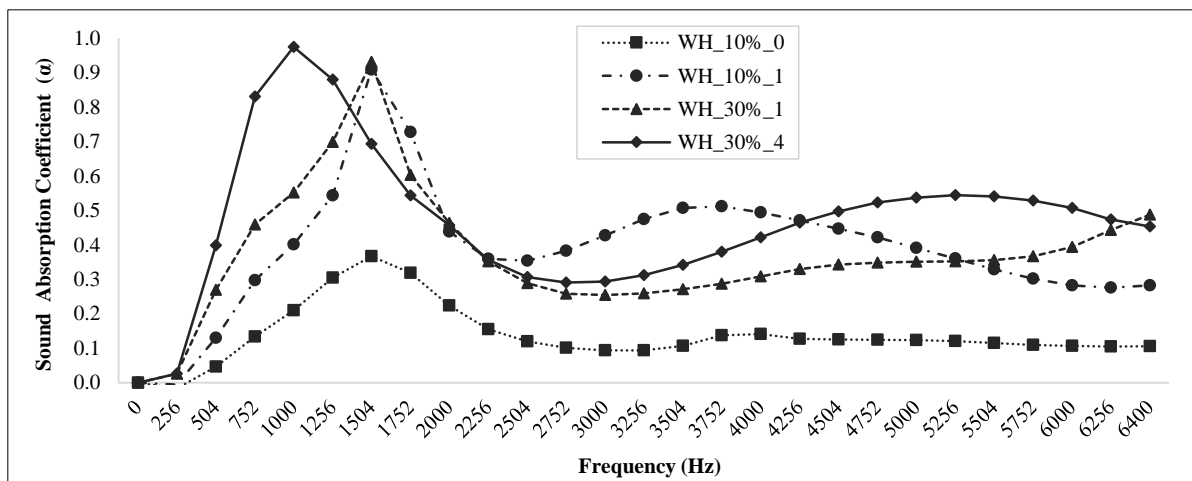


Figure 12. The sound absorption coefficient ( $\alpha$ ) of the water hyacinth-gypsum composite



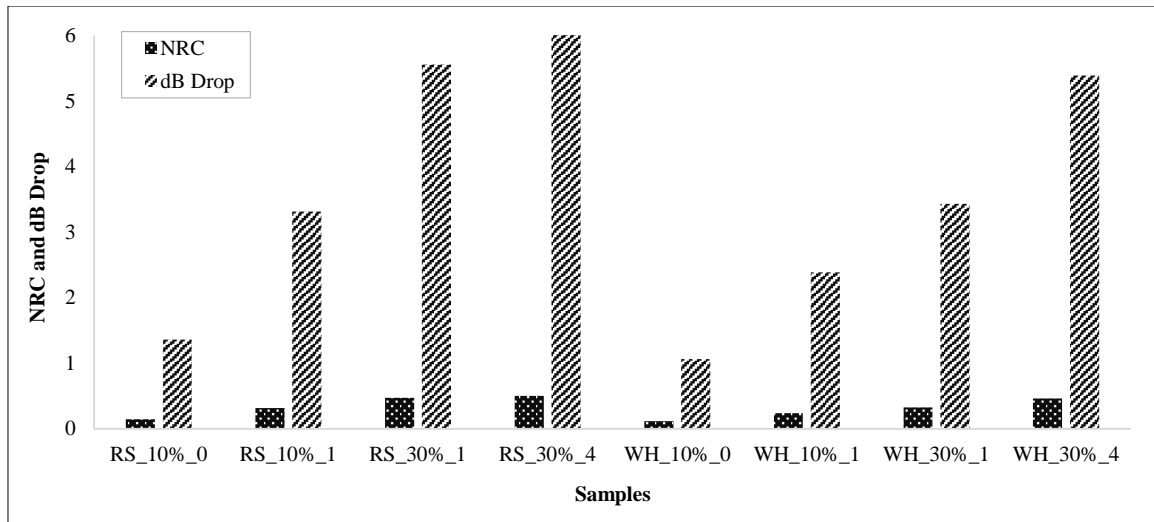


Figure 13. The decibel drop (dB) results of the impedance tests and the equations used for each material

