Sound absorption properties of rigid polyurethane foam composites with rubber-wood sawdust as a natural filler

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Abstract. Rigid closed-cell polyurethane (PU) foam is well-known for its ability to withstand external force. On the other hand, due to the closed-cell nature, its ability to absorb sound is doubtful since hollowed materials are supposed be better in sound absorption. However, the composites fabrication with non-reactive fillers was thought to improve sound absorption ability since it might prohibit the formation of closed cell in the process. In this research, rigid polyurethane foam was prepared from polyether polyol and polymeric methylene di-isocyanate (p-MDI) formulated with water as a blowing agent. Natural rubber-wood sawdust was used as a filler. The percentages of rubber-wood sawdust in the polyurethane foam composites were varied by 0, 1, 3, 5 and 7%. The measurement of sound absorption coefficient has been done using impedance tube technique. The results showed that the rigid closed-cell polyurethane foam with 0% filler exhibits poor acoustic absorption. Additionally, sound absorption coefficient results showed that a sample with higher amount of rubber-wood sawdust allowed the sound wave to be absorbed at wider frequency range. This could be explained that the rubber-wood sawdust filler played an important role in sound absorption property.

1. Introduction

Noise is undesirable sound precepted by human. Noises rise from many sources such as traffics, factories or even household. To reduce the perturbation of noises, sound absorption must be taken as a measure. Sound absorption is a physical phenomenon where sound wave energy is attenuated inside a material resulting in the reduction of wave energy. Stacy [1] defined that sound absorption is a part of sound wave hitting surface that does not reflect. There are many ways to attenuate sound wave such as increasing air resistance [2] or even using destructive superposition between incident wave and reflected wave [3]. The term ‘acoustic material’ is commonly used and applied for material showing high levels of sound absorption. To make an acceptable sound absorbing material, several factors affecting sound absorption property of acoustic material should be concerned such as, porosity, hardness, elasticity or even surface morphology [4] etc.

Polyurethane (PU) is one of the most widely used polymers in various industries. The characteristics of polyurethane depends upon the initial substances and fabrication processes. With isocyanate and polyol as typical reactants, catalysts, surfactants, and water as a blowing agent, it will turn out to be polyurethane with distinguished properties. One of the important commercial polyurethane products is foam that is widely employed in many versatile purposes. It can be categorized as either rigid or soft
depending upon their mechanical properties. The ability of polyurethane foam to absorb sound is exceptional [5] so that majority of acoustic foam panels used nowadays is made from polyurethane. However, polyurethane foam used as acoustic material has opened cell since porous materials are effective in sound absorption with broadband absorption frequencies [6]. Its ability in sound absorption is due to hollows inside the foam. These hollows increase air resistance resulting in the attenuation of airborne sound waves. The advantage of polyurethane foam is processability, and it is easy to be cut into several shapes. This allows it to be more effective since some specific surface geometries were found to be relevant in sound absorption property [3]. In addition, polyurethane foam panel does not cause environmental problem due to airborne transmission during installation unlike rockwool [6], one of the conventional soundproofing materials. The long-term usage of polyurethane foams is less concern in health compared to those from rockwool which is easily to be breathed into body respiratory system.

Rigid closed-cell polyurethane foam is a different kind of polyurethane. Its polymeric crosslink density is higher resulting in less flexibility, higher rigidity and better strength compared to soft open-cell polyurethane foam. However, rigid closed-cell polyurethane foam and its sound absorption property are still questionable since closed-cell property might inhibit sound to pass through its content.

There are several studies on sound absorption ability of natural products. Bamboo fibers has been found to be a good sound absorber [6]. Rice straw particle board can also absorb sound in the range of 900 – 8,000 Hz even with low density [7]. Sugarcane bagasse in the form of particle panel performs well in sound reduction especially in the range of 500 – 2,000 Hz [8]. One of benefits of natural products is that it is safe for earth environment. Most of natural product used as acoustic material are waste from agricultures.

Pará rubber tree (Hevea brasiliensis) is widely planted in southern parts of Thailand. Not only its latex which is the most economical part for producing natural rubber, Pará rubber tree is also used in variety of purposes. Old Pará rubber trees unable to produce latex are cut down into woods which are mostly further employed for furniture. Sawdust is fine wooden grain material left from wood processing. Usually, high amount of sawdust is deposed since it cannot not make any values. Sawdust from rubber wood processing is also plenty making it effective as a resource. Not only it can reduce agricultural waste, but the physical characteristics of rubber-wood sawdust itself is also interesting.

In this paper, rubber-wood sawdust with rigid polyurethane foam is combined into a composite material as a filler and matrix, respectively. The amount of rubber-wood sawdust inside polyurethane matrix is at 0, 1, 3, 5 and 7 percent by weight. Sound absorption coefficients of samples at some frequencies have been measured by impedance tube using two-microphone transfer function method.

