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A Study on Sound-Absorbing Acoustic Panels from Egg Trays with Recycled Materials (Paper & Plastic)

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ABSTRACT

Noise is an unpleasant and unwanted sound for every human and animal. Noise can also interfere with one's communication and concentration. Nowadays, many sound absorber panels have been produced to overcome arising noise issues. A sound absorber panel works to absorb sound either in low or high frequencies. Usually, in Malaysia, synthetic materials are used for producing sound absorber panels. Glass fibre and minerals are the most common examples of synthetic materials used to produce sound absorber panels. In particular, glass fibre has a good result in sound absorption. However, it also brings negative effects to humans' health, such as skin inflammation, redness, cough, breathlessness, and others. Therefore, for this study, natural materials from recycling have been used to produce sound absorber panels, which are egg trays, papers, and plastics. The panels were tested with the impedance tube test to obtain the sound absorption coefficient (SAC) and the noise reduction coefficient (NRC). The values of sound absorption of plastics and papers are good at the frequency of 2,000 Hz (i.e., 0.75 and 0.74, respectively). However, the value of SAC for papers increased to 0.86, compared to the value of SAC for plastics that decreased to 0.67. Furthermore, the value of NRC for papers is better than plastics. Next, the reverberation room test was also performed on the panels to obtain the echo time value (RT) in the current unit. The comparison of echo time for this test is between the values for a room with and without panels. The results from the test showed that the value of echo time for the room with the panels is better than the room without panels.

Keywords: Noise, Sound Absorber, Glass Fibre, Frequency, Echo Time.

1. INTRODUCTION

Noise pollution is usually defined as unwanted sound or noise that is not required [1]. This disturbance noise is also known as noise pollution, which often haunts local communities, especially for residents around cities, as well as industrial and commercialization areas [2-19]. According to the World Health Organization (WHO), noise pollution is ranked third as the most dangerous environmental pollution after air and water pollution. Noise does not only impact human psychology but also flora and fauna [1]. Following noise pollution that often affects people and the environment, sound-absorbing panels have been introduced for use in all types of space. Different types of sound absorption panels have been produced from a variety of sound absorption materials in the market [20-21]. Every sound absorber produces different sound absorption rates [20]. Nowadays, a lot of sound absorber panels are made using less environmentally friendly materials, which are synthetic [22]. Among synthetic materials used are glass fibres and minerals. Studies have shown that glass fibre can absorb sound better than other synthetic materials. However, other studies on health issues mentioned that glass fibre is not suitable to be used as a material for sound absorbing purposes [23,24]. It is stated that if humans

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breathe in the air filled with glass fibre dust for too long, they will experience skin inflammation, redness, sore throat, cough, bronchitis, breathlessness, and lung-related illness [2].

Besides, acoustic panels made from fibreglass involve high costs [25]. Therefore, acoustic panels made from natural materials become an option in producing sound-absorbing panels. Natural substances used do not affect health and the substances have more environmentally friendly properties [26]. In this study, the sound-absorbing panels are produced from egg trays, plastics, and papers, and all of these materials are recyclable. The materials are not only used to produce sound-absorbing panels, but recycling is also practised, which will lead to lower panel costs with the three (egg trays, plastics, and papers) recycled materials.

In the production of these acoustic panels, the material orientation for sound-absorbing panels plays an important role to ensure its effectiveness [27]. The materials selected to produce acoustic panels are egg trays, plastics, and papers. Plastics are chosen as the main ingredient because plastics have long product lifetime, completely free of fibres, do not emit health impairing particles, and have high acoustic performance. Besides that, papers are chosen as the material in this study due to its characteristics. It is also supported by [3], where a source of natural fibres that has the potential as a composite is paper. The ability of papers to absorb sound has also been proven by [4]. Generally, papers have rheological properties, which can be compacted and compressed. In addition, papers also have fineness and detail of the pores. With these properties, papers can be used as a material in acoustic panel samples for sound absorption testing. Based on basic orientation, triangle or pyramid orientation gives the best absorption performance for high frequency [5]. An egg tray is one of the examples of materials with pyramid orientation that can be easily obtained. As supported by [6], the orientation of an egg tray is capable of dispersing and rebounding sound wave as shown in Figure 1. Therefore, the surface of an egg tray is very helpful in sound absorption. Figure 1 shows the surface of an egg tray used to absorb sound.