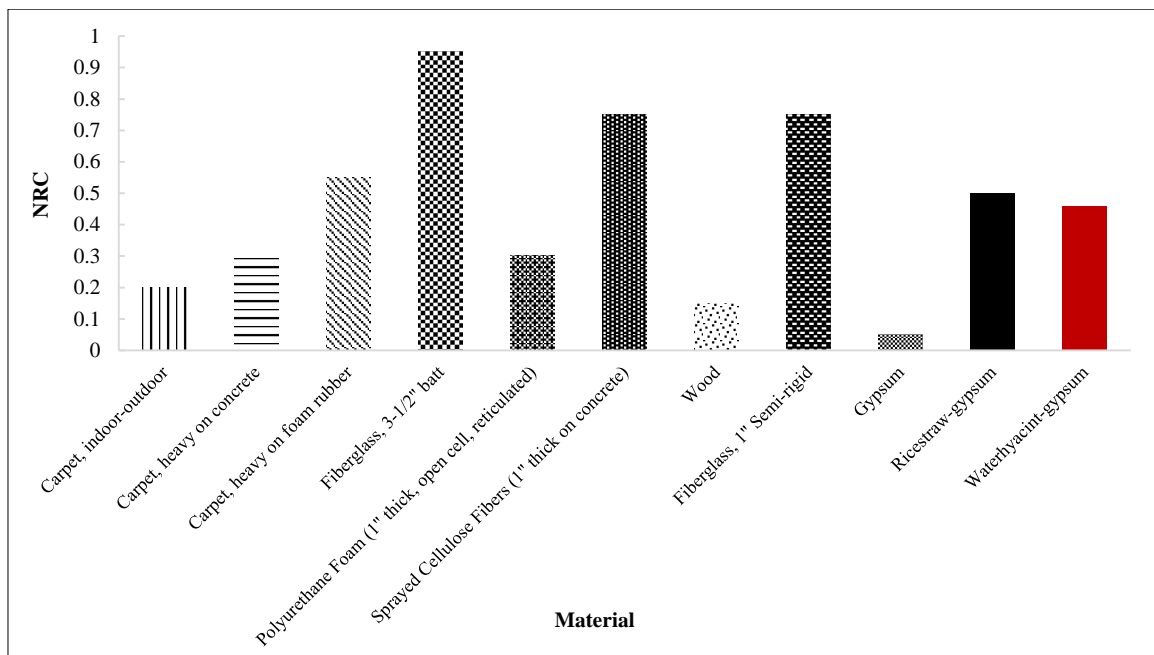


Figure 14. A comparison of the maximum NRC value of acoustic materials examined and commercialized