2. Materials and methods

2.1. Material preparation

Two components A and B were prepared. Component A consisted of polyether polyol, catalyst, surfactant, and sawdust (with 0, 1, 3, 5 and 7 % by weight of polyol) Component B consisted of polymeric methylene di-isocyanate (p-MDI) formulated with water as a blowing agent. Polyurethane foam was fabricated using one-shot process where component A and B were mixed inside a vessel. Mixture of component A and B were stirred by mechanical stirrer with the rotor speed of 1,000 rpm until it became homogeneous which is usually within 5 minutes.

Then, polymerization process started so that polyether polyol and isocyanate formed ‘urethane bond’ resulting in higher molecular weight. During this step, carbon dioxide gas was formed making the polyurethane expand its volume drastically and become foam. After the expansion finished, polyurethane foam was kept inside its vessel for 24 hours in order that polymeric bond could be stabilized. Polyurethane foams were cut into cylindrical shape by drill press combined with circular blade. Samples cutting is one of the crucial steps since sound absorption coefficient measurement is very sensitive to material deformation especially to the sample edge. Samples must be completely fitted in the sample holder to avoid unexpected anomaly in sound absorption spectrum.
2.2. Sound absorption coefficient measurement

![Diagram of impedance tube](image.png)

**Figure 1.** Schematic diagram of impedance tube using two-microphone transfer function method.

Sound absorption coefficient measurements have been performed using inhouse impedance tube built according to ASTM E1050-98 [9] and ISO 10534-2 [10] standard. The schematic diagram of the impedance tube is illustrated in figure 1. The impedance tube consists of the main tube with 1,000 and 40 mm for length and internal diameter, respectively. The cylindrical polyurethane sample was placed at the sample holder on one end of the impedance tube while the sound speaker was put on the other end. Two measurement microphones with 1/2 inches diameter, naming mic1 and mic2, were placed next to the sample holder with distance \( x \) and \( x - s \), respectively. Microphones were hermetically sealed to the wall of the impedance tube to avoid the disturbance of external sound sources. Broadband noise was generated using noise generator and then emitted from the speaker. Incident sound wave from the speaker reaches the sample resulting in two products, reflected wave and absorbed wave. Two microphones detect the combination of incident wave and reflected wave while absorbed wave would never be detected.

The magnitudes of sound wave combinations are different for each microphone. Transfer function \( H_{12} \) between sound waves of two microphones were determined. Complex sound reflection coefficient has been calculated using this equation [9,10]:

\[
R = \frac{H_{12} - e^{-ik_0s}}{e^{ik_0s} - H_{12}} e^{2ik_0x_1}
\]

where \( R \) is complex sound reflection coefficient. \( H_{12} \) is a transfer function between two microphones, and \( x_1 \) is the displacement between sample and mic1 microphone. Moreover, \( s \) is the displacement between two microphones and \( k_0 \) is a complex wave number. Finally, absorption coefficient could be defined as follows:

\[
\alpha = 1 - |R|^2
\]

where \( \alpha \) is sound absorption coefficient, and \( R \) is complex sound reflection coefficient.

Sound absorption is ranged from 0 to 1 since 0 and 1 refers to zero absorption and 100% absorption, respectively. In this research, sound absorption coefficients spectra of polyurethane foam samples have been investigated with frequencies ranged from 125 to 5,000 Hz.
3. Results and discussion

3.1. Polyurethane foam characteristics
All polyurethane foams have yellowish cream color as shown in figure 2. The characteristic ‘closed cell’ is prominent even without microscope. Its closed-cell property made samples to prevent fluids e.g. water or air pass through. Polyurethane foams have been cut into cylindrical shape using drill press equipped with circular blade. All cylindrical samples have 40 mm for diameter and 50 mm for length. The appearance of polyurethane foam in cylindrical shape is shown in figure 3.

![Figure 2. Typical prepared polyurethane foam.](image1)

![Figure 3. Cylindrical shape of polyurethane foam sample.](image2)

3.2. Sound absorption coefficient of polyurethane foam samples
Transfer function is determined from sound pressure level of each microphone. As a result, sound absorption coefficients at the frequency range from 125 to 5,000 Hz have been calculated according to equation (1) and (2). It is commercially acceptable for acoustic material to have sound absorption coefficient greater than 0.6 meaning that incident sound wave is absorbed more than 60%. Figure 4 shows absorption coefficient of commercial acoustic foam with the same dimension as the samples. It was used as a reference since it made from soft open-cell polyurethane foam. Its absorption coefficient has been measured using the same instrument as the samples. Figure 5, 6, 7, 8 and 9 show sound absorption coefficient results of rigid closed-cell polyurethane foam samples with no filler, 1, 3, 5 and 7 percent by weight, respectively.