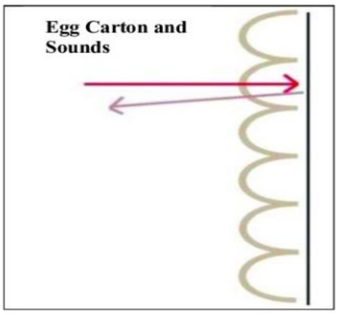


Figure 1. Surface of an egg tray [6].

Factors affecting the results include thickness, compression, density, tortuosity, and the position of the sample [28]. In the research conducted by [7], they mentioned that the thickness of absorbent materials is one of the main parameters that influence absorption performance. This indicates that good sound absorption depends on the thickness of the material. The thicker the material, the better the absorption can be achieved. Next, the effect of compression on sound absorption can play an important role in the field of automotive acoustics [8,29]. For example, the liner of a seat in a vehicle is subjected to cycles of compression/expansion as passenger weight. The result leads to suppression under the porous material (fibrous or holes), which produced variations in physical parameters [8]. In addition, the density of a substance can also affect sound absorption. Usually, materials with high density will be able to absorb a lot of noise due to the sliding surface of a sound wave and a fibre material [30]. Generally, a dense material will absorb sound energy compared to less dense material. A compressed and dense material has low porosity, which has a significant impact on the performance of sound absorption [7].

Research by [9] pointed out that tortuosity is the internal effect of a substance on its acoustic properties. Tortuosity affects the location of the crest of the wave that is produced, where porosity and flow resistance affect the height and width of the peak [10]. The value of tortuosity can also specify the level of high frequency for a material that can absorb sound [11]. Next, the position of the sample also can affect the results of the test conducted by several studies. For instance, the absorption of the sound was affected when the samples are placed in a corner, side, and ceiling to make a three-axis mode (longitudinal, transverse, and vertical) [12]. All of these points show that the performance of sound absorption is affected. Therefore, it can be said that an effective absorber depends on its characteristics.

The objective of this research is to produce sound-absorbing panels at a much lower cost using recyclable materials and to analyze the performance of sound-absorbing panels. The panels are made of egg trays, papers, and plastic waste. This approach applies the concept of recycling and minimizing the disposal of the materials. This study is one of the new alternatives for producing a sound absorber. The absorbers are produced from recycled plastics with egg trays and recycled papers with egg trays. This research helps to reduce waste and its disposal by recycling these materials to reduce pollution. Noise pollution that often occurs can be reduced with new products, such as acoustics panels that are modified with the use of recycled materials in a cost-effective approach.

2. MATERIAL AND METHODS

This study is conducted to address the problems that arise in our daily lives. The issues need to be identified before listing short steps or methods to resolve the problem. After that, work planning should be carefully planned to avoid problems during the experiment. Any factors or side effects that may cause problems during the experiment should be carefully considered. In addition, the objectives of the study should be reviewed to ensure that the purpose of the study is to be achieved. Work planning began with identifying problems such as noise disturbance, excessive noise suppression in large halls, anti-noise room production and other noise issues. After identifying the problem, a scientific study should be conducted on the properties of the material to be used. In this case, experiments will be conducted using egg trays, plastic and paper as sound absorbers. Subsequently, a sample experiment will be conducted in the laboratory to determine the level of sound absorption by both materials. The results of the experiment will produce the next data analyzed. This study will conclude with a discussion of the results obtained between the two materials. Figure 2 shows the flow chart for the work process performed.

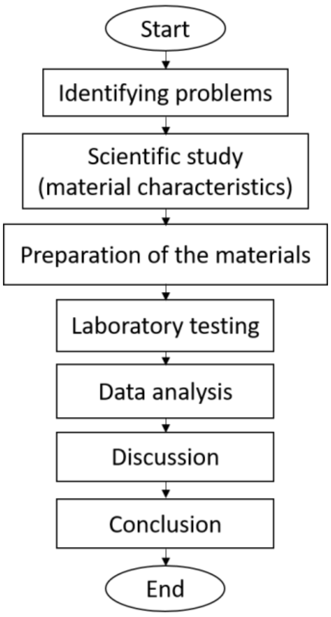


Figure 2. Flowchart of the methodology of research.