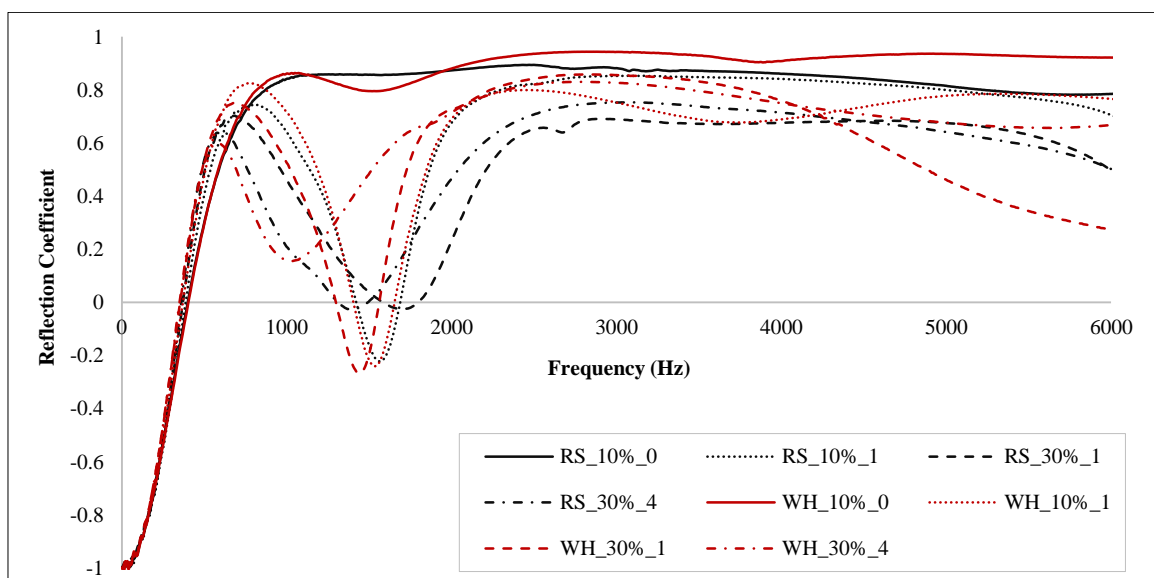


Figure 15. The reflection coefficient of each sample in the impedance test

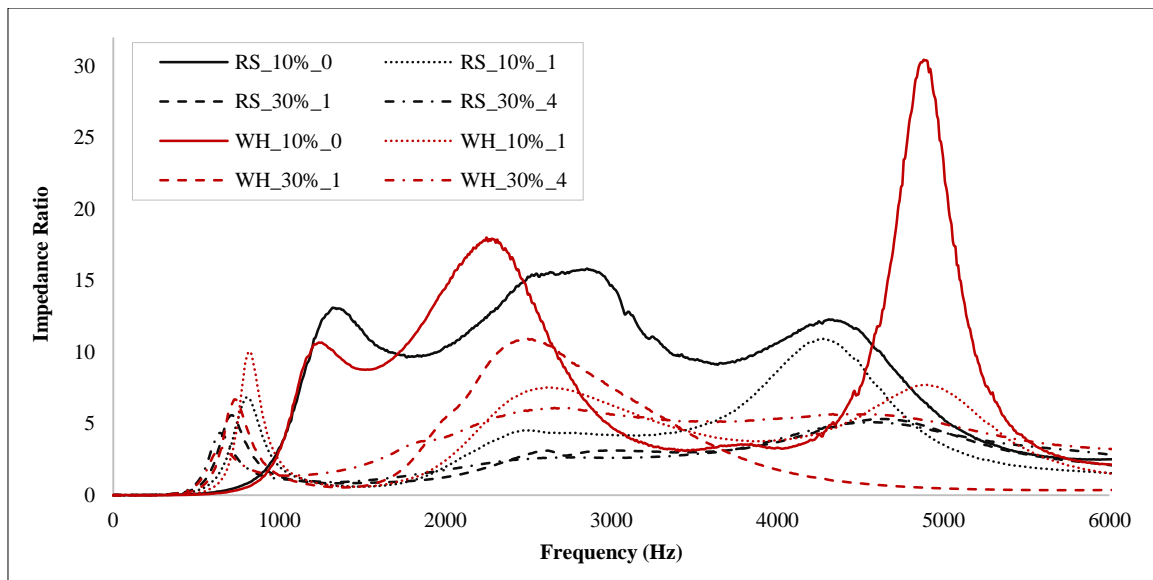


Figure 16. The impedance ratio of the impedance test

The addition of four perforations to the rice straw-gypsum composite maximised its  $\alpha$  to 1.00. At frequencies above 3000 Hz, it had an  $\alpha$  of 0.33. Meanwhile, the  $\alpha$  of the 10% rice straw-gypsum composite with one perforation increased to 0.89 at a frequency of 1500 Hz then decreased to 0.25 at a frequency of 1500 Hz. At a frequency of 3000 Hz, the  $\alpha$  increased again to 0.60 at 6000 Hz. Therefore, the addition of rice straw fibre increased the  $\alpha$ . Despite changes in the frequencies, the addition of perforations increased the  $\alpha$ . Figure 9 depicts the  $\alpha$  of the water hyacinth-gypsum composite.