![Figure 4. Sound absorption coefficient of commercial acoustic foam (soft open-cell polyurethane foam).](image3)

![Figure 5. Sound absorption coefficient of unfilled rigid closed-cell polyurethane foam.](image4)
Figure 6. Sound absorption coefficient of rigid closed-cell polyurethane foam sample with 1% rubber-wood sawdust.

Figure 7. Sound absorption coefficient of rigid closed-cell polyurethane foam sample with 3% rubber-wood sawdust.

Figure 8. Sound absorption coefficient of rigid closed-cell polyurethane foam sample with 5% rubber-wood sawdust.

Figure 9. Sound absorption coefficient of rigid closed-cell polyurethane foam sample with 7% rubber-wood sawdust.

Commercially available acoustic foam made from soft open-cell polyurethane foam shows an expected result. It exhibits good sound absorption since sound wave is absorbed with broadband frequency range starting from 1,000 to 5,000 Hz where the sound absorption coefficient is higher than 0.6. Rigid closed-cell polyurethane foam with no filler (0%) presents poor sound absorption ability since almost no frequency reaches maximum absorption coefficient below 0.6. Furthermore, sound absorption spectrum is not broadband unlike one from commercial acoustic foam. It shows some absorption in narrow frequency ranges of sound wave can be absorbed.

It can be clearly seen that rigid polyurethane foams with 1, 3, 5% rubber-wood sawdust led to the increase in absorption coefficient compared to the sample with no filler. There are some peaks showing the sound absorption coefficient above 0.6 at the frequency ranges around 2,500 – 3,500 Hz and 4,200 – 4,700 Hz. This can be explained that rubber-wood sawdust might play some roles in improving sound absorption properties of rigid polyurethane foam.

Rigid PU foams with 7% rubber-wood sawdust filler shows highest sound absorption coefficient among all rigid closed-cell polyurethane foam. There are absorption coefficient peaks that are above 0.6 such as the frequency range of 1,200 – 2,400 Hz and 3,000 – 4,700 Hz. Absorption peaks becomes broader, and characteristic becomes similar to commercial acoustic foam made from soft opened-cell
polyurethane. This could be the results of open-cell foam from the effect of fillers as filler addition could lead to an embrittlement of cell walls and therefore favour their cell opening [11,12].

It is promising that using natural filler like rubber-wood sawdust might improve sound absorption properties of rigid closed-cell polyurethane foam. However, further studies beside sound absorption is necessary. Surface morphology using scanning electron microscope or FTIR measurement can be used to solidify the hypothesis of how rubber-wood sawdust affects rigid closed-cell polyurethane foam structure.

4. Conclusion
Rigid closed-cell PU foam with no filler exhibits poor sound absorption property. It might be that its closed-cell nature does not allow sound wave to easily pass through its content. Rigid closed-cell PU foams using rubber-wood sawdust as natural filler improve sound absorption properties. By using higher amount of sawdust, frequency ranges, where sound absorption coefficient reaches 0.6, become widen. Rigid closed-cell PU foam with 7% rubber-wood sawdust shows widest frequency range where sound absorption coefficient is greater than 0.6. Furthermore, it can be proven that natural filler such as sawdust might improve sound absorption property in rigid closed-cell foam. Further investigation such as surface morphology measurement using SEM should be done in order to clarify the effect of natural filler on foam morphology and properties.

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References
[1] Stacy E 1959 J. R. Soc. Promo. Health 79 789
[2] Tang X, Jeong C H and Yan X 2018 J. Acoust. Soc. Am. 144 EL100
[3] Shao C, Long H and Cheng Y 2019 Sci. Rep. 9 13482
[4] Eijk J V D, Kosten C W and Kok W 1950 Appl. Sci. Res. B 1 50
[5] Gwon J G, Kim S K and Kim J H 2015 Mater. Des. 89 448
[6] Koizumi T, Tsujiuchi N and Adachi A 2002 WIT Press. 59 157
[7] Yang H S, Kim D J and Kim H J 2003 Bioresour. Technol. 86 117
[8] Carvalho S T M, Mendes L M, Cesar A A S, Florez J B, Mori F A and Rabelo G F 2015 Mater. Res. 18 821
[9] ASTM E1050-98 1998 Standard Test Method for Impedance and Absorption of Acoustical Materials Using A Tube, Two Microphones and A Digital Frequency Analysis System (Pennsylvania: American Society for Testing and Materials) p 8
[10] ISO 10534-2 1998 Acoustics - Determination of Sound Absorption Coefficient and Impedance in Impedance Tubes (Geneva: International Organization for Standardization) p 13
[11] Saint-Michael F, Chazeau L, Cavaille J Y and Chabert E 2006 Compos. Sci. Technol. 66 2700
[12] Czlonka S, Sienkiewicz N, Strakowska A and Strzelec K 2018 Polym test. 72 32