The main materials used for producing sound-absorbing panels were egg trays, recycled papers, and recycled plastics. Figure 3 shows the main materials used in this study. The materials helped in improving the sound absorption characteristics.

(a) (b) (c) (d)

Figure 3. Main materials for producing sound absorption panels: (a) Plywood as a support panel, (b) egg trays, (c) recycled papers, and (d) recycled plastics.

Different samples were produced using different combinations of materials. The dimension of the panels produced was 600 × 600 mm. The designs of the panels are illustrated in Figure 4. The egg trays were put together and recycled papers filled the egg trays. Lastly, the panels were covered with a black cloth in the final step. The steps were repeated until 10 panels were produced.

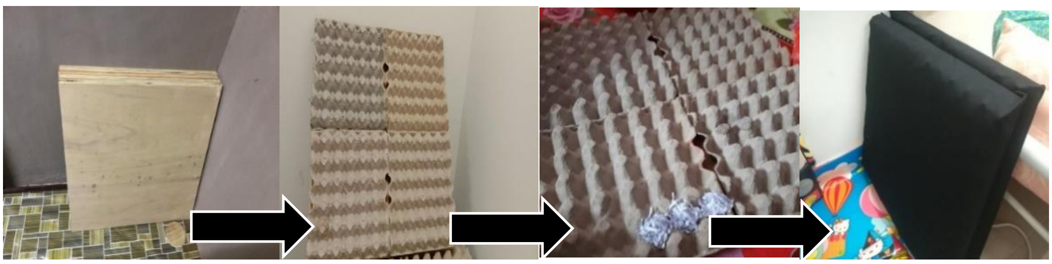


Figure 4. Absorption panels (egg trays with recycled papers) design stages.

Using the same measurement, the panels made of egg trays and recycled plastics were produced. 10 panels were also produced for this type of panel. In the final step, the panels were covered by black cloth, as shown in Figure 5.

Figure 5. Absorption panels (egg trays with recycled plastics) design stages.

The next samples were prepared in circular-shaped. About three samples were constructed: egg trays only, egg trays with recycled papers, and egg trays with recycled plastics. For the first sample, the egg trays were covered by a black cloth. Figure 6 presents the stages of making a circular-shaped sample with recycled papers. Meanwhile, Figure 7 illustrates the stages of making a sample consisting of egg trays and recycled plastics. In this stage, panels with two different measurements were produced (i.e., 28 and 98 mm).

Figure 6. Design stages of a circular-shaped sample (egg trays with recycled papers).