The  $\alpha$  of the solid 10% water hyacinth-gypsum composite reached 0.37 at a frequency of 1500 Hz, which then decreased to below 0.2 at a frequency of 1500 to 6400 Hz. The  $\alpha$  of the 10% water hyacinth-gypsum composite with one perforation was 0.91 at a frequency of 1500 Hz, which decreased to 0.35 at a frequency of 2500 Hz, increased to 0.51 at a frequency of 3500 to 3700 Hz, then decreased to 0.28 at 6400 Hz. The addition of one perforation to the 30% water hyacinth-gypsum composite increased its  $\alpha$  to 0.93 at 1500 Hz, which then increased to 0.49 at 6400 Hz. The addition of perforations to the 30% water hyacinth-gypsum composite increased the  $\alpha$  to 0.97 at 1000 Hz, which then decreased to 0.29 at 3000 Hz, increased to 0.54 at 5000 to 5750 Hz, and decreased to 0.45 at 6400 Hz. Therefore, the higher the water hyacinth fibre content and number of perforations, the higher the  $\alpha$ . Furthermore, the  $\alpha$  of composites containing different amounts of fibre remained relatively the same so long as the number of perforations remained the same. However, the frequency did shift.

When sound waves enter a porous material, perforations support the sound absorption process and decrease the level of sound reflection. Friction occurs between high-speed wind molecules and stagnant wind molecules. When the sound waves rub against the rough surface of the porous walls, abrasion of the sound waves occurs. Sound absorption occurs when the kinetic energy of sound waves is converted into heat energy [43]. Calculating the  $\alpha$  of the rice straw-gypsum composite and the water hyacinth-gypsum composite indicated how many decibels each composite was able to absorb. Figure 10 shows the reduction in decibels of every composite variation. As seen, the rice straw-gypsum composite was able to reduce noise levels better than the water hyacinth-gypsum composite. The composite with 30% fibre and four perforations had the best design variation.

Both NRC and noise pressure reduction are interrelated. The sound reduction coefficient was obtained using the  $\alpha$ . The NRC is a rating that is used to measure how effectively a material absorbs sound. The NRC was calculated by taking the arithmetic mean of the  $\alpha$  of the material at 250, 500, 1000, and 2000 Hz and then rounding it off to the nearest 0.05. Although the standard test procedure measures absorption efficiencies at 125 Hz and 4000 Hz, these values were not used to calculate the NRC. The NRC approximates the centre frequency, making it suitable for most situations but not all. The higher the NRC, the better the sound absorption of a material. The NRC obtained was then used to calculate the decrease in noise pressure in the following equation.

$$d = -20 \log_{10}(1 - NRC) \quad (1)$$

where  $d$  is the decibel drop (dB) while the NRC is the sound reduction coefficient, which directly relates to the  $\alpha$  when a sample is tested. Based on the test results and with the above calculations, the rice straw-gypsum composite with four perforations had the best dB (6.07 dB).

The 30% rice straw-gypsum composite with four perforations had the highest decrease in sound pressure (6.07 dB) during the impedance tube test. The water hyacinth-gypsum composite with four perforations decreased noise by 5.39

dB. As seen in Table 2, the highest decrease in noise that the water hyacinth-gypsum composite with four perforations achieved was still less than that of the rice straw-gypsum composite with one perforation. Therefore, the higher the fibre content and number of perforations in the rice straw-gypsum and water hyacinth-gypsum composites, the higher the sound absorption and dB. As such, these composites could be used as absorbent walls in a noisy environment and decrease auditory and non-auditory effects on persons exposed to noise.

**Table 2. The noise reduction coefficient (NRC) and decibel drop (dB) of the composites**

	Ricestraw-gypsum				Waterhyacint-gypsum			
	10%_0	10%_1	30%_1	30%_4	10%_0	10%_1	30%_1	30%_4
NRC	0.14	0.31	0.47	0.50	0.11	0.24	0.32	0.46
dB drop (dB)	1.36	3.31	5.55	6.07	1.06	2.38	3.43	5.39

As seen in Figure 14 and Table 3, the NRC of the prepared composites were compared to that of the  $\alpha$  of several composite materials examined in extant studies to determine their feasibility [44]. The 3-1/2" fiberglass batt has the highest NRC (0.90 to 0.95). Nevertheless, the prepared composites still performed better than some of the other materials, such as the indoor-outdoor carpets, heavy concrete or foam rubber, polyurethane foam (1" thick, open cell, reticulated), and wood. The NRC of the prepared composites were equivalent to that of the sprayed cellulose fibres (1" thick on concrete) and better than that of the the gypsum reinforcement and adhesive material alone as pure gypsum only has an NRC of 0.00 to 0.05. Thus, the innovation of making natural composites reinforced with gypsum is a good improvement in the field of acoustics.

**Table 3. A comparison of the NRC of acoustic materials examined and commercialised by extant studies and the prepared composites**

Material	NRC
Carpet, indoor-outdoor	0.15 – 0.2
Carpet, heavy on concrete	0.2 – 0.3
Carpet, heavy on foam rubber	0.3 – 0.55
Fiberglass, 3-1/2" batt	0.9 – 0.95
Polyurethane Foam (1" thick, open cell, reticulated)	0.3
Sprayed Cellulose Fibers (1" thick on concrete)	0.50 – 0.75
Wood	0.05 – 0.15
Fiberglass, 1" Semi-rigid	0.50 – 0.75
Gypsum	0.00 – 0.05
Ricestraw-gypsum	0.5
Waterhyacint-gypsum	0.46

The dB performance also related to the reflection coefficient and the impedance ratio of the prepared samples. As seen in Figures 15 and 16, there was an inverse correlation between the reflection coefficient and the  $\alpha$  and dB. Adhesives and gypsum were used as reinforcement due to the low density of the prepared samples. The fibre content and number of perforations greatly affected the the reflection coefficient of the prepared samples. A fibre content of 30% performed better than 10% while four perforations was the best design. Differences were also observed in the frequency range of each composite. Samples with one perforation performed better at a frequency of 1500 Hz. However, at low frequency ranges or below 1500 Hz, samples with four perforations performed better, especially at 1000 Hz. At high frequencies of above 4000 Hz, composites with 30% fibre and one perforation performed best. These results were used to select samples for the field test. Subsequent panels were made to contain 30% rice straw fibre reinforced with gypsum and perforation. The selection was made based on several factors; such as better performance at low and high frequency ranges and more straightforward sampling.

The results of the impedance tube tests showed that the rice straw-gypsum composite with four perforations performed the best among all the tested composites. This composite achieved an  $\alpha$  coefficient of 1.0 at a frequency of 1500 Hz, indicating that it absorbed almost all of the incident sound. The NRC of this composite was also high, reaching 0.50, which means that it could reduce noise levels effectively. These results were satisfactory compared to other damping materials that have been studied, indicating that the rice straw-gypsum composite could be a promising material for soundproofing applications.

### 3.2. Acoustic Panels on Field Test Results

Figure 17 depicts the results of the field tests and show changes in the noise level and heart rate of each respondent. Pre-panel installation, the average noise around the operator was 100.89 dB, with a maximum noise of 104.6 dB, and the average heart rate of all the respondents was 56.56, with a maximum of 82. Post-panels installation, the noise and heart rate of the respondents changed at all the sampling points. The noise level and overall heart rate decreased. The heart rate trendline post-installation was visibly below the heart rate. The average noise post-installation at the same point pre-installation was 94.16 dB, with a maximum noise of 96.2 dB while the average heart rate was 56.6, with a maximum value of 79.

Therefore, there was a reasonably good reduction in noise, which also affected the heart rate of the machine operators. As seen in Figure 17, one respondent in particular; Respondent 2; experienced the highest noise level of 104.6 dB pre-panel installation. When measured at the same point post-panel installation, Respondent 2 only experienced 94.8 dB; which is a reduction of 9.8 dB. Meanwhile, Respondent 25 experienced the lowest reduction in noise (2.8 dB). This could may be explained by differences in the position of the machines that each respondent operates. More specifically, operators of machines located in the middle of the room or in between two other machine operators experienced the highest noise levels while those located the farthest from the sound source had the advantage of low noise levels even pre-panel installation.