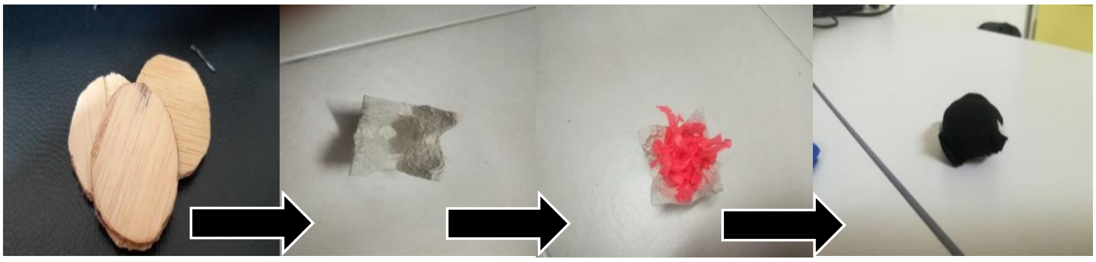


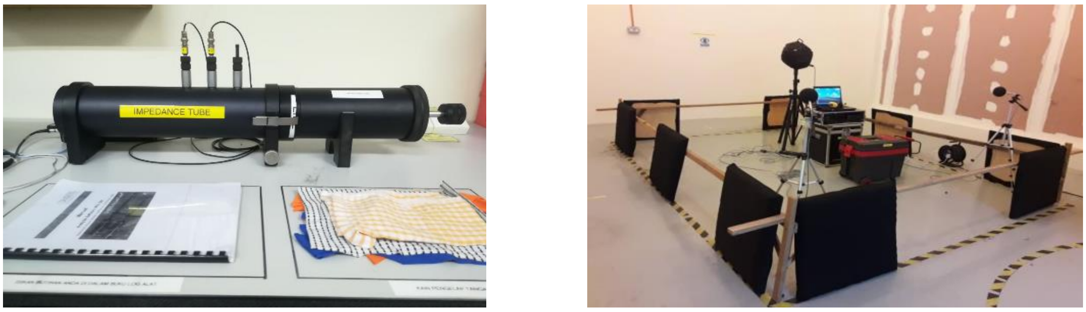
Figure 7. Design stages of a circular-shape sample (egg trays with recycled plastics).

Generally, panels with the dimension of 600 × 600 mm are used in the reverberation room test. The circular-shaped samples were produced for impedance tube test with two different diameters. According to the test conducted, all the characteristics of the designed panels are required. Comparisons were made between each material that can affect the performance of sound-absorbing panels. Some of the characteristics of the designed materials are listed in Table 1.

Table 1 Details of sound-absorbing panels

Parameter	Panels			
	Egg Trays with Papers		Egg Trays with Plastics	
Diameter (mm)	98	28	98	28
Thickness (cm)	2.9	1.7	2.0	1.9
Density (g/cm^3)	0.105	0.287	0.141	0.256

Impedance tube test was conducted to obtain and analyze the sound absorption coefficient (SAC). The value of SAC depends on the presence of air space and the depth of the supporting material on the tube. This test needs to consider whether to use low or high frequency because it can also affect the value of SAC. Figure 8 (a) shows the arrangement of the impedance tube equipment.



(a) (b)

Figure 8. Arrangement of the equipment: (a) Impendence tube test and (b) echo room.

Next, the second test was conducted in an acoustic room. Each panel was arranged vertically around the noise source and the microphones, as shown in Figure 8 (b). According to ISO 354, the experimental material is placed in parallel with a wall surface to reduce the echo effect of the horizontal axis of the wall. This is also supported by [13], where the absorbent material was laid in a room echo, the position of the noise source of sound, microphones, sample room temperature and humidity, and all transmission noise are the factors that play an important role in the experiment conducted. This test was carried out to determine the reverberation time of an empty room, egg trays with papers, and egg trays with plastics. All the tests were repeated three times to obtain the average values of the data. The data and graph were then recorded.

3. RESULTS AND DISCUSSION

In order to analyze and obtain sound absorption data for panels, the studied materials were tested using the impendence tube. From the test, the data discussed were the sound absorption coefficient (SAC) and the noise reduction coefficient (NRC). The SAC (α) is known as acoustic energy measurement absorbed by the material and usually, the obtained value is shown in decimal number between 0 and 1.0. The value of SAC that is nearest to the value of 1.0 or the highest value indicates that the material has a good absorbing sound ability. The study conducted by [14] also stated that higher α value indicates that the absorption of the material is very good. All the data of SAC of the materials were recorded from the impendence tube test. The values were analyzed based on the sound absorption average (SAA) standard with the frequencies of 500, 1,000, 2,000, and 4,000 Hz.

Based on Figure 9, the values of SAC for both materials are good at the frequencies of 500 to 2,000 Hz. At 1,000 Hz, the SAC of the plastics and papers increased, with the values of 0.27 and 0.30, respectively. The absorption value of both materials is in moderate absorption rate. Furthermore, there are no significant differences in the values of absorption coefficients of plastics and papers at high frequency (i.e., 2,000 Hz). Both materials absorbed sound at high absorption rate with the values of 0.75 for plastics and 0.74 for papers. However, based on the observation from the graph, at the frequency of 4,000 Hz, the SAC values for the egg trays and plastics, as well as the egg trays and papers differ significantly, as presented in Figure 9, with the SAC values of 0.67 and 0.86, respectively. The difference in the SAC for both materials is due to the nature and ability of the material to absorb sound. From the results obtained, the egg trays with papers can absorb sound better than the egg trays with plastics. This indicates that papers have excellent sound absorption properties.