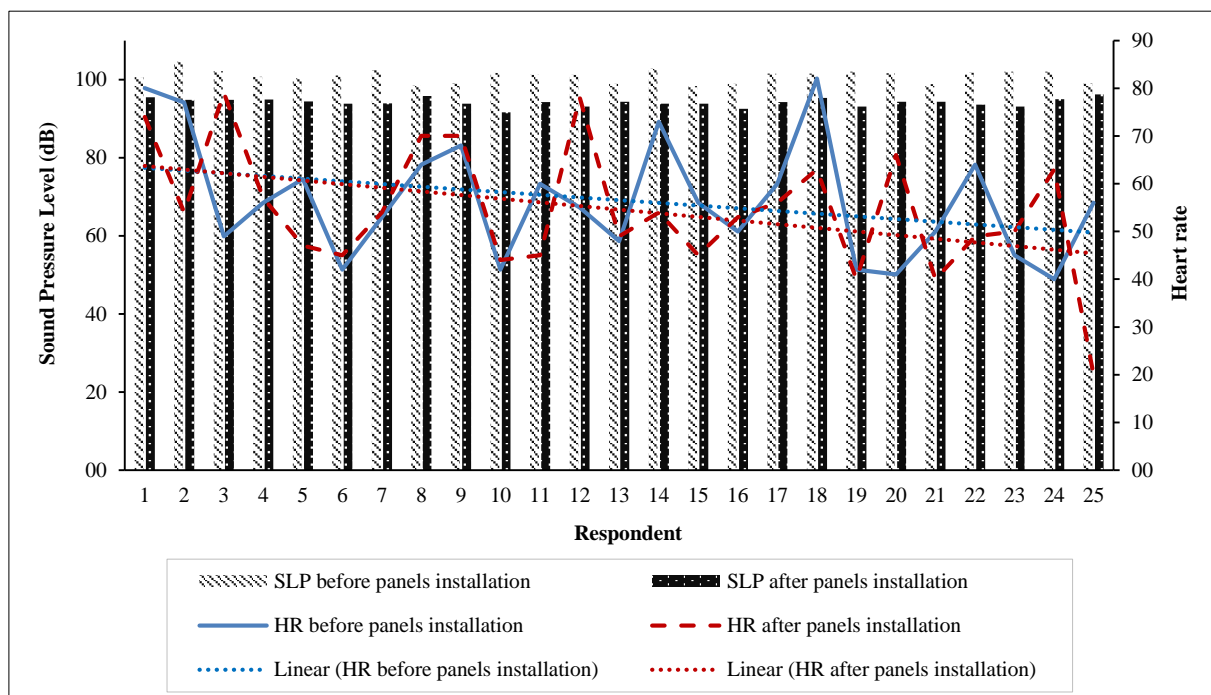


Figure 17. The sound pressure during field testing and the heart rate of the respondent

The results showed that although the installation of panels was adequate to reduce the noise level, the panel design and the number or dimensions of the panels could be improved to further reduce the noise level. Nevertheless, the installation of panels had a good effect and was even able to reduce the stress levels of the respondents, as evidenced by their heart rates. The relevant company had requested that the dimensions and number of panels be limited so that they did not interfere with the activities of its employees and the operations of its machines. The maximum number of panels that the company permitted was installed in the factory. Therefore, improvements could be made by selecting new materials or creating new geometries to enhance the performance of the acoustic damping device.

The field test results indicated that the installation of acoustic panels around the noise source could reduce noise levels in the textile industry by up to 9.8 dB. The maximum noise level reduction achieved was from 104.6 dB pre-installation to 94.8 dB post-installation. The decrease in noise levels was also found to affect the heart rate of workers, as indicated by the measurement results of the respondents. The trendline test showed that the heart rate decreased as the noise level decreased, indicating that the installation of acoustic panels could improve the well-being of workers by reducing their stress levels.

### 3.3. Stress Level Statistical Testing

Statistical tests were carried out to determine the stress levels of the respondents who were operating the machines. These respondents were given a 42-question survey over a 30-day period that aimed to determine changes in attitudes pre- and post-panel installation. Although questionnaires were distributed to 25 respondents, only 21 responses could be used in the data processing stage as the responses of four respondents differed significantly.



A Shapiro-Wilk normality test that was conducted to show the presence of noise pre-panel installation ( $p = 0.559$ ) and noise post-panel installation ( $p = 0.693$ ). The distribution of the data was deemed normal and a paired t test could be performed. Table 4 provides the results of the data testing. The difference in the mean noise pre- and post-panel installation over the 30-day period was 6.1 dBA, with  $p = 0.00$ . There was a difference in the noise with the installation of the rice straw-gypsum composite. The minus sign indicates that the mean noise post-panel installation was less than the noise pre-panel installation.

**Table 4. Noise paired t test pre- and post-panel installation**

Noise (dBA)	n	Mean $\pm$ SD	Mean Difference $\pm$ SD	IK 95%	t	p
After intervention	21	94.5 $\pm$ 0.8	-6.1 $\pm$ 2.1	-6.94 s/d-5.1	-13.7	0.00
Before intervention	21	100.5 $\pm$ 1.6				

The Shapiro-Wilk normality test showed that the results were normally distributed, and thus, the prerequisites for a paired sample t test were met. The results of the paired t test showed that there was a significant difference between heart rates. The mean heart rate post-panel installation (50.8) was lower than the heart rate pre-panel installation (65.5).

**Table 5. The heart rate-based stress levels using paired t test pre- and post-panel installation**

Stress level based on heart rate monitoring	n	Mean $\pm$ SD	Mean Difference $\pm$ SD	IK 95%	t	p
Stress level (post-intervention)	21	50.8 $\pm$ SD	-14.6 $\pm$ 11.9	-20.1 s/d 9.2	-5.6	0.00
Stress level (pre-intervention)	21	65.5 $\pm$ SD				

Noise has direct and indirect effects on humans. Exposure to high noise through direct pathways damages the ear and causes deafness while exposure via indirect pathways interfere with communication as well as cognitive and emotional responses, thereby causing stress responses; such as discomfort and depression. Stress responses activate the autonomic nervous system and endocrine system (pituitary gland and adrenal glands) and, if the stress occurs continuously (chronic), it can affect blood pressure, blood lipids, blood viscosity, blood glucose, and cause heart disease [45].

Dysfunction of the autonomic nervous system is associated with several psychiatric disorders [46]; such as depressive disorders [47] post-traumatic stress disorders, anxiety disorders [48], and schizophrenia. Heart rate is a transdiagnostic biomarker for clinical checks in identifying a subject's risk of developing physical and psychiatric health problems [49].

Heart rate had been used as an indicator of cardiac health. A resting heart rate above 80 bpm is associated with a 33% and 45% increased risk of cardiovascular death, and a heart above 60 bpm presents a risk of cardiovascular disease (CVD) of 1.19 (0.95-1.50) at a 95% confidence interval. There is a non-linear correlation between heart rate and heart failure [50]. Workers who are exposed to acute and chronic noise can produce biological stress responses in the form of body pressure, hypertension, heart rate, cardiac arrhythmia, vascular resistance, and cardiac output. The heart rate indicator for workers exposed to noise above 85 dB showed an increase in heart rate compared to exposure to noise below 85 dBA [51]. Heart rate and blood composition can change due to exposure to noise, where the heart rate can rise to 3 beats per minute for every 10% increase in the minutes of exposure to peak noise that does not disappear [52]. Noise exposure creates an autonomic imbalance, which results in a continuous increase in heart rate even though the noise source has been turned off [53].

This study used heart rate and heart rate variability as stress response biomarkers from the autonomic nervous system of workers exposed to noise. The stress prediction measurements were based on physiological signals from the workers who were exposed to noise. Each worker had to wear a Xiaomi® Mi Band 5 smartwatch, which was equipped with a photoplethysmogram (PPG) and a stress measurement sensor. The Xiaomi® Mi Band 5 has a PPG sensor and uses heart rate data to determine the interval between each heartbeat. When using the stress feature, the Xiaomi® Mi Band 5 uses the heart rate and heart rate variability (HRV) data to determine the interval between each heartbeat. Technical advances have also made it possible to measure the HRV by detecting the pulse with a belt around the chest [54] or on the wrist [55]. The respondents were workers worked eight hours a day in the loom-weaving section of a textile factory in Central Java, Indonesia. A random sampling method was used to select the respondents. A Benetech® sound level meter was used for the noise measurements while a Xiaomi® Mi Band 5 smartwatch was used for the stress measurements. Paired t tests were performed to determine differences in noise levels and stress levels pre- and post-panel installation.