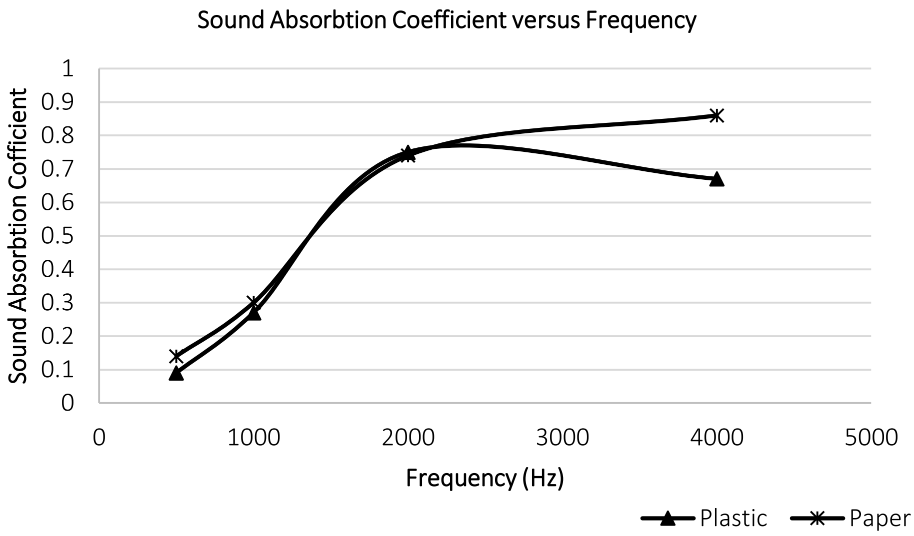


Figure 9. Graph of sound absorption coefficient against frequency.

The NRC is the ability of a surface to absorb sound for the incoming sound energy to be absorbed or not reflected by the surface. The absorbed noise energy is described in the form of sound energy ratio to the incident energy and referred to as the SAC. Absorption power is the absorption value represented by the rate of 1 to 0. If a material does not directly absorb sound, the absorption coefficient is 0. In other words, a substance that has an absorption coefficient of 0 reflects the original sound as a whole [14]. The formula for NRC calculation is shown in Equation (1):

$$\text{Noise Reduction Coefficient} = \frac{\alpha_{500} + \alpha_{1000} + \alpha_{2000} + \alpha_{4000}}{4} \quad (1)$$

Figure 10 shows a comparison of the NRC of the original materials used in several studies but using the same method. The results proved that the materials can absorb sound well based on the calculation of NRC. The egg tray recorded the value of NRC of 0.4 [6], whereas the egg trays with OPEFB and rice straw obtained NRC values of 0.56 and 0.60, respectively [15]. Meanwhile, the egg tray with kapok fibre recorded the value of NRC of 0.57 [16], whereas the egg trays with corn skin and sugar cane achieved NRC values of 0.55 and 0.59, respectively [11]. Finally, the egg trays with plastics and papers achieved NRC values of 0.45 and 0.51, respectively. The echo produced due to sound waves hitting any obstacles is different, depending on the material of the obstacle [17]. This means that the obstacle materials will not absorb the sound wave that meets at the surface. For example, sound can be heard in a small space with hard walls. The hard wall prevents it from being absorbed by the sound wave, thus echoes can be produced. Meanwhile, if echoes hit a soft surface, the sound wave will be absorbed. For instance, echoes are caused by the violations of sound waves inside a cave.

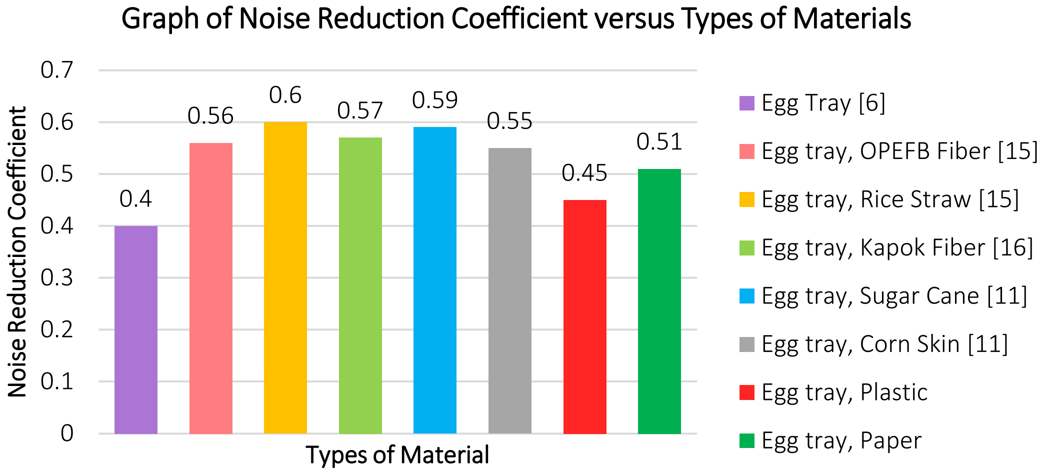


Figure 10. Graph of noise reduction coefficient against types of materials.

Based on the results, there is different reverberation time obtained for the room with and without absorption panels. The results show obvious differences at low frequency (i.e., 400 Hz) compared to high frequency. The maximum reverberation time for the empty room for Microphone 1 is 4.81 s, 3.53 s for the egg trays with papers, and 3.88 s for the egg trays with plastics. For Microphone 2, the maximum reverberation time for the empty room is 4.83 s and both of egg trays with papers and egg trays with plastics is 3.55 s. From the testing, the egg trays with paper are more suitable for low frequency due to the characteristics of the materials. In a study, [18] mentioned that a paper possesses high fibre porosity and can be manufactured in a manner in which the properties can be easily controlled, thus making it ideal as sound absorbers. They also highlighted that compared to other materials, a recycled paper has similar properties as coir fibre and is quite comparable with other commercial sound absorbers for the same thickness. Next, [3] stated that one of the potential sources of natural fibres for composites is paper. Good absorption of sound for a paper has also been proven by [4]. A paper has a rhetorical nature that can be compacted and compressed. Besides, a paper also has delicate features and pores that can be a good sound absorber. Egg trays with papers demonstrated its good performance as sound-absorbing panels based on the results in this experiment. Figures 11 and 12 present the average results of reverberation time for both microphones.

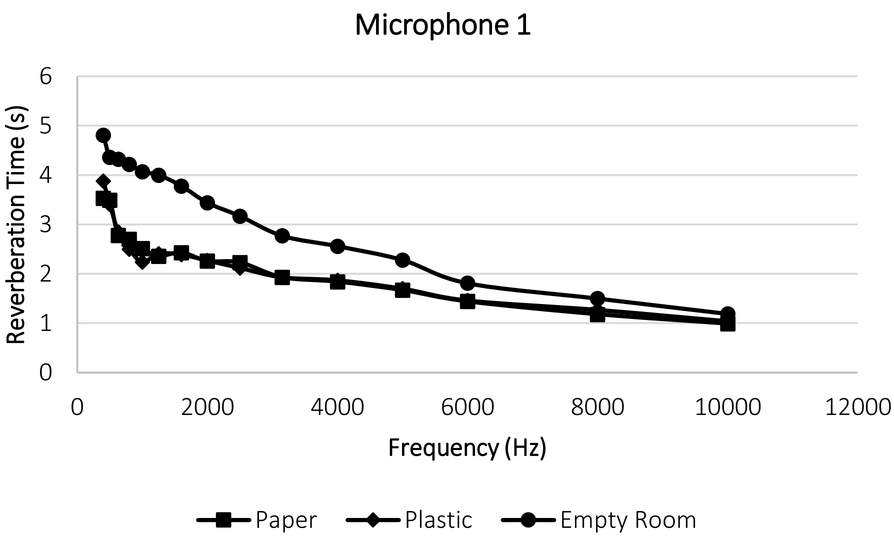


Figure 11. Reverberation time for Microphone 1.