The variation in the length of time between each heartbeat is regulated by the body's autonomic nervous system (ANS), which also controls the heart. The ANS consists of parasympathetic and sympathetic branches. The sympathetic branch of the ANS is active when stress is being experienced and keeps the limbs in a state of alert while the parasympathetic branch of the ANS is the relaxing part of the nervous system. When the sympathetic branch is active,

the heart rate increases in a more regular rhythm so that the HRV decreases. When the parasympathetic branch is active, the heart rate decreases according to the body's needs but with a rhythm that is not too strict, thereby increasing the HRV. Heart rate variability (HRV) is an indicator of the balance of the activity between the two branches of the autonomic nervous system. A low HRV means high stress, while a high HRV means low stress. It measures this balance in the time and frequency domains and, as it is affected by stress, it can be used as an objective assessment of stress [56, 57]. This study conducted examined textile workers who were exposed to noise >85 dBA, which exceeded the permissible level of noise by the Occupational Safety and Health Administration (OSHA) and the Indonesian Ministry of Manpower. The pre-experimental one-group pretest-posttest design was used (pictured experimental design). Pre-panel installation, the average noise level was 100.5 dBA with an average stress level of 65.5 (moderate stress category), as measured by the heart rate and heart rate variability, which were converted to stress levels on the Xiaomi® Mi Band 5 smartwatch. After 30 days of using the rice straw-gypsum noise-absorbing material, the noise level had decreased by 6 dBA and stress level had decreased by 14.6.

The questionnaire results showed that the installation of acoustic panels had a significant effect on the stress levels of workers in the textile industry. The results suggest that the installation of acoustic panels could provide a more comfortable and less stressful working environment, which could contribute to improving the overall well-being of workers.

## 4. Conclusion

The characteristics and performance of two types of reinforced composites and gypsum adhesives containing varying amounts of natural fibre were evaluated using impedance tubes and field tests. The impedance tube test results were satisfactory compared to other damping materials that have been studied. The acoustic performance of the prepared samples in the impedance tube was evaluated by examining their  $\alpha$ , NRC, dB, and reflection coefficients. The rice straw-gypsum composite with four perforations performed best. The maximum  $\alpha$  of the rice straw-gypsum composites reached 1.0 at a frequency of 1500 Hz, while that of the water hyacinth-gypsum composites with the same variations reached 0.97 at a frequency of 1100 Hz. The NRC of the rice straw-gypsum composites reached 0.50, while that of the water hyacinth-gypsum composites reached 0.46. The NRC was good compared to other acoustic materials that have been studied. The NRC of all the variations also exceeded the NRC of pure gypsum. Based on the NRC, the rice straw-gypsum composites were able to decrease sound pressure by up to 6.0 dB. The reflection coefficient results indicate that each sample had different characteristics.

The rice straw-gypsum composites had the best reflection coefficient performance in the high (above 4000 Hz) and low (1100–1900 Hz) frequency ranges. The field test results indicated a correlation between sound pressure and heart rate during the production process. It was proven that noise in the textile industry can be reduced by installing panels around the noise source. The maximum noise level reduction achieved in the field was 9.8 dB. The maximum noise measured in the field during pre-panel installation was 104.6 dB. This decreased to 94.8 dB post-panel installation. Furthermore, the decrease in the noise level was proven to affect heart rate, as indicated by the measurement results in the trendline test that was presented. To validate the measurements that were conducted on the respondents, a questionnaire was used to subjectively evaluate each respondent. The results of the statistical tests showed significant pre- and post-panel installations. Therefore, the installation of acoustic panels affected the stress levels of the respondents. The findings of this study provide valuable insights for industries looking to improve their working environment and reduce stress levels in their workforce. The use of natural fibers in composite materials also has the potential to be an eco-friendly and sustainable solution for soundproofing applications. Future research could explore the use of other natural fibers and adhesive materials to develop more efficient and effective soundproofing materials.

## 5. Declarations

### 5.1. Author Contributions

Conceptualization, M.P. and A.P.; methodology, M.P. and Sum.; software, M.P.; validation, M.P., A.P. and Sun.; formal analysis, M.P.; investigation, M.P.; resources, M.P.; data curation, M.P.; writing—original draft preparation, M.P. and A.P.; writing—review and editing, M.P.; visualization, Sun.; supervision, Sum., A.P., and Sun.; project administration, M.P.; funding acquisition, M.P. All authors have read and agreed to the published version of the manuscript.

### 5.2. Data Availability Statement

The data presented in this study are available in the article.

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## 5.4. Conflicts of Interest

The authors declare no conflict of interest.

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