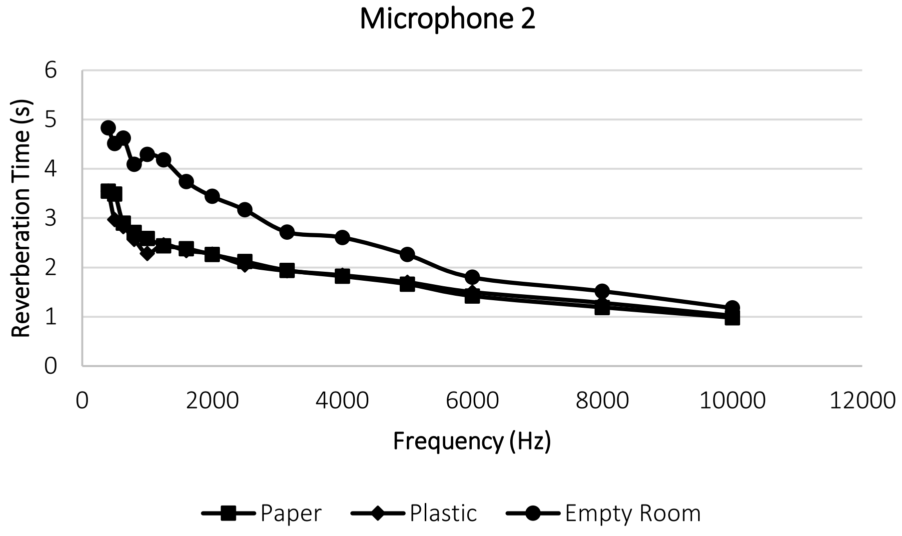


Figure 12. Reverberation time for Microphone 2.

Figure 13 shows the comparison of reverberation time for previous studies using different types of materials. The figure shows the material of egg tray with sugar cane and the egg tray with corn skin [11], the egg tray with OPEFB fibre and the egg tray with rice straw [15], and the egg tray with kapok fibre [16]. From the same figure, at 5,000 Hz, the reverberation time for the egg tray with sugar cane is 1.71 s, whereas the egg tray with corn skin recorded 1.68 s. The egg trays with OPEFB fibre and rice straw recorded reverberation time of 1.34 s and 1.37 s, respectively, at the same frequency. The graph also shows the data of reverberation time using the egg tray with kapok fibre. As a result, at 5,000 Hz, kapok fibre recorded a reverberation time of 1.79 s for Microphone 1.

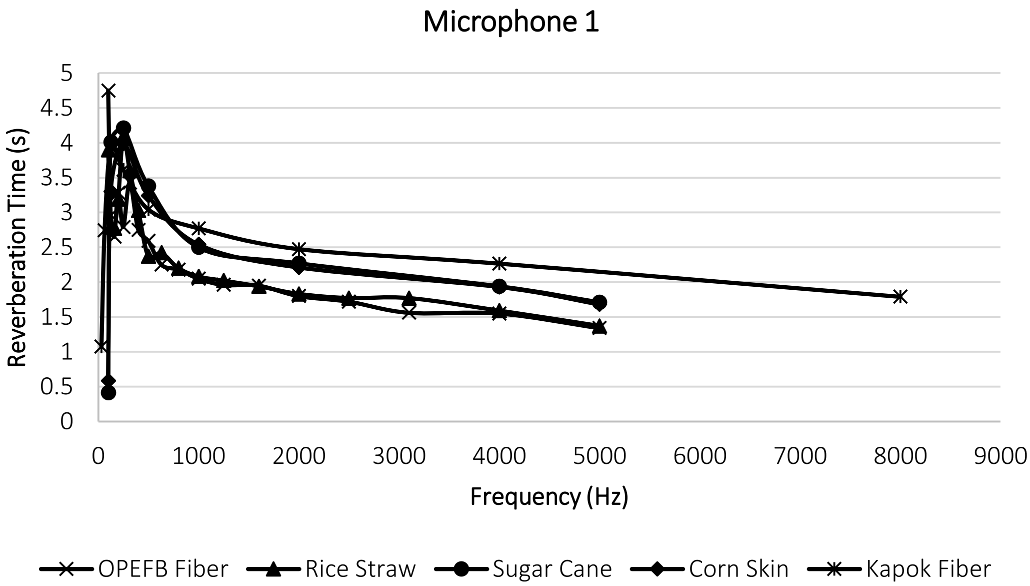


Figure 13. Comparison of reverberation time for previous studies from Microphone 1.

On the other hand, Figure 14 shows the comparison of reverberation time using different materials from Microphone 2. At 5,000 Hz, the egg trays with sugar cane and corn skin recorded reverberation time of 1.66 and 1.63 s, respectively. The reverberation time of 1.33 s and 1.35 s was achieved for the egg trays with OPEFB fibre and rice straw, respectively. At the same frequency, kapok fibre recorded reverberation time of 1.852 s for Microphone 2. From all of the studies, it can be concluded that the egg trays with sugar cane, corn skin, plastics, and papers recorded an approximate pattern at 5,000 Hz, which is reverberation time in the range of 1.63 s to 1.71 s. Meanwhile, at 5,000 Hz, the egg trays with OPEFB fibre and rice straw recorded lower reverberation time than the egg trays with plastics and papers. Lastly, at the same frequency (i.e., 5,000 Hz), the egg tray with kapok fibre shows the reverberation time in the range of 1.79 s to 1.852 s. This shows that kapok fibre has good reverberation time compared to all of the materials. The egg trays with plastics and papers also achieved a quite good echo time as the reverberation time recorded was 1.67 s and 1.70 s for Microphone 1, respectively, whereas, for Microphone 2, the reverberation time recorded was 1.66 s and 1.70 s, respectively.

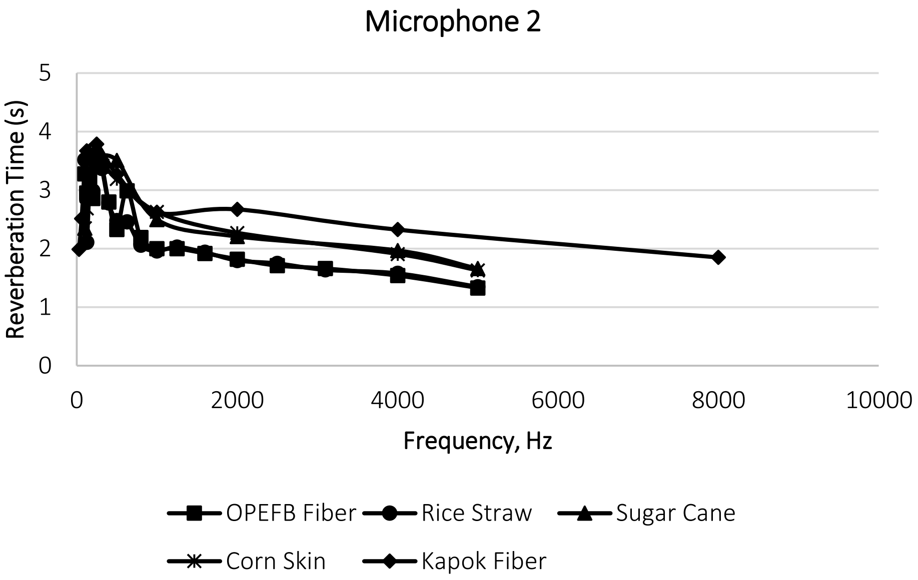


Figure 14. Comparison of reverberation time for previous studies from Microphone 2.

4. CONCLUSION

From the study, it can be concluded the absorption of sound is different for different types of materials for acoustic panels. The impedance tube test provides the data to determine the level of SAC, and it is used to calculate the value of NRC. Different materials produced different data, depending on certain factors. The value of SAC of 0.86 for the egg tray with paper and its NRC value of 0.51 prove that the egg tray with paper is a better sound absorber than the egg tray with plastic. This statement is also supported by the echo test, which stated that there is an echo time difference between the empty room and the room with 10 sound-absorbing panels. At 5,000 Hz, the egg tray with paper in an echo room recorded reverberation time of 1.67 s for Microphone 1 and 1.66 s for Microphone 2. Meanwhile, the egg tray with plastic recorded 1.70 s for both microphones. Finally, the used of egg trays with paper and egg trays with plastic as an acoustic panel are good in sound absorption, and reverberation time and these materials have potential to be commercialized with advanced research developments.